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Optimization of machine parameters of Parvatiya Sugam motorized thresher using response surface methodology

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Abstract: A Parvatiya Sugam Thresher was designed and developed at College of Home Science GBPUA & T, Pantnagar, Uttarakhand, India. It is a low cost motorized machine for threshing paddy crops especially for hill region, it is user friendly and more efficient in its working. The machine performance was evaluated for optimal design parameters viz, height 755 mm, time 5.1 minutes and crop load 1.5 kg. Comparative performance tests between the newly developed (Parvatiya sugam thresher) and existing thresher were conducted to the optimization. Test result indicates that Parvatiya sugam thresher gives better result compared to existing thresher. It was inferred that ½ hp motor was introduced to have optimum drum speed and threshing performance of paddy thresher.

Keywords: Agriculture, Design and development, Optimization, Thresher

INTRODUCTION

Agriculture plays important role in Uttarakhand for human sustenance, as it supports 75 – 80 percent of the population and forms the nucleus of most human activities in the State (Anonymous, 2009). The farming situation in Uttarakhand is not homogeneous but is closely related to its varied geographical characteristics. Land fragmentation, dispersal of holdings and terraced farming is the characteristic features of hill agriculture (Anonymous, 2009). The major crop in the state includes paddy, wheat, maize and other pulses and millets. Hill region of Uttarakhand state is having some limitation in agriculture hence paddy threshing cannot be completely mechanized. Threshing consumes 25 percent of the total energy utilized in paddy cultivation. Bullock treading and beating of paddy bundles on wooden plank or stone platform are the two methods farmers practice in the hill region of small land holding although it has low output, higher grain damage and involved more drudgery to the farmers. Therefore need was felt to design and a small motorized thresher especially for hill region. Another axial paddy thresher was developed at IRRI, Philippines with a capacity of 100 kg h^{-1} (Khan, 1971). It was used and popularized in the northern region of India but hill farmers were not able to purchase it because they had difficult terrain, fragmented and small holding lands and low production. Prakash (1979), designed and developed a pedal operated multicrop thresher that had a capacity of 140 kg h^{-1} with a wire loop tip height of 62 mm at a peripheral velocity (linear velocity of the peg tip) of 750 m min^{-1}, the peg height (height of the peg tip from the drum surface) was 66 mm and tip clearance (distance between the inner surface of the housing and the peg tip) was 33 mm. The threshing capacity and efficiency of the pedal thresher was significantly higher (at the 1% level of significance) as compared to bullock treading, drum beating and manual threading (Miah *et al.*, 1994). During manual beating operation, the operator had to sit in bending position (15-20 from vertical), which was ergonomically not desirable for long time operation. Since wrong posture may cause serious injury (Kumar *et al.*, 2001). Apart from the wrong operating posture, it has been observed that none of threshing methods give full satisfaction to users which give maximum production with minimum energy expenditure and drudgery. Parvatiya sugam thresher was designed and developed and tested with the objective of the present study was to determine optimum machine parameters for using response surface methodology (RSM) and Box Benkehn design.

MATERIALS AND METHODS

Existing threshing methods used in the region: Traditional agriculture was mostly dependent on human labor and draught animal. During the manual operation of human beings, the load on the operator as well as occupational and health hazards were found to be increased which lead to impairing the performance of the operator. Paddy threshing by manually operated paddy thresher is popular among the farmers, since more than 60 percent in hill area is under the category of small and marginal farmers.

Raw material: One paddy variety i.e. PR-113, Popularly grown in the belt of hill region was selected for the experimental study.

Development of Parvatiya sugam thresher: The need was felt to develop a thresher especially for hill

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Table 1. Constant parameters for optimization.

S.N.	Parameters	Value/ Name
1	Speed	350 RPM
2	Power	½ hp
3	Variety	PR-113

Table 2. Independent variable for optimization.

S.N.	Parameters	Levels	Range
1	Height (mm)	3	690, 750, 810
2	Time (Minutes)	3	5, 10, 15
3	Crop load (Kg)	3	1, 1.5, 2

Table 3. Dependent variable for optimization.

S.N.	Parameters	Value/ Name
1	Production	Kilogram
2	MSD (Musculoskeletal disorder)	Percentage
5	TCCW (Total cardiac cost of work)	Beats
6	RPE (Rate of perceived exertion)	Percentage

Table 4. Process variable and their levels.

