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Development and evaluation of multi millet thresher

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Abstract: In tribal areas of India, traditional methods of threshing of minor millets like little millet (*Panicum sumatrense*), M_1, kodo millet (*Paspalum scrobiculatum*), M_2, foxtail millet (*Setaria italica*), M_3, proso millet (*P. miliaceum*), M_4, barnyard millet (*Echinochloa frumantacea*), M_5, finger millet (*Eleusine coracana*), M_6 is done of beating by sticks or treading out the crop panicle under the feet of oxen. This operation is most time consuming, labour intensive, drudgery prone, uneconomical, lower output and obtain low quality products. A thresher for these millet crops was developed and optimization of the operating parameters with little millet was done by using Response surface methodology (RSM). The optimized parameters were 7.79% (d.b) moisture content, 105 kgh^{-1} feed rate, 625 rpm cylinder speed, 5 mm threshing sieve size which gave maximum threshing efficiency of 95.13% and cleaning efficiency of 94.12%. After optimization of parameters the thresher was tested for threshing of all the six minor millets with proper adjustments of sieve. Threshing capacity of M_1, M_2, M_3, M_4, M_5 and M_6 were obtained as 89, 137, 140, 91, 88 and 99 kg/h, respectively with more than 96% threshing efficiency and less than 2% broken grain.

Keywords: Cleaning efficiency, Multi millet thresher, Shear and impact cutting, Threshing efficiency

INTRODUCTION

Millets are very important food crop of tribal people and believed to be first domesticated cereal crop which is mostly grown in tribal and hilly areas of India and many Asian and African nations (Gbabo et al., 2013). These crops are grown in rain fed areas and temperature more than 20°C where other crops yield are very poor and are less prone to disease and pests. In India, millets are major staple food in the state of Uttarakhand, Chhattisgarh, Tamil Nadu, Odisha and Karnataka where these are grown widely with yield as high as 3 t/ha. Maximum production (thousand tonnes), productivity (kg/ha) and area of production (thousand ha) of different millets in India are of Finger millet (1964.9, 1179, 1641.6), followed by Barnyard millet (180.1, 863, 208.6), Kodo millet (146.3, 366, 399.4), Little millet (113.2, 364, 310.9), Foxtail millet (62.9, 607, 103.7) and Proso millet (26.4, 556, 47.5). Millets are very nutritious and important crop for balanced diet, rich in vitamins, protein, carbohydrate, minerals, fibers, iron, amino acid, phosphorus, magnesium, potassium and also good source of energy. The epidemiological evidences indicate that person on millet based diets have good resistance for degenerative diseases such as heart disease, diabetes, hypertension etc (Anonymous, 2001).

Traditionally in tribal and hilly areas, threshing of millet crop is done either beating by sticks or by treading out the crop panicle under the feet of oxen. These threshing operations are most time consuming, energy intensive (19.9 kJ/min), labour intensive, drudgery prone and uneconomical. The mechanized threshing of millets can reduce the drudgery of farmers/labours, improve the quality of product. With existing socio economic condition of millet growing tribal farmers, the large capacity threshers are inappropriate and even the small size thresher with large scale sophistication are difficult to be adopted (Singh *et al.*, 2002). Worldwide number of studies have been done for threshing of various crops but a very few studies has been reported on millet threshing. Therefore, development of thresher for all millet crops was found necessary which can do threshing of all millets.

Physical properties of crop are very important for the design and development of machine. Singh *et al.* (2010) studied different physical properties of barnyard millet. Baryeh (2002) evaluated different physical properties of millets and expressed as function of moisture content between 5−22.5%. (Singh *et al.*, 2003) developed a thresher at Vivekananda institute of Hill Agriculture (ICAR), Almora, Uttarakhand, India and was modified at IIT, Kharagpur. It was observed that threshing of millet is better in case of combination of impact and shear on the crop. Therefore the machine for threshing of all six minor millets was developed on the principle of combination of shear and impact at Central Institute of Agricultural Engineering, Bhopal, India.

Many researchers have worked on the optimization of

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process parameters like milling, threshing (Singh *et al.,* 2004; Tiwari *et al.,* 2007; Singh *et al.,* 2008). Ajav and Adejumo (2005) studied the performance evaluation by taking moisture content, cylinder speed and feed rate as independent parameter to obtain the maximum threshing efficiency. Kushwaha *et al.* (2005) developed an okra seed extractor and evaluated the effect of drum speed and moisture content on extracting efficiency. Singh *et al.* (2008) developed a pedal operated paddy thresher and optimized the independent parameter like drum speed for getting highest threshing efficiency. Similarly Singh *et al.,* (2010) optimized the value of drum speed for threshing of finger millet.

Response surface methodology (RSM) is defined as the statistical method that uses quantitative data from an appropriate experimental design to determine and simultaneously solve multivariate equations. The main advantage of RSM is that it reduces the number of experiments needed to evaluate multiple parameters and their interactions. It was used successfully by many scientists for optimization of different parameters for different operations (Goyal *et al.,* 2008; Singh *et al.,* 2008; Ushakumari *et al.,* 2007; Nath and Chattopadhyay, 2007). The present study was undertaken to use RSM to optimize the operational parameters: moisture content(MC), feed rate(FR), drum speed(DS), threshing sieve size(TSS) to maximize the threshing and cleaning efficiencies of the thresher.

