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Effect of operating parameters on performance of finger millet pearling machine

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Abstract

The effect of operational parameters such as feed rate (FR), drum speed (DS), and concave clearance (CC) was studied on the performance of a pearling drum. The pearling drum consists of pearling cylinder, pearling sieve, concave, and outer casing of the drum. The response surface method with CCRD experimental design was used to study the effect of operational parameters on pearling drum. The considered levels for optimizing operational parameters viz., FR, DS, and CC were 40–80 kg/h, 5–10 m/s, and 3–15 mm, respectively. The maximum pearling efficiency (PE) and minimum grain damage (GD) were found to be 98.40%, and 0.12%, respectively at FR, DS, and CC of 71.89 kg/h, 7.13 m/s, and 5.13 mm, respectively. The validation of the performance of pearling drum was carried out at optimized levels of parameters, the PE was found to be 99% with no GD against predicted PE of 98.40% and GD of 0.12%.

KEYWORDS
CCRD, finger millet processing, pearling drum, pearling process, response surface methodology

1 | INTRODUCTION

The millet is the sixth mostly produced cereal crop in the world, predominantly consumed in South Asia and Africa and gaining its importance in North America due to increasing diaspora (Devi et al., 2014; McSweeney, Ferenc, et al., 2017). India is the largest producer of millets and has various varieties including Pearl millet (*Pennisetum glaucum*), Finger millet (*Eleusine coracana*), Foxtail millet (*Setaria italica*), and Kodo millet (Yang et al., 2012). Because of its superior nutritious value, finger millet stands unique among the minor cereals. Nutritionally, millets are superior to rice and wheat, containing carbohydrates of 81.5%, protein 9.8%, crude fiber 4.3%, and minerals 2.7% (Kaur et al., 2020). It is also an excellent source of iron (4.27 ± 0.6 mg/100 g), calcium (348 ± 3.5 mg/100 g), and zinc (36.6 ± 3.7 mg/100 g) (Kumar et al., 2020). The seed coat of finger millets has high polyphenols and flavonoids content which made it one of the most potent millets in terms of antioxidant activity (Balasubramaniam et al., 2020; Chandrasekara et al., 2012). In addition to the above nutritional benefits, the finger millets are gluten-free and help in lowering the glycemic index in foods thus reported as advantageous in managing Type 2 diabetes (McSweeney, Seetharaman, et al., 2017).

Finger millet grains are very small in size, measuring between 1.2 and 1.7 mm in diameter (Powar et al., 2019a, 2019b). The physiology of finger millet consists of a naked caryopsis and is majorly composed of the seed coat (13%–15%), germ (1.5%–2.5%), and endosperm (80%–85%; Hulse et al., 1980). Traditionally, processing methods such as decortication, malting, fermentation, roasting, flaking, and grinding are used to process millets (Kharat et al., 2019). The endosperm of finger millet is soft and fragile, and it cannot sustain the impact and pressure of pearling, resulting in the seed coat fragmenting into finer pieces (Dharmaraj & Malleshi, 2011). As a result, millet is never decorticated and is always pulverized with the seed coat, with the entire meal being used for food preparation. The seed coat is often brick red too dark in color, with polyphenols and pigments that polymerize, and turn dark and unappealing when cooked. Furthermore, the seed coat gives its meals a distinct odor and fibrous texture, which affects their sensory properties (Ushakumari, 2009). Because the seed coat prevents the grain from swelling during cooking and extended heating burst opens the grain, revealing the endosperm contents, finger millet cannot be cooked as discrete grains for consumption like rice. This does not only cause solids to release out but also turns the product into a sticky mass, lowering consumer acceptance (Dharmaraj & Malleshi, 2011). Therefore, the outer seed coat (glume) needs to be removed from the kernel before consumption.