Independent variable		Codes level		
Name	Code	-1	0	1
		Actual Level		
Height (mm)	X_1	690	750	810
Time (Minutes)	X_2	5	10	15
Load Density (Kg)	X_3	1	1.5	2

Table 5. Experiment data for various responses.

Std	Run	Factor X_1 Height (mm)	Factor X_2 Time (Min)	Factor X_3 Crop load (Kg)
13	1	0	0	0
7	2	-1	0	1
3	3	-1	1	0
6	4	1	0	-1
14	5	0	0	0
9	6	0	-1	-1
16	7	0	0	0
11	8	0	-1	1
10	9	0	1	-1
5	10	-1	0	-1
12	11	0	1	1
2	12	1	-1	0
15	13	0	0	0
4	14	1	1	0
17	15	0	0	0
8	16	1	0	1
1	17	-1	-1	0

Table 6. ANOVA for production during an experiment.

Source	DF	Sum of square	Mean of square	F Value
Model	9	947.36	105.26	5.51***
Linear	3	736.5	245.5	12.78***
Quadratic	3	80.29	26.76	1.40
Interactive	3	131	43.66	2.28
Error	7	133.70	19.10	
Total	16	1081.06		

region and developed thresher based on the basic design of existing thresher of the VL peddle thresher. It has a drum, canopy and peddle operated cycle with seat. The peddle operated thresher involves two people, one person engaged in cycling and other one is involved in feeding operation. The cycle seat is not suitable for farmers, it leads to drudgery during threshing activity for long duration and it was not according to the expectations of users need. During threshing of paddy, peddle operation demands more energy and time. Till now motorized thresher especially for small farm holdings and hill region were not popularized. During the development it was observed that there is tremendous scope of improvement to get the best output.

Parvatiya Sugam thresher is a low cost motorized machine for threshing paddy crops. A motor was introduced at the first stage to simplify the thresher mechanism. The power is transmitted from the prime mover to threshing drum through belts and pulleys. The machine runs on ½ hp power and operated by an electric motor. VL peddle thresher cycles have been replaced by motor to reduce the energy expenditure and threshing time. Due to the mechanical process drum speed increased and the length of the thresher was also reduced. Thresher canopy is also increased in length wise to protect spilled grain during threshing. The body of the machine is made of mild steel of iron to withstand maximum wear and tear. Paddy is rear and led to the threshing drum, where the combs act upon each straw and separate the husk from the grain. The feeding system is safe and that it retains the complete straw and does not chop it. Optimized the design reduce the threshing time and give maximum output with minimum threshing time. Similar type of design also developed by Singh *et al.* (2003).

Response surface methodology (RSM) analysis through box Behenkan experiment design: For conducting RSM analysis of the thresher, the process parameters selected along with their range were height, time and crop load. The height of the machine was varied over three ranges 690 mm, 750 mm, 810 mm. The time of threshing was also varied over the three level viz 5 minutes, 10 minutes, 15 minutes whereas load density of rice bundles were varied 1 ½ kg, 2 kg, 2 ½ kg. The responses selected were production, total cardiac cost of work (TCCW), musculoskeletal disorder (MSD) and rate of perceived exertion (RPE).

Optimization experiments were designed using response surface methodology (RSM) with the help of design expert 8.06 software and surfur software 9.0 was employed for the geographical optimization and used for simultaneous optimization of the multiple responses. The constant parameter (Table 1), independent parameters (Table 2) and dependent parameters (Table 3) that were taken up in this study.

The Box Behenken design was used and in that each numeric factor (Independent variable) was varied over 3 levels. The total number of experiments based on RSM was observed to be 17. The 3 level of each

Table 7. Total effect of individual parameter on production experiment.

Source	DF	Sum of square	Mean of square	F Value
Model	9	947.36	105.26	5.51***
Height(x_1)	4	124.38	31.09	1.62
Time(x_2)	4	734.06	183.51	9.60***
Load (x_3)	4	220.35	55.08	2.88
Error	7	133.70	19.10	
Total	16	1081.06		

***, **, * significant at 10, 5 and 1 % level of significance respectively; F tab value (7,9) = 2.50; F tab value (7,4) = 3.97 (10%); F tab value (7,9) = 3.9; F tab value (7,4) = 6.09 (5%); F tab value (7,9) = 5.61; F tab value (7,4) =14.97 (1%)

Table 8. ANOVA for total cardiac cost of work during an experiment.