MATERIALS AND METHODS

Raw material: Different millets like little, kodo, proso, foxtail, barnyard and finger millet of local varieties were collected from small village Patalkot/ Dhindhori tribal areas of MP. Physical properties of all millets (Table 1) were observed to suitable for the proper threshing of millet. The moisture content of the crops was kept 5 to 11% for performance analysis and digital moisture meter was used for this purpose.

Design and development of the thresher: A multi millet thresher was designed and developed for threshing of the millets based on the different properties of the minor millets. Developed machine works on the principle of impact and shear force acting on the ear head of the crop for the purpose of threshing of millets. The threshing drum was fitted with three rows of canvas strips and three rows of cutting knives places alternately as some of the millet crop requires cutting action and some requires shear for complete threshing. The knives arrows provides impact cutting of crop stem during threshing and the canvas strip rows gives gentle abrasion and shear on the grain for removing the grains from the glumes. The threshing chamber is fitted with a sliding sieve which is allow repetitive impact and shear to complete detach of glumes from the grains which helps in complete threshing of millets.

Ergonomic consideration in the design of the thresher: In general these crops threshed inside the boundary of the house. The ergonomic and safety is very important especially for the use of tribal women worker. Ergonomic considerations were used in the design of thresher for safety of the worker. The length of the feeding chute was kept 900 mm as per IS: 9020−2002. Grip handles of threshing sieves were made as per inner grip diameter for better comfort of the worker. Shaker assembly for cleaning system was provided with packing for reduction of vibration and noise. Rubber transportation wheels instead of cast iron wheels were provided for easy transportation and for absorption of vibration during operation. The machine is attached with safety guards over power transmission system. A flapper was fitted in the feeding chute to arrest the dust which may create health problems of the worker.

Evaluation of multi millet thresher: The multi millet thresher prototype was evaluated after development. For the evaluation little millet crop was taken after harvesting. The crop was taken as the whole crop for threshing. But after the optimization the final thresher was tested with all six minor millets by taking only the ear heads of kodo millet, foxtail millet, barnyard millet and finger millet except little millet and proso millet as recommended by the tribal farmers. The feed rate was controlled manually by the help of a worker and maintained from 75 to 120 kgh^{-1}. They had to feed the whole crop as per requirement. A two hp, single phase electric motor was used as power source and the power is transmitted to the threshing drum, aspirator by the help of belt drive. For variation of drum speed from 500 to 1000 rev/min different size of pullies were used according to the requirement. The air flow rate was

Table 1. Specifications of the developed CIAE multi millet thresher**.**

Length	2027 mm
Width	1048 mm
Height	1200 mm
Weight of the machine	180 kg
Threshing chute length	900 mm
Cost of the machine	Rs 45,000/-
Power requirement	2 hp, single phase electric motor
Machine noise level	84 db
Threshing capacity	80-150 kg/h (depending on millet comodity)
Dehulling capacity	20-80 kg/h (depending on millet comodity)
Pearling capacity of finger millet	200-250 kg/h

Table 2. Coded values and corresponding real values used in experimentation.

Independent variable	Coded value	–α (–1.414)	–1	0	+1	+ α (+1.414)
Moisture content (M_c), % db	Actual value	3	5	7	9	11
Feed rate (F_r), kg/h		60	75	90	105	120
Drum speed (D_s), rpm		500	625	750	875	1000
Threshing sieve size (T_{ss}), mm		3	5	7	9	11

Table 3. Experimental design for thrshing of little millet using CCRD with four independent variables.

Run	Independent variables				Dependent variable	
	Moisture content (M_c), % (db)	Feed Rate (F_r), kg/h	Drum Speed (D_s), rpm	Threshing Sieve Size (T_{ss}), mm	Threshing efficiency (T_e), %	Cleaning efficiency (C_e), %
1	5 (-1)	75(-1)	875(+1)	5(-1)	97	96
2	7 (0)	90(0)	750(0)	11(+α)	92	93
3	9 (+1)	105(+1)	625(-1)	9(+1)	85	87
4	9(+1)	105(+1)	875(+1)	9(+1)	90	89
5	9(+1)	75(-1)	875(+1)	5(-1)	94	94
6	5(-1)	105(+1)	875(+1)	9(+1)	93	91
7	9(+1)	75(-1)	875(+1)	9(+1)	91	91
8	9(+1)	105(+1)	875(+1)	5(-1)	96	93
9	7(0)	90(0)	1000(+α)	7(0)	99	97
10	5(-1)	75(-1)	625(-1)	9(+1)	91	88
11	7(0)	90(0)	750(0)	7(0)	90	96
12	9(+1)	105(+1)	625(-1)	5(-1)	95	90
13	7(0)	60(–α)	750(0)	7(0)	96	93
14	9(+1)	75(-1)	625(-1)	5(-1)	90	87
15	11(+α)	90(0)	750(0)	7(0)	84	86
16	5(-1)	105(+1)	875(+1)	5(-1)	95	94
17	9(+1)	75(-1)	625(-1)	9(+1)	88	92
18	7(0)	90(0)	750(0)	7(0)	89	94
19	7(0)	120(+α)	750(0)	7(0)	94	90
20	5(-1)	75(-1)	875(+1)	9(+1)	96	95
21	7(0)	90(0)	750(0)	7(0)	94	93
22	3(–α)	90(0)	750(0)	7(0)	90	89
23	7(0)	90(0)	750(0)	3(–α)	93	96
24	7(0)	90(0)	750(0)	7(0)	92	93
25	7(0)	90(0)	500(–α)	7(0)	96	89
26	7(0)	90(0)	750(0)	7(0)	92	95
27	5(-1)	105(+1)	625(-1)	5(-1)	95	90
28	5(-1)	75(-1)	625(-1)	5(-1)	93	90
29	7(0)	90(0)	750(0)	7(0)	92	90
30	5(-1)	105(+1)	625(-1)	9(+1)	93	89