The pearling operation in which the upper seed coat is removed from the finger millet improves the quality of food products, and improve the test and texture of food product (Powar et al., 2020). Traditionally, the finger millet is pearled using three different methods: rubbing grains in a gunny sack, leg pounding, and stone pounding which are time-consuming and laborious (Joshi et al., 2015). Very limited efforts are made for designing and developing mechanically operated finger millet pearling machines. The Finger millet pearling drum works on the principle of impact and rubbing force (Powar et al., 2020). The impact force on the grain is imparted by the spinning drum, while the rubbing force is applied by the moment of grain between the concave and rotating drum. The seed coat is released from the grain by the impact force, and the husk is removed by the rubbing force. The finger millet thresher-cum-dehusker was invented by Dassanayake et al. (2010). The machine capacity, damaged grains, blown grains, threshing efficiency, cleaning efficiency, and pearling efficiency (PE) was found to be 32 kg/h, 0.58%, 0.83%, 94.3%, 92.47%, and 94.91%, respectively. A finger millet pearler was developed by Verma et al. (2014) with optimized parameters such as 0.51 g/cc dispersion density, 12-min residence time, and 1200 rpm roller speed, and recorded the PE of 83.68%. Tejaswini et al. (2018) developed a finger millet thresher-cum-pearler and evaluated its performance at varying grain moisture content, drum speed, and feed rate (FR). At the second pass of grains from the pearler, the optimum value of PE was discovered at 10% (w.b.) moisture content, 900 rpm DS, and 150 kg/h FR, the PE, cleaning efficiency, and broken grain was determined to be 80.1%, 88.2%, and 4.3%, respectively. In the mechanical pearler, the hull of the grain is scraped away by the grinding action of the rotating drum and the friction of other grains. The pearling effectiveness of this pearler is quite low, resulting in increased losses due to seed breakage and more unpearled grains being produced (Verma et al., 2014). Successful efforts in designing, developing, and evaluating an integrated thresher-cum-pearler were made by Powar et al. (2019a) and (2019b). An integrated type of thresher-cum-pearler, pearling drum is directly coupled with a threshing drum. Therefore, the grains are directly conveyed to pearling drum after threshing. As a result, it is very crucial to maintain the optimum FR for the pearler during operation. Kamble et al. (2003) stated that the operating parameters such as FD, DS, and CC are the important parameters has a direct influence on the performance of the drum. Verma et al. (2014) studied the effect of operational parameters on the performance of finger millet dehuller-cum-pearler using the response surface method (RSM). The statistical experiment was designed with three levels of each independent parameter, that is, dispersed density (0.43–0.55 g/cc), residence time (12–18 min), and roller speed (1200–1600 rpm). The PE was found to be 83.68% with optimized parameters viz. 0.51 g/cc dispersed density, 12 min residence time, and 1200 rpm of the roller speed. After analyzing all the previous studies, it has been concluded that not a single article addressed the effect of operational parameters (FD, DS, and CC) on performance of the pearling drum. As a result, the research was undertaken with objectives, to study the effect of operational parameters on performance of pearling drum. The operational parameters of the pearling drum were also optimized; the optimized parameters will be useful in designing new integrated thresher-cum-pearlers.

2 | MATERIALS AND METHODS

2.1 | Preparation of sample

The finger millet panicles (Variety: *Dapoli-1*) were collected from the local farmers of the Konkan region, in India. The initial moisture content of the finger millet ear head was determined using the standard hot air oven method. Three samples weighing 50 g each were dried at a temperature of 105°C ± 1°C for 24 h. The initial moisture content of finger millet panicles was found as 15%. These finger millet panicles were sun-dried and maintained a moisture content of 10% at the time of threshing. The dried finger millet panicles are first threshed with a threshing drum and used for pearling operation.

2.2 | Theoretical design of pearling drum

Pearling drum consists of different components such as a threshing cylinder (Figure 1a and Figure A1), concave (Figure 1b, c and Figure A2), pearling sieve (Figure A3), and outer casing (Figure 1b and c). The diameter of the pearling drum was calculated by using Equation (1) (Varshney et al., 2004; Figure A4).

$$\vartheta_{cp} = \frac{\pi \times D_{cp} \times N_{cp}}{60} \tag{1}$$

where D_{cp} is the diameter of cylinder; N_{cp} is the rpm pf threshing cylinder; ϑ_p is the peripheral velocity of threshing cylinder.

The speed of pearling drum was assumed to be 750 rpm (economical speed from an energy consumption point of view; Varshney et al., 2004). Singh et al. (2010) found that the effective peripheral speed of the finger millet threshing and the pearling cylinder was 8 m/s. Putting the above values of peripheral speed and revolution per minute of the pearling drum in Equation (1) the diameter of the threshing drum was calculated as 200 mm. Taking an aspect ratio of 1.5:1, the length of the cylinder was 300 mm (Aware, 2012).