Source	DF	Sum of square	Mean of square	F Value
Model	9	1.139E+006	1.266E+005	11.37***
linear	3	1098599.16	366199.72	32.88***
Quadratic	3	6338.43	2112.81	0.189
Interactive	3	34383.04	11461.01	1.02
Error	7	77949.52	11135.65	
Total	16	1.216 E+006		

Table 9. Total effect of individual parameter on total cardiac cost of work experiment.

Source	DF	Sum of square	Mean of square	F Value
Model	9	1.139E+006	1.266E+005	11.37***
Height (x_1)	4	16099.65	4024.91	0.36
Time(x_2)	4	1090088.88	272522.22	24.47***
Load(x_3)	4	67515.14	16878.78	1.515
Error	7	77949.52	11135.65	
Total	16	1.216 E+006		

***, **, * significant at 10, 5 and 1 % level of significance respectively; F tab value (7,9) = 2.50; F tab value (7,4) = 3.97 (10%); F tab value (7,9) = 3.9; F tab value (7,4) = 6.09 (5%); F tab value (7,9) = 5.61; F tab value (7,4) =14.97 (1%)

Table 10. ANOVA for musculoskeletal disorder during experiment.

Source	DF	Sum of square	Mean of square	F Value
Model	9	1031.47	114.61	5.53***
linear	3	875	291.66	14.08***
Quadratic	3	103.15	34.38	1.66
Interactive	3	50	16.66	0.80
Error	7	145.00	20.71	
Total	16	1176.47		

variable that were taken are depicted in table 4. The experiment design is given in table 5.

Comparative performance evaluation of Parvatiya sugam thresher and existing methods of threshing: Comparative performance evaluation of Parvatiya sugam thresher and existing thresher was conducted with the help of using PR-113 variety. Physiological parameters viz. total cardiac cost of Work (TCCW), musculoskeletal disorder (MSD) and rate of perceived exertion (RPE) were recorded and analyzed in order to determine the suitability of the machine for threshing at PR-113 variety of paddy.

RESULTS AND DISCUSSION

Optimization of the process parameters using response surface methodology (RSM): RSM is a collection of mathematical and statistical techniques that can be useful for modeling and analyzing situations in which a response of interest is influenced by several variables and the objective is to optimize this response **(**Sampaio *et al.*, 2006). The RSM was applied to optimize the operating parameter (Heigh, Time and Crop load) considering during the experiment. ANOVA test was applied to evaluate the adequacy (by applying the lack-of-fit test) of different models and to evaluate the statistical significance of the factors in the model. In order to examine the goodness and evaluate the adequacy of a fitted model, the coefficient of determination (R2) was calculated. Design Expert 8.0.7 software and surfer software 9.0 were employed for the graphical optimization, similar techniques were also reported by Pishgar *et al.* (2012).

Development of a second order model: The second order model was used to interpret the effect of Height, Time, and crop load on various responses such as Production, Total cardiac cost of work (TCCW), musculoskeletal disorder (MSD), rate of perceived exertion (RPE). The complete second order model was fitted to the data and the adequacy of the model was tested consider R^2 and F test.

Following the general form of the model is being considered for three dependent variable.

$$y = B0\sum_{i=1}^{3} Bi \times i + \sum_{i=1}^{2}\sum_{j=i+1}^{3} Bij \times i \times j + \sum_{i=1}^{3} Bii \times i^2$$

Experimental data were analyzed employing multiple regression techniques to develop response functions and variable parameters optimized for the best outputs.