maintained below the terminal velocity of the grains and above the terminal velocity of chaff. The speed of aspirator was maintained by the use of belt drive.

The moisture content was varied by adding of water to the sample. The samples were prepared by spraying the desired amount of distilled water to the samples, thoroughly mixed, sealed in separate polyethylene bags and then kept for a week for uniform distribution of moisture throughout the samples. Before each experiment required amount of samples were taken out and allowed to warm up to the room temperature (Goyal *et al.*, 2008; Singh *et al.*, 2010). The amount of water required for desired moisture content was calculated by the following equation (Karababa, 2006; Altuntas and Yildiz, 2007; Singh *et al.*, 2010).

$$Q = \frac{Wi(Mf - Mi)}{100 - mf} \qquad \text{................ (1)}$$

The evaluation was done by taking the required sample of 10 kg each time and the data were collected. Some formulas used for calculation of threshing efficiency, cleaning efficiency were,

Threshing efficiency = threshed grains received from all the outlets with respect to total grain input expressed as percentage by mass.

TE=100–percentage of unthreshed grains ....(2)

Percentage of unthreshed grains

$$Z = \frac{D}{A} \times 100 \qquad \text{............. (3)}$$

Table 4. Analysis of variance for threshing efficiency.

Source	Sum of Squares	df	Mean Square	F Value	p- value > F	
Model	283.33	14	20.23	6.57	0.0004	Significant
M_c	54.00	1	54.00	17.54	0.0008	
F_r	0.16	1	0.16	0.05	0.8191NS	
D_s	32.66	1	32.66	10.61	0.0053	
T_{ss}	37.50	1	37.50	12.18	0.0033	
$M_c \times F_r$	1.00	1	1.00	0.32	0.5771NS	
$M_c \times D_s$	1.00	1	1.00	0.32	0.5771NS	
$M_c \times T_{ss}$	12.25	1	12.25	3.98	0.0645NS	
$F_r \times D_s$	6.25	1	6.25	2.03	0.1746NS	
$F_r \times T_{ss}$	9.00	1	9.00	2.92	0.1079NS	
$D_s \times T_{ss}$	1.00	1	1.00	0.32	0.5771NS	
M_c^2	38.67	1	38.67	12.56	0.0029	
F_r^2	18.10	1	18.10	5.88	0.0284	
D_s^2	56.67	1	56.67	18.41	0.0006	
T_{ss}^2	0.96	1	0.96	0.31	0.5839NS	
Lack of Fit	30.66	10	3.06	0.98	0.5402	not significant

Table 5. Analysis of variance for cleaning efficiency.

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	223.33	14	15.95	5.79	0.0008	Significant
M_c	10.67	1	10.67	3.87	0.0679NS	
F_r	88.17	1	88.17	32.00	< 0.0001	
D_s	13.5	1	13.5	4.9	0.0428	
T_{ss}	0.00	1	0.00	0.00	1 NS	
$M_c \times F_r$	4.00	1	4.00	1.45	0.2469NS	
$M_c \times D_s$	0.25	1	0.25	0.091	0.7674NS	
$M_c \times T_{ss}$	4.00	1	4.00	1.45	0.2469NS	
$F_r \times D_s$	6.25	1	6.25	2.27	0.1528NS	
$F_r \times T_{ss}$	6.25	1	6.25	2.27	0.1528NS	
$D_s \times T_{ss}$	70.58	1	70.58	25.61	0.0001	
M_c^2	10.01	1	10.01	3.63	0.076 NS	
F_r^2	1.44	1	1.44	0.52	0.4808NS	
D_s^2	0.58	1	0.58	0.21	0.652NS	
Lack of Fit	19.83	10	1.98	0.46	0.8606	*Not significant*

Where, D =Quantity of unthreshed grains collected from all outlets per unit time
A =Total grain input per unit time
Cleaning efficiency = Clean grain received at main grain outlet with respect to the total grain mixture received at main grain outlet expressed as percentage by mass.

$$CE = \frac{M}{F} \times 100 \qquad \text{.............. (4)}$$

Where, M = Quantity of clean grain obtained from the sample taken at main grain outlet.
F = Total quantity of the sample taken at main grain outlet.