The simultaneous impact and rubbing of finger millet panicles were achieved with canvas belts fitted on the periphery of the cylinder using M.S. flats. As per Singh et al. (2010), eight flat strips with canvas belts around the pearling drum were effective considering the maximum pearling. Therefore, eight numbers of M.S. flat strips with canvas belts were fixed on the drum. The impact forces experienced by canvas strip are given by following Equation (2):

$$P_s = \frac{q \times u}{(1-f)} \tag{2}$$

where P_s is the impact forces experienced by each strip (N); q is the feed rate (kg/s); u is the peripheral speed (m/s); f is the wear coefficient for canvas (0.7–0.9).

In the previous investigation done by Powar et al. (2019a) and (2019b), the capacity of pearling drum is twice that of the threshing drum, if the same drum dimensions were used for pearling operation. As a result, the capacity of the pearling drum was considered as 80 kg/h. Therefore, the impact forces experienced by each strip were found to be 1.76 N. This force is assumed to increase 8–10 times more to attach the kernel and break the remaining material into pieces (Singh et al., 2010). Therefore, the design of impact force is 14.08 N. The bending moments experienced by the strip were calculated using Equation (3). The bending moments experienced by the strip were found to be 2534.4 N-mm.

$$M_b = P_{sd} \times l_{SS} \tag{3}$$

where M_b is the bending forces experienced by strip (N-mm); l_{ss} is the length of canvas strip support (mm).

The section modules of strip support can be computed from the classical flexure formula (Equations 4 and 5) given by Singh et al. (2010) as follows:

$$Z_s = \frac{M_b}{f_b} \tag{4}$$

$$Z_s = \frac{b_s {d_s}^2}{6} \tag{5}$$

where M_b is the bending moment (N-mm); f_b is the bending stress of milled steel (N/mm^2); b_s is the width of canvas support (mm); d_s is the thickness of canvas support (mm).

Therefore, M_b, 2534.4 N-mm; f_b, bending stress for rectangular milled steel section 100 N/mm^2; b_s, 180 mm. The thickness of the canvas strip supporter was found to be 2.46 mm. As a result, a commercially available 3 mm M.S. flat plate was selected for the fabrication.

To provide maximum rubbing force on finger millet grain concave bars were provided on the periphery of the drum. Therefore, the number of bars required to cover the peripheral area of the drum was calculated using Equation (6).

$$N_b = \frac{P_{cl}}{D_b} \tag{6}$$

where N_b is the no of bars; P_{cl} is the peripheral concave length (mm); D_b is the diameter of the bar (mm; considered 6-mm diameter).

The peripheral concave length was calculated using the following equation:

$$P_{cl} = P_{dl} - P_{lo} \tag{7}$$

where P_{dl} is the peripheral length of the drum (mm); P_{lo} is the peripheral length of open area (mm; hopper opening width [50 mm] + Sieve opening width [60 mm]), mm.

Therefore, 108 bars were required to cover peripheral concave length. Pearling sieve increases the residence period of grain inside the drum, resulting in repeated impact and rubbing. It was fitted in the open space of lower pearling concave. The pearling sieve had circular openings. The diameter was taken based on the 95th percentile finger millet grain diameter to pass all grains through it. As the diameter was 1.85 mm, the sieve size opening was selected as 2 mm. pearling sieve was made of a 16-gauge mild steel sheet having 2 mm ϕ holes with a length of 300 mm and projected width of 60 mm.

2.3 | Pearling drum

The drum consists of a rotating pearling cylinder, concave (made from 6 mm round bar), pearling sieve (size of hole 2 mm), and outer casing of drum. The pearling cylinder was made of mild steel (16-gauge thickness) sheet with 200-mm diameter and 300-mm length (Figure 1a). The canvas belt of sizes 5 × 30 × 180 mm was fitted on the M.S. flat strips, to avoid direct contact between grain and M.S. strips to reduce impact force and increase the soft abrasion action to remove glumes from the grains (Figure A1). The pearling sieve was made of mild steel (16-gauge thickness) of diameter 2 mm holes with a length of 300 mm and a width of 60 mm (Figure 1c). It was fitted in the open space provided at the lower pearling drum. The maximum pearling capacity was found to be 80 kg/h. Based on previous studies, the levels of independent parameters (operational parameters) were considered as an FR of 40–80 kg/h, CC of 3–15 mm, and DS of 5–10 m/s (Figure A4).