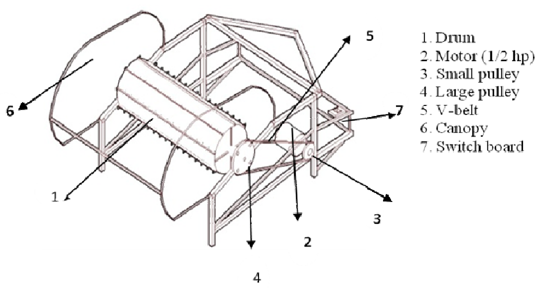

Fig.1. *Line diagram of Parvatiya sugam thresher.*

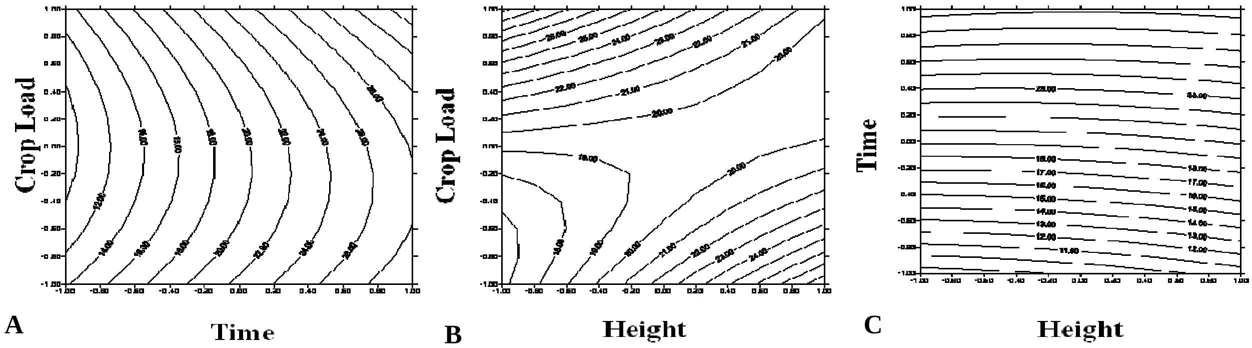

Fig.2. *contour plots for production during experiment.*

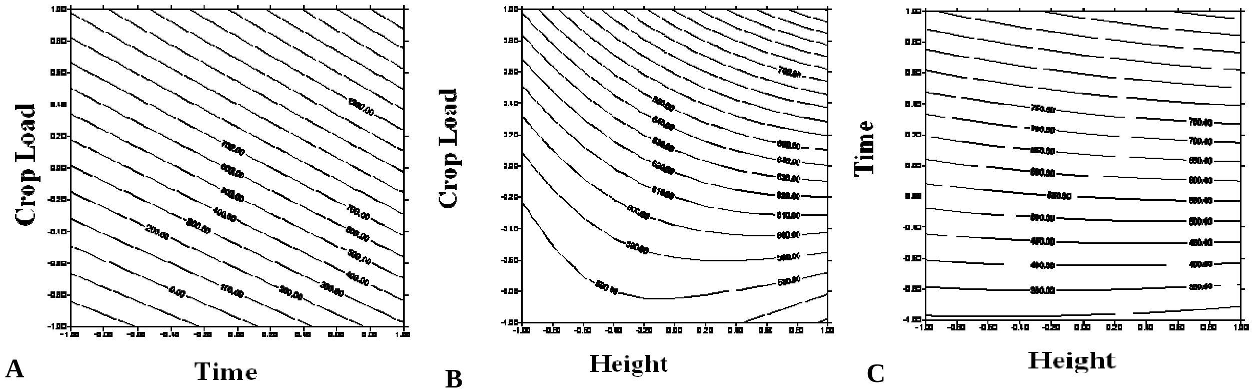

Fig. 3. *Contour plots for total cardiac cost of work during experiment.*

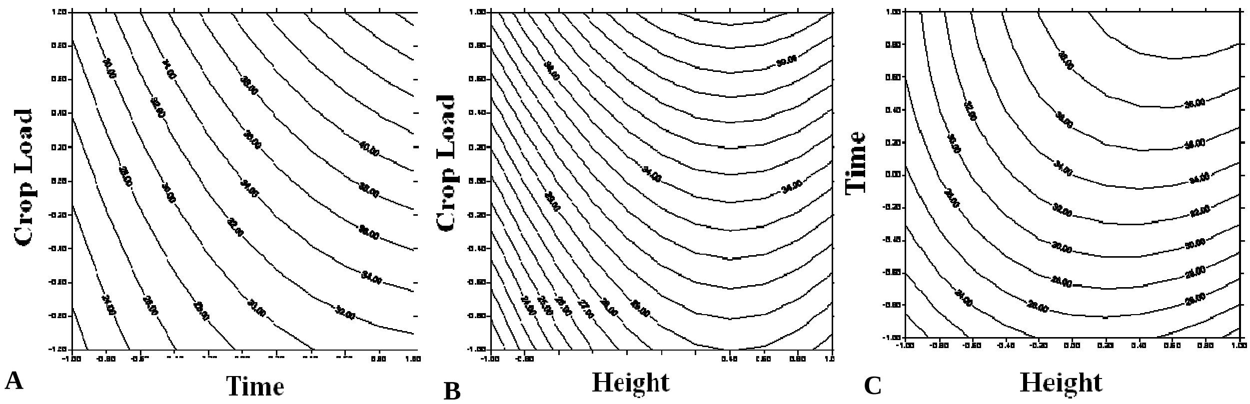

Fig. 4. *Contour plots musculoskeletal disorder during experiment.*

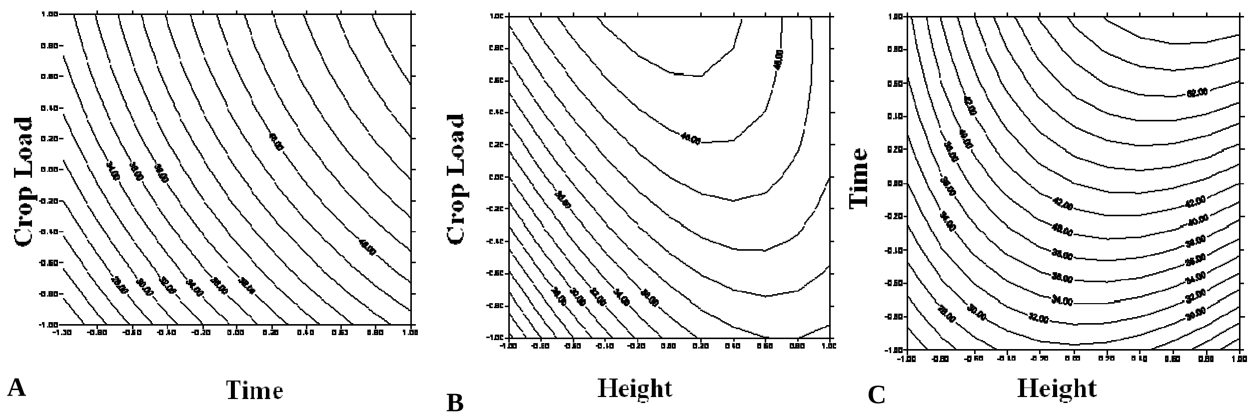

Fig. 5. *Contour plots rate of perceived exertion during experiment.*

Table 11. Total effect of individual parameter on Musculoskeletal disorder experiment.

Source	DF	Sum of square	Mean of square	F Value
Model	9	1031.47	114.61	5.53***
Height(x_1)	4	222.76	55.69	2.68
Time(x_2)	4	516.84	129.21	6.23***
Load (x_3)	4	338.55	84.63	4.08
Error	7	145.00	20.71	
Total	16	1176.47		

***, **, * significant at 10, 5 and 1 % level of significance respectively; F tab value (7,9) = 2.50; F tab value (7,4) = 3.97 (10%); F tab value (7,9) = 3.9; F tab value (7,4) = 6.09 (5%); F tab value (7,9) = 5.61; F tab value (7,4) =14.97 (1%)

Table 12. ANOVA for rate of perceived exertion during an experiment.