Experimental design: Central Composite Rotatable Design (CCRD) (Rastogi *et al.*, 1998; Singh *et al.*, 2011) was considered as experimental design with four independent parameters moisture content, feed rate, threshing drum speed and threshing sieve size for optimization. The responses were obtained in terms of threshing and cleaning efficiency and optimized by use of RSM.

CCRD for optimization of operational parameters: The operational parameters were fixed at 5 levels (Table 2) as per CCRD and a total number of 30 experiments were carried out (Table 3). Seven repeated experiments were conducted at the central points of the coded variables to calculate the error sum of squares and the lack of fit of the developed regression equation between the responses and independent variables.
The parameters were optimized by using Design expert 7.0.0 software, which gave optimum values based on experimented results.

RESULTS AND DISCUSSION

Threshing efficiency: Analysis of variance was conducted for threshing efficiency and is presented in the table 4. The ANOVA data shows high F value (6.58) which implies the model to be significant at 0.1% level of significance. The linear effect of moisture content was highly significant on threshing efficiency at 0.1%

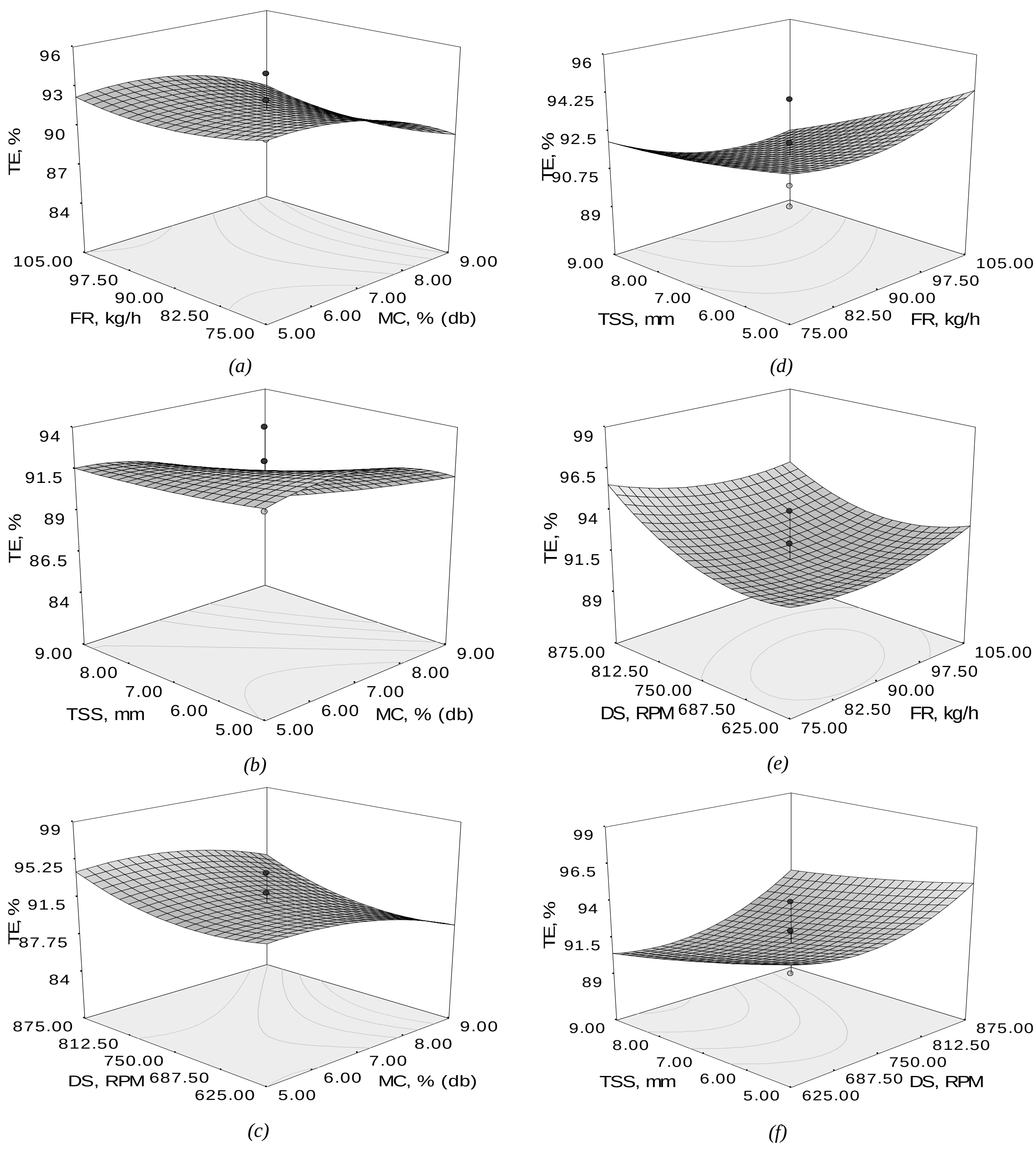


Fig. 1. *Response surface contours for threshing efficiency of millets as a function of (a) Feed rate moisture content, (b) threshing sieve size and moisture content, (c) drum speed and moisture content, (d) threshing sieve size and Feed rate, (e) drum speed and Feed rate and (f) threshing sieve size and drum speed.*

level of significance and effect of drum speed and threshing sieve size were significant at 1% level of significance. The quadratic term of drum speed is highly significant ($p<0.001$) and moisture content ($p<0.01$) and feed rate (0.05) had significant effect on threshing efficiency. The lack of fit was obtained non significant on threshing efficiency. No significant effect was found in case of all the interactions of the variables. The regression equation obtained for the response threshing efficiency with four independent variables neglecting the high error generating terms was presented in the equation 5.