2.4 | Experimental design

The central composite rotatable design (CCRD) was used for the experiment design and testing. The three important independent parameters that affecting on the PE and grain damage (GD) viz., FR (X_1), DS (X_2), and CC (X_3) were considered for the study. In CCRD, the RSM was utilized to optimize the operational parameters of a pearling drum using a second-order polynomial equation (Savic et al., 2015, 2016). The FR varied from 40 to 80 kg/h, DS from 3 to 15 mm, and CC from 5 to 10 m/s. The above independent levels are coded into five different levels viz., + 1.682 (L1), + 1 (L2), 0 (L3), − 1 (L4), and − 1.682 (L5), respectively (Table 1). The following Equations (8) to (11) were utilized to convert independent variables x_1 (FR), x_2 (DS), and x_3 (CC) into their real forms as X_1, X_2, and X_3, respectively.

$$X_i = \frac{X_i - X_m}{X_D} \tag{8}$$

Here, $i = 1$, 2, and 3

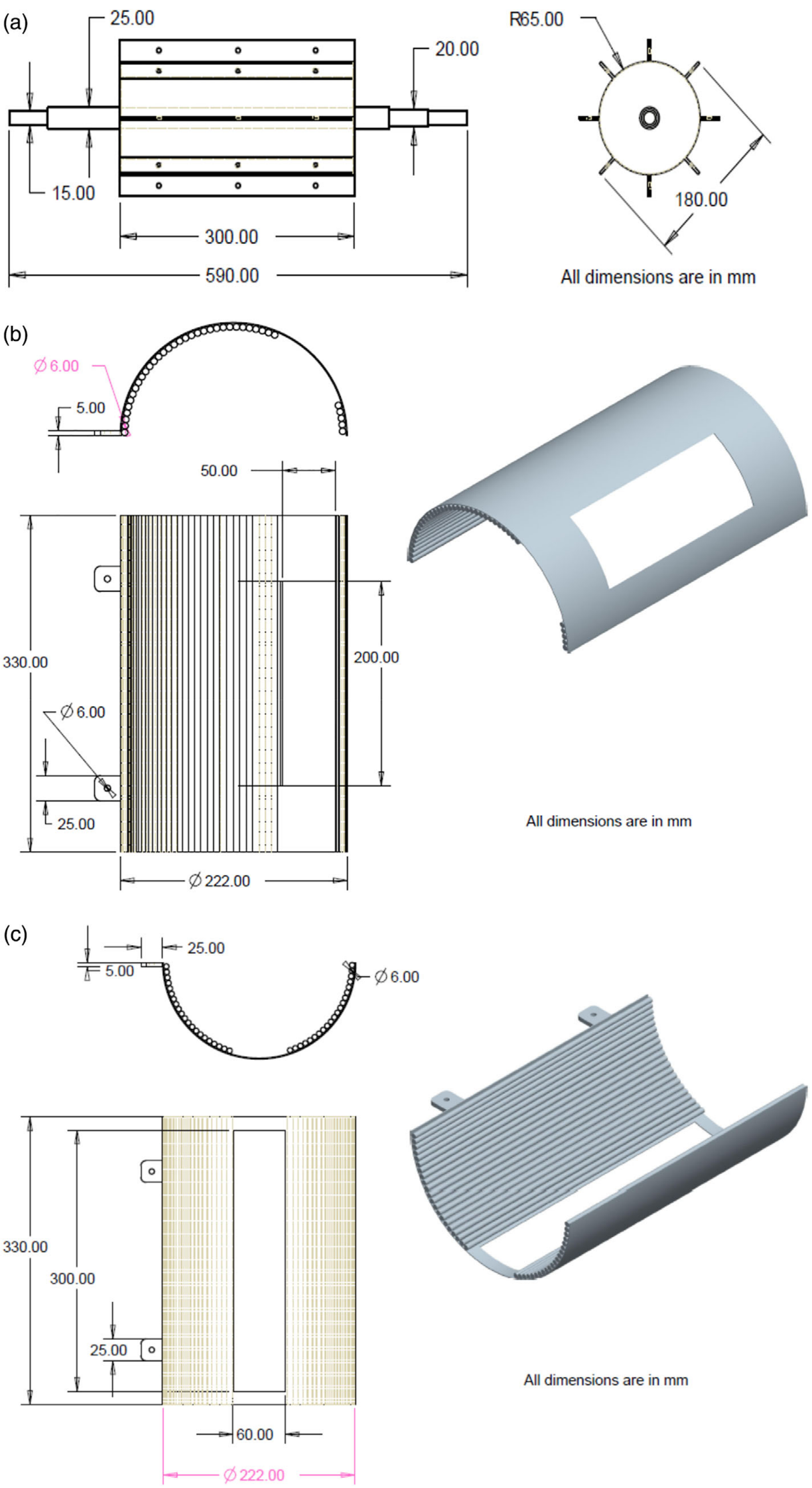

FIGURE 1 Components of pearling drum (a) pearling drum without canvas belt, (b) upper pearling concave, and (c) lower pearling concave

$$X_D = \frac{X_{max} - X_m}{a_m} \tag{9}$$

$$x_i = \frac{X_{max} - X_{min}}{2} \tag{10}$$

$$a_m = 2^{0.25\,k} \tag{11}$$

where X_{min} is the minimum value of independent variables; X_{max} is the maximum value of independent variables; a_m is the extreme coded

TABLE 1 The levels of independent parameters as stated by the CCRD for performance testing of the pearling drum

S. no.	Independent variables	L1 (− 1.68)	L2 (− 1)	L3 (0)	L4 (1)	L5 (+ 1.68)
1	FR (X_1), kg/h	40	48	60	72	80
2	DS (X_2), m/s	3	5	9	13	15
3	CC (X_3), mm	5	6	7.5	9	10

value (maximum = $+a_m$; minimum = $-a_m$); k is the number of independent variables considered for optimization; x_d is the accuracy of variable; X_i is the coded value of the ith variable. The nonlinear second-order polynomial regression Equations (12) and (13) were developed to optimize PE and GD.