Source	DF	Sum of square	Mean of square	F Value
Model	9	2356.47	261.83	4.36***
Linear	3	1900	633.33	10.5***
Quadratic	3	240	80	1.33
Interactive	3	200	66.66	1.11
Error	7	420.00	60.00	
Total	16	2776.47		

Table 13. Total effect of individual parameter on rate of perceived exertion experiment.

Source	DF	Sum of square	Mean of square	F Value
Model	9	2356.47	261.83	4.36***
Height(x_1)	4	1900	633.33	10.55***
Time(x_2)	4	240	80	1.33
Load (x_3)	4	200	66.66	1.11
Error	7	420.00	60.00	
Total	16	2776.47		

***, **, * significant at 10, 5 and 1 % level of significance respectively; F tab value (7,9) = 2.50; F tab value (7,4) = 3.97 (10%); F tab value (7,9) = 3.9; F tab value (7,4) = 6.09 (5%); F tab value (7,9) = 5.61; F tab value (7,4) =14.97 (1%)

The regression coefficient of the complete second order model and their significance has been reported in the table 14. The high P value indicated that a model had a significant lack of fit and therefore considered to be inadequate. The lower the value of P, better would be a model. The model has P value lower than 0.1 were accepted similar study was also conducted by Singh *et al.* (2008).