$$Te = +91.50 - 1.50\ M_c + 1.17\ D_s - 1.25T_{ss} - 1.19\ M_c^2 + 0.81\ F_r^2 + 1.44\ D_s^2 \quad (5)$$

Where, T_e = Threshing efficiency, %

M_c = Moisture content, % (d.b)

D_s= Drum speed, rev/min

T_{ss}= Threshing sieve size, mm

F_r= Feed Rate, kgh^{-1}

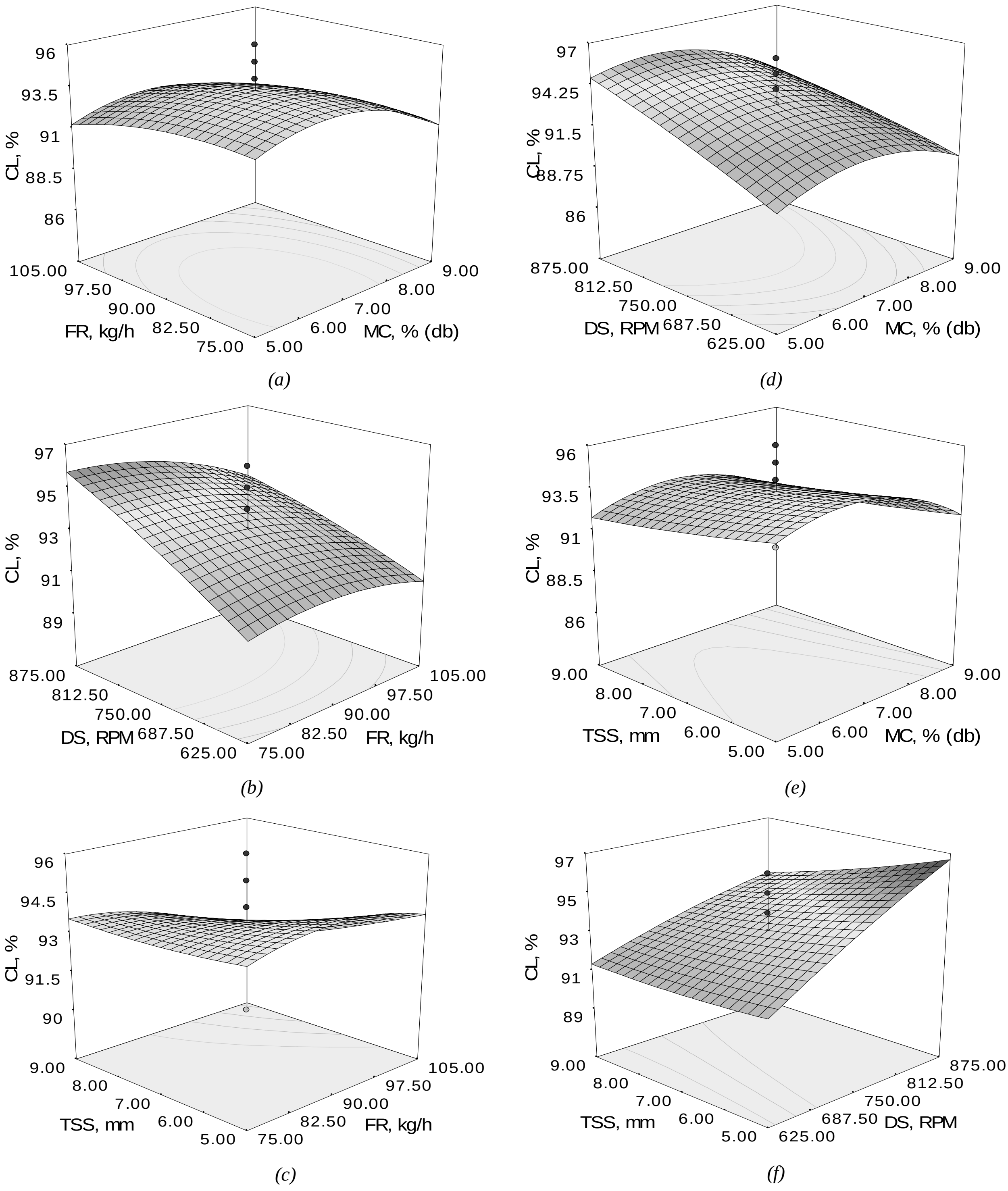
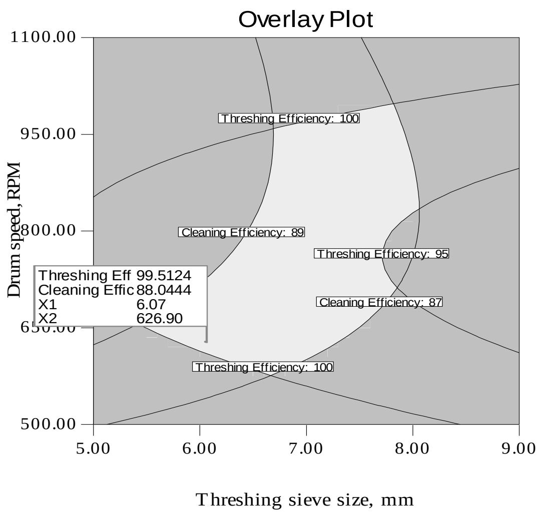