$$\mathrm{PE} = b_0 + \sum\nolimits_{i=0}^{3} b_i x_i + \sum\nolimits_{i=1}^{3} b_{ii} x_{ii}^{2} + \sum\nolimits_{i=1}^{2} \sum_{j=i+1}^{3} b_{ij} x_i x_j \tag{12}$$

$$\mathrm{GD} = b_0 + \sum\nolimits_{i=0}^{3} b_i x_i + \sum\nolimits_{i=1}^{3} b_{ii} x_{ii}^{2} + \sum\nolimits_{i=1}^{2} \sum_{j=i+1}^{3} b_{ij} x_i x_j \tag{13}$$

where b_0 is the constant; b_i is the linear regression coefficient; b_{ii} is the quadratic regression coefficient; b_{ij} is the interaction regression coefficient; x_i is the coded value of variable.

The derived nonlinear equations' goodness of fit (Flof) was checked using F-value and calculated using Equation (14).

$$F_{\mathrm{lof}} = \frac{\sum_{i=1}^{N} (Y_{ai} - Y_{ci})^2 - \sum_{i=1}^{n_c} (Y_{ai} - Y_{\mathrm{av}})^2}{\mathrm{N} - \text{no. of coefficients in regression equation} - \mathrm{N_c} + 1} \tag{14}$$

where Y_{ai} is the experimental value of the ith response; Y_{av} is the average of actual values of responses; Y_{ci} is the calculated value of the ith response; N is the total number of experiments, n_c is the number of central experiments.

The 20 experiments were carried out in a random order, according to the CCRD (Table 2). Six replicated experiments were performed at the coded variables' center points to compute the error sum of squares and the lack of fit of the constructed regression equation between the responses and independent variables.

2.5 | Performance parameters

2.5.1 | Pearling efficiency

PE was calculated by counting the number of unpearled grains from 100 grains collected from the main grain outlet using Equation (15) (Powar et al., 2020).

$$\mathrm{PE} = (100 - N_{up}) \tag{15}$$

where PE is the pearling efficiency (percent); N_{up} is the number of unpearled grains.