Effect of independent variables on different responses: The process parameters selected along with their range were height, time and crop load. The height of the machine was varied over three ranges 690 mm,750 mm,810 mm. The time of threshing was also varied over the three levels viz 5 minutes, 10 minutes, 15 minutes whereas load density of rice bundles were varied 1 ½ kg, 2 kg, 2 ½ kg. The responses selected were Production, Total cardiac cost of work (TCCW), Heart rate (HR), Musculoskeletal disorder (MSD), and Rate of perceived exertion (RPE).

Effect of height, time and crop load on production: Significance of independent variable i.e. height, time, crop load of production data was tested using ANOVA (Table 6). In order to show the effect of variable (Height, Time and Crop Load) and to determine the operating range for best results (Table 7), contour plot was drawn. Contour plot fig. 2A depicts the effect of time and crop load on production it was observed that production was found to be maximum with crop load. From fig. 2B which shows the effect of height and crop load on production, it was observed that a minimum region at center which is called as saddle point which shows that there is no effect of height and crop load on production. Whereas fig. 2C shows effect of height and time on production, it was observed that production was increased with time and height parameters.

Effect of height time and crop load on total cardiac cost of work: Significance of independent variable i.e. height, time, crop load on the total cardiac cost of work data was tested using ANOVA (Table 8) and total effect on cardiac cost of work was analyzed (Table 9). From Contour plot fig. 3A shows the effect of time and crop load on Total Cardiac Cost of Work, it was observed that total cardiac cost of work was increased with the time of threshing and crop load whereas fig. 3B which shows the effect of height and crop load on total cardiac cost of work, it was observed that only height affects the total cardiac cost of work. Fig. 3C which shows the effect of height and time on total cardiac cost of work, it was observed only height affects the total cardiac cost of work during experiment.

Effect of height time and crop load on musculoskeletal disorder: Significance of independent variable i.e. height, time, crop load on musculoskeletal disorder data was tested using ANOVA (Table 10) and total effect on musculoskeletal disorder was observed (Table 11). From Contour plot fig. 4A which were contour plots depicting the effect of time and crop load on Musculoskeletal Disorder, it was observed that masculoskeletal disorder was found to be increased with the time of threshing and crop load. From fig. 4B which shows the effect of height and crop load on masculoskeletal disorder, it was observed height and crop load affects the masculoskeletal disorder. From fig. 4C shows the effect of height and time on masculoskeletal disorder, it was observed that masculoskeletal disorder was increased with the time of threshing and height of thresher.

Effect of height time and crop load on rate of perceived exertion: Significance of independent variable i.e. height, time, crop load on rate of perceived exertion data was tested using ANOVA (Table 12) and total effect on perceived exertion was analyzed (Table 13). From Contour plot fig. 5A depicting the

Table 14. Result of regression analysis for responses.

Source	Production		Total cardiac cost of woork		Masculoskeletal disorder		Rate of preceived exerton	
	Cofficient	**P value**	**Cofficient**	**P value**	**Cofficient**	**P value**	**Cofficient**	**P value**
Model	19.40	0.0174	622.78	0.0021	34.00	0.0173	44.00	0.0325
X_1	0.50	0.7557	26.27	0.5041	3.75	0.0526	5.00	0.1106
X_2	9.50	0.0005	363.31	< 0.0001	7.50	0.0023	12.50	0.0026
X_3	1.25	0.4451	68.08	0.1108	6.25	0.0060	7.50	0.0290
X_1, X_2	-0.50	0.8256	37.75	0.4975	2.50	0.3083	5.00	0.2377
X_1, X_3	-5.50	0.0400	33.49	0.5458	0.000	1.0000	-5.00	0.2377
X_2, X_3	1.50	0.5145	77.77	0.1840	2.50	0.3083	0.000	1.0000
X_1^2	0.30	0.8920	-9.64	0.8567	-4.50	0.0821	-7.00	0.1061
X_2^2	-0.70	0.7520	31.56	0.5589	-2.00	0.3972	-2.00	0.6126
X_3^2	4.30	0.0833	20.41	0.7032	0.50	0.8281	-2.00	0.6126
R^2	0.8763		0.9360		0.8768		0.8487	
F Value	5.51		11.37		5.53		4.36	
Lack of fit	Ns		Ns		Ns		Ns	

Table 15. Constraints for optimization of parameters.