Fig. 2. *Response surface contours for cleaning efficiency of millets as a function of (a) Feed rate and moisture content, (b) drum speed and feed rate, (c) threshing sieve size and feed rate (d) drum speed and moisture content, (e) threshing sieve size and moisture content and (f) threshing sieve size and drum speed.*

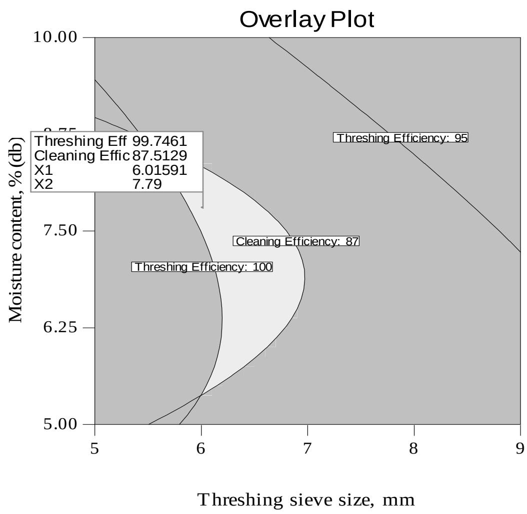
Response surface plots and contours of threshing efficiency as function of moisture content, feed rate, drum speed and threshing sieve size are showed in Fig 1 a, b, c, d, e and f. Threshing efficiency was found slow decreased with increase of moisture content from 5 to 7% and decrease was rapid thereafter within the experimental range of feed rates, threshing sieve size and drum speed (Fig. 1a, 1b, 1c). It can be observed from Fig. 1a that at a fixed feed rate of 75 kgh^{-1} threshing efficiency was decreased from 92 to 91.5% slowly as the moisture content was increased up to 7% and decreased rapidly thereafter up to 90%. Kamble *et al.*

Table 6. Comparison of physical and threshing parameters of selected minor millets.

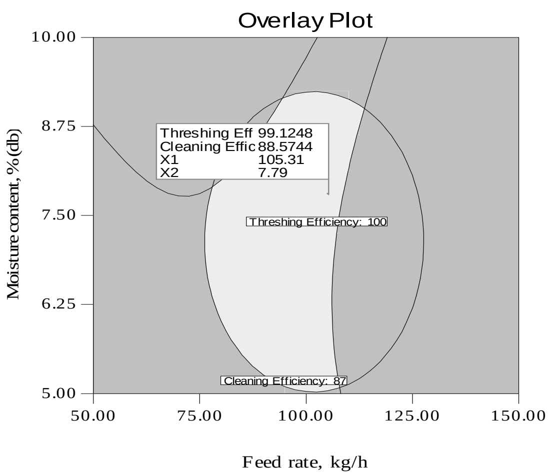
Millets	Dia (mm)	Sphericity (fraction)	Bulk density (kg/m^3)	Thousand grain weight (gm)	Threshing capacity (kg/h)	Threshing efficiency (%)	Broken grain (%)	Cleaning efficiency (%)
Panicum sumatrense (M1)	2.26^{b}	0.481^{a}	815.0^{c}	2.08^{a}	88.7^{a}	97.57^{a}	1.70^{b}	97.13^{a}
Paspalum scrobiculatum (M2)	3.41^{b}	0.818^{e}	747.0^{a}	4.20^{d}	116.7^{b}	99.33^{b}	0.50^{a}	98.96^{b}
Setaria italic (M3)	2.35^{b}	0.512^{b}	753.7^{a}	2.39^{b}	95.3^{a}	99.40^{b}	1.20^{b}	99.12^{b}
Panicummiliaceum (M4)	1.95^{a}	0.485^{a}	825.3^{c}	2.32^{b}	95.0^{a}	97.33^{a}	1.60^{b}	96.98^{a}
Echinochloa frumantacea (M5)	2.32^{b}	0.544^{c}	895.3^{d}	3.35^{c}	108.3^{b}	96.33^{a}	0.54^{a}	95.89^{a}
Eleusine coracana (M6)	1.63^{a}	0.681^{d}	802.0^{b}	2.35^{b}	102.0^{a}	99.40^{b}	0.00^{a}	99.27^{b}



(a)



(c)



(b)

Fig. 3. *Super imposed contours plots of (a) drum speed and threshing sieve size, (b) moisture content and feed rate and (c) moisture content and threshing sieve size.*

(2003) conducted the study of pearl millet thresher and got the reduced threshing efficiency with increase of moisture content because high moisture content increased the plasticity of the grain. Bansal and Lohan (2009) obtained higher threshing efficiency at lower moisture content during threshing of seed crops. Kushwaha *et al.* (2005) developed an Okra seed extractor and evaluated at different moisture content from which they got the result as extracting efficiency was decreased with increase of moisture content. Fulani *et al.* (2013) resulted that higher threshing efficiency observed at lower moisture content in case of cowpea. Increase in threshing efficiency was observed very slowly with increase of feed rate within all experimental range of moisture content, threshing sieve size and drum speed (Fig. 1a, 1d, 1e). Abo-El-Naga *et al*. (2015) found increased threshing efficiency with increase of feed rate. In the present study, threshing efficiency was found to be increased rapidly with increased of drum speed with all experimental range of moisture content, feed rate and threshing sieve size (Fig. 1c, 1e, 1f). At a fix moisture content of 5% the threshing efficiency was increased from 88 to 95% as the drum speed increased from 625 to 875 rev/min. This may be due to more impact action of the drum per unit time on the crop. Kamble *et al.,* 2003 studied the effect of drum speed on threshing of pearl millet. It was observed that increase in drum speed increased the threshing efficiency in a high range. Bansal and Lohan (2009) also found higher threshing efficiency at high drum speed in case of seed crops. Ajav and Adejumo (2005) studied performance evaluation of an okra thresher and got the similar result as increase in cylinder speed increased the threshing efficiency. Singh *et al.*, 2008 studied the effect of threshing drum speed on threshing performances of pedal operated VL paddy thresher and got the same result. Sinha *et al*. (2007) studied the effect of drum speed on chickpea seed crop threshing, Fulani *et al*. (2013) also found similar result that threshing efficiency increased with increase of drum speed. Simonyan and Imokheme (2008) studied the effect of drum speed on sorghum threshing and they also got similar observations of increased threshing efficiency with increase of drum speed as in present study (Fig. 1c). Threshing efficiency was found very slowly decreased with increased of threshing sieve size within all the experimental range the moisture content, feed rate and drum speed (Fig. 1b, 1d, 1f). If we fix the feed rate at 75 kgh^{-1} threshing, efficiency was found decreased from 91 to 90% as the sieve size increased from 5 to 9 mm (Fig. 1d). The sieve size was selected for making suitable for all six minor millet according to their size. Higher size of sieve could not give necessary impact and caused grain loss.

Cleaning efficiency: Analysis of variance for response surface variable cleaning efficiency is presented in the Table 5. The ANOVA data shows that the model is significant at 0.1% level of significance whose F value is 5.8. The linear effect of feed rate on cleaning efficiency was highly significant ($p < 0.001$). The effect of drum speed is significant at 5% level of significance. The interaction of drum speed and threshing sieve size had significant effect on cleaning efficiency at 0.1% level of significance. The effect of moisture content and threshing sieve size had no significant effect on cleaning efficiency. The effect of the interactions except drum speed and threshing sieve size on cleaning efficiency were non significant. All the quadratic terms of independent parameters had no significant effect on cleaning efficiency. The regression equation obtained for cleaning efficiency as the function of four independent variables neglecting the high error generating terms was presented in the equation 6.

$$Ce = +93.50 - 0.67\,Fr + 1.92\,Ds - 0.62\,Ds \times Tss \quad \ldots\ldots..(6)$$

Where, Te = Threshing efficiency, %

Mc = Moisture content, %

Ds = Drum speed, rev/min

Tss = Threshing sieve size, mm

Fr = Feed Rate, kgh^{-1}

Response surface plots and contours of cleaning efficiency as function of moisture content, feed rate, drum speed and threshing sieve size are showed in Fig 2 a, b, c, d, e and f. Cleaning efficiency was found slowly decreased when moisture content increased from 5 to 7% and decreased thereafter rapidly within the experimental range of feed rates, threshing sieve size and drum speed (Fig. 2a, 2d, 2e). It can be observed from Fig. 3a that at a fixed feed rate of 75 kgh^{-1} the cleaning efficiency was decreased slowly as the moisture content was increased up to 7% and decreased rapidly thereafter up to 91%. Bansal and Lohan(2009) reported higher cleaning efficiency at lower moisture content in case of seed crops. Simonyan *et al.*, (2006) also reported same result in case of cleaning performance of stationary sorghum thresher. Fulani et al. (2013) found higher cleaning efficiency at lower moisture content during threshing of cowpea thresher. Cleaning efficiency was observed slowly decreasing with increase of feed rate in case of all the experimental range of moisture content, threshing sieve size and drum speed (Fig. 2a, 2b, 2c). This may be due to the increase of grain handling due to increase of feed rate. Threshing efficiency was found to be increased rapidly with increase of drum speed with all experimental range of moisture content, feed rate and threshing sieve size (Fig. 2b, 2c, 2d). At a fix moisture content of 5% the threshing efficiency was increased from 88.8 to 94.5% as the drum speed increased from 625 to 875 rpm. This may be due to more impact action the chaff were broken down into small parts which were blown away easily because terminal velocity of chaff decreased with its reduced mass. Ajav and Adejumo, 2005 studied performance evaluation of an okra thresher and got the same result as increase in cylinder speed increased the cleaning efficiency. Fulani et al., 2013 obtained high cleaning efficiency at higher drum speed in case of cowpea thresher. Bansal and Lohan (2009) also found similar result. Cleaning efficiency was found slowly decreased as the threshing sieve size increased within all experimental range of drum speed (Fig. 2f) and no effect was found with increased threshing sieve size within all the experimental range the moisture content and feed rate (Fig. 2c, 2e).This may be due to the reason that with increase of drum speed threshing efficiency increased and material to be cleaned also increased which reduced the cleaning efficiency. If we fix the feed rate at 75 kgh^{-1}cleaning efficiency was found same as the sieve size increased from 5 to 9 mm (Fig. 2c).