Name	Goal	Lower limit	Upper limit
Height	Minimum	-1	1
Time	Minimum	-1	1
Crop Load	Minimum	-1	1
Production	Maximum	-1	1
Total Cardiac Cost of Work	Minimum	-1	1
Masculoskeletal Disorder	Minimum	-1	1
Rate of Perceived Exertion	Minimum	-1	1

Table 16. Optimum value of parameters of experimentation of paddy thresher machine.

Value	Height (mm)	Time (minutes)	Crop Load (kilogram)	Production (kilogram)	Total Cardiac Cost of Work (Beats)	Musculoskeletal Disorder (Percent)	Rate of Perceived Exertion (Percent)	Desirability
Coded	0.43	-1	-1					
Actual	775	5.1	1.5	16.60	299	20.95	20.86	0.73

Table 17. Comparative performance of the Parvatiya sugam thresher and the existing pedal thresher.

S. N.	Physiological parameters	Existing VL pedal thresher	Parvatiya Sugam Thresher
1	Average working heart rate (Beats/min)	120.63	108.57
2	Average energy expenditure (kJ/min)	10.45	8.54
3	Peak heart rate (Beats/min)	130.00	113.33
4	Peak energy expenditure (kJ/min)	11.56	8.77
5	Average TCCW (Beats)	592.30	452.16
6	Average physiological cost of work (Beats/min)	39.84	30.14

effect of time and crop load on Rate of Perceived Exertion, it was observed that rate of perceived exertion was found to be increased with the time of threshing and crop load. From fig. 5B which shows the effect of height and crop load on production, it was observed that a crop load increased more rate of perceived exertion than height of thresher. From Fig 5C shows the effect of height and time on rate of perceived exertion, it was observed that rate of perceived exertion was increased with the time of threshing more rather than height.

Optimization of parameters (height, time, crop load) for described responses: Numerical optimization was carried out using design software and regression analysis was done on the basis of selected parameters (Table 14). The goal was fixed to maximize the production and minimize the total cardiac cost of work and musculoskeletal disorder. The responses namely production, total cardiac cost of work, musculoskeletal disorder and rate of perceived exertion were taken into consideration for optimizing. The goal seeking begins at a random starting point and proceeds up and down the steep slope on the response surface for a maximum and minimum value of the response respectively. Importance to the responses and independent variables were given on the basis of the objective of the study. Maximum importance was (+++++) was given to production and total cardiac cost of work (TCCW) musculoskeletal disorder (MSD) (++++) and rate of perceived exertion (RPE) (+++) the goal was kept at in the range, similar study was also reported by Rai *et al.* (2012). The goal set up for optimization of variables and responses is reported in table 15.

During optimization 17 solutions were obtained, out of which the most suitable criteria, was selected. The selected solution was tested for the actual conditions. It was observed that out of three independent variable. Optimum results were obtained when the Height 775 mm, time 5.1 minutes and crop load was 1.5 kilograms. The optimum value of different parameters obtained are given in table 16.

Comparative performance of the Parvatiya Sugam thresher and the existing pedal thresher: In comparative performance of Parvatiya Sugam Thresher and existing VL Peddle thresher showed that Average working heart rate (Beats/min), Average energy expenditure (kJ/min), Peak heart rate (Beats/min), Peak energy expenditure (kJ/min), Average TCCW (Beats), Average physiological cost of work (Beats/min) was found to be minimum in Parvatiya sugam thresher (Table 17).

Significance of the study: Parvaliya sugam thresher is a low cost motirized machine for thushing paddy crops. It is a user friendly thresher for farm workers and will help to reduce drudgery and energy expenditure of the respondents. It is ergonomically sound, comfortable and constructed as per the anthopometric measurement of workers. This optimized design thesher will reduce the threshing time and give maximum output with minimum threshing time.

Conclusion

The machine performance of Parvatiya Sugam paddy thresher was found optimum on height 755mm, time 5.1 minutes and load density 1 ½ kg. The corresponding production was found 16.69 kg with 299 beats Tccw, 20.94 percent MSD and 20.86 percent RPE and overall desirability were found to be 0.73 percent. Hence these combinations shows that maximum production with minimum time, energy and musculoskeletal disorder was obtained by Parvatiya sugam thresher.

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