Optimization of the variables was done by using the design expert 7.0.0 software by taking threshing and cleaning efficiencies as the two responses. The graphical optimization was presented in the Fig 3 a, b, c. By combining the values given in the flagged areas of Fig. 3 a, b and c the optimized values obtained were moisture content 7.79%, feed rate 105.31 kgh^{-1}, drum speed of 626.9 rpm, threshing sieve size of 6.0 mm by giving the maximum threshing efficiency of 99.5% and cleaning efficiency of 88.5%. The values were closer to the values obtained in the numerical optimization values. On this basis a new thresher was fabricated with the optimized values.

Testing of the thresher with all the millets: The thresher was operated according to the optimized values of optimized operating parameters. Threshing of six minor millets was done and threshing capacity, threshing efficiency and broken grain were measured. The data were analyzed SPSS (v-10) to assess the suitability of the thresher for the six minor millets and arranged according to Duncan multiple ranges test (DMRT) in the Table 6. The physical parameters of the millets were compared with each other and found significant at 5% level of significance. The output with different millet was also found significantly different at 5% level of significance.

The diameter of all the millets was compared with each other for the design of sieve. The result was obtained that diameter of M_1 (2.26 mm), M_2 (3.41 mm), M_3 (2.35 mm) and M_5 (2.32 mm) are insignificant with each other and M_4 (1.95mm) and M_6 (1.63mm) are insignificant to each other but M_1, M_2, M_3 and M_5 are significantly different as compared to $M_4$and M_6. Sphericity affects the design of outlet and slope of the screen for easy gravity flow. The sphericity of M_1 (0.481) and M_4 (0.485) are insignificant to each other but significantly different from M_2 (0.818), M_3 (0.512), M_5 (0.544), M_6 (0.681). Bulk density is required for the design of hopper for feeding of crop. The bulk density of M_1 (815.0kg/m^3), M_4 (825.3kg/m^3) and M_2 (747.0kg/m^3), M_3 (753.7kg/m^3) are insignificant to each other but significantly different from M_5 (895.3kg/m^3) and M_6 (802.0kg/m^3). Thousand grain weight of all millets was obtained and compared from which the result was obtained that M_3 (2.39 gm), M_4 (2.32), M_6 (2.35 gm) were insignificant to each other but significantly different from M_1 (2.08gm), M_2 (4.20gm) and M_5 (3.35 gm). The threshing capacity was obtained for each millet. Threshing capacity of M_1 (88.7 kgh^{-1}), M_3(95.3 kgh^{-1}), M_4 (95.0 kgh^{-1}) and M_6 (102.0 kgh^{-1}) are insignificant to each other but significantly different from M_2 (116.7 kgh^{-1}), and M_5 (88.7 kgh^{-1}). The threshing efficiency of M_1 (97.57%), M_4 (97.33%) and M_5 (96.33%) are different from threshing efficiency of M_2 (99.33%), M_3(99.40%) and M_6 (99.40%). The broken grain percentage of M_2 (0.50%), M_5 (0.54%) and M_6 (0.00%)were significantly different from M_1 (1.70%), M_3 (1.20%) and M_4 (1.60%). The cleaning efficiency of M_1 (97.13%), M_4 (96.98%) and M_5 (95.89%) are different from cleaning efficiency of M_2(98.96%), M_3 (99.12%) and M_6 (99.27%). The values of threshing and cleaning values of the minor millets after testing were higher than the optimized values. This may be due to the reason that at the time of testing for optimization whole crop was fed into, but during the testing of all minor millets, only the ear heads were fed into the thresher.

Conclusion

The machine was developed and the independent variables were optimized for maximum threshing and cleaning efficiency for threshing of all six minor millets. The optimized values of the independent variables for maximum threshing efficiency (99.5%) and cleaning efficiency (88.5%) were 7.79% moisture content, 105.31 kgh^{-1} feed rate, 626.9 rpm cylinder speed, 6 mm threshing sieve size. The thresher was found suitable for threshing of all six minor millets. It was adopted successfully by the tribal people for threshing of all six minor millets.

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