TABLE 2 Experiment design for optimizing operational parameters

Experiment No.	FR (kg/h)	DS (m/s)	CC (mm)	PE (%)	GD (%)
1	48	6	5	96	0
2	72	6	5	98	0
3	48	6	13	93	0
4	72	6	13	95	0
5	48	9	5	97.66	0.9
6	72	9	5	99	0.7
7	48	9	13	95	0.5
8	72	9	13	96.66	0.2
9	40	7.5	9	96	0.4
10	80	7.5	9	98	0
11	60	7.5	3	98.66	0.5
12	60	7.5	15	93	0
13	60	5	9	91	0
14	60	10	9	99.33	1.3
15	60	7.5	9	97	0
16	60	7.5	9	96.33	0
17	60	7.5	9	95.66	0.2
18	60	7.5	9	96.66	0
19	60	7.5	9	96	0.2
20	60	7.5	9	97	0.2

2.5.2 | Visible grain damage

GD was the ratio of the quantity of damaged grains collected from main outlets per unit time to total grains input per unit time using Equation (16) (Powar et al., 2020).

$$\mathrm{GD} = \left(\frac{w_{\mathrm{dg}}}{w_{\mathrm{tg}}}\right) \times 100 \tag{16}$$

where GD is the grain damage (percent); w_{dg} is the damaged grains collected from main outlets per unit (g); w_{tg} is the total grains input per unit time (g).

2.6 | Statistical analysis

All experiments were conducted in duplicate with results expressed as mean values ± SD. The CCRD experiment, and Duncan multiple comparison tests used ($p \leq .05$) to evaluate the significant effects highlighted by the response surface methodology were performed using the Design-Expert software (Stat–ease, Minneapolis). Means differences (one-way analyses of variance).

3 | RESULTS AND DISCUSSION

3.1 | Analysis of pearling drum performance

The maximum pearling drum capacity was found to be 80 kg/h. The pearling drum performance was investigated, and their relation with PE and GD is explored in the following sections.

3.1.1 | Pearling efficiency

It can be observed from Figure 2a that, at fixed DS (7.13 m/s), the PE increases with a decrease in CC, and the maximum PE (98.2%) was found at 3 mm CC. Similarly, the PE increases with an increase in FR at all DS. At a fixed value of CC of 5.43 mm, the PE increases with DS at all FR and attaining maxima (PE 99.77%) at 80 kg/h of FR (Figure 2b). At a fixed value of optimum FR of 71.89 kg/h, the PE increases with an increase in DS all CC and attaining maxima (PE, 99.6%) at 10 m/s of DS (Figure 2c). Decrease in concave space between drum canvas strip and concave bar, which increases the rubbing force imparted on the finger millet grains, ultimately, it increases the PE, similarly, minimum PE at the higher CC was observed due to lack of required rubbing force exerted on finger millet grains and, therefore, grains fallout from concave sieve without pearling. Kamble et al. (2003) studied the effect of CC on threshing efficiency of pearl millet. They reported that if CC decreases it increases the threshing efficiency. Impact and rubbing force increase linearly with an increase in DS, ultimately it increases the PE, a reverse trend observed at lower DS. Verma et al. (2014) developed a finger millet dehuller-cum-pearler and studied the effect of dispersion density, residence time, and drum speed on PE. They reported that the pearling efficiency increase with increase in drum speed. An increase in FR enhances the PE, which could be due to maximum friction between the canvas to grain, grain to grain, and grain to the concave bar, if the FR decreases it develops less friction between them, subsequently there is lower PE. Similar effect also reported by Sudajan et al. (2002) for sunflower threshing.

According to the *F*-values in Table 3, the linear component of DS has a greater influence on PE than the FR and CC. At the linear levels, CC, DS ($p < .0001$), and FR ($p < .0001$) had a substantial effect on PE, but no significant effect was seen at the interactions and quadratic levels. Even at the 10% level of significance ($p < .1$), the interaction and quadratic components of all three variables had no meaningful effect on PE. The numerical presentation (Equation 17) in the fluctuation of the PE (%) with different variables X_1, X_2, and $X3$ was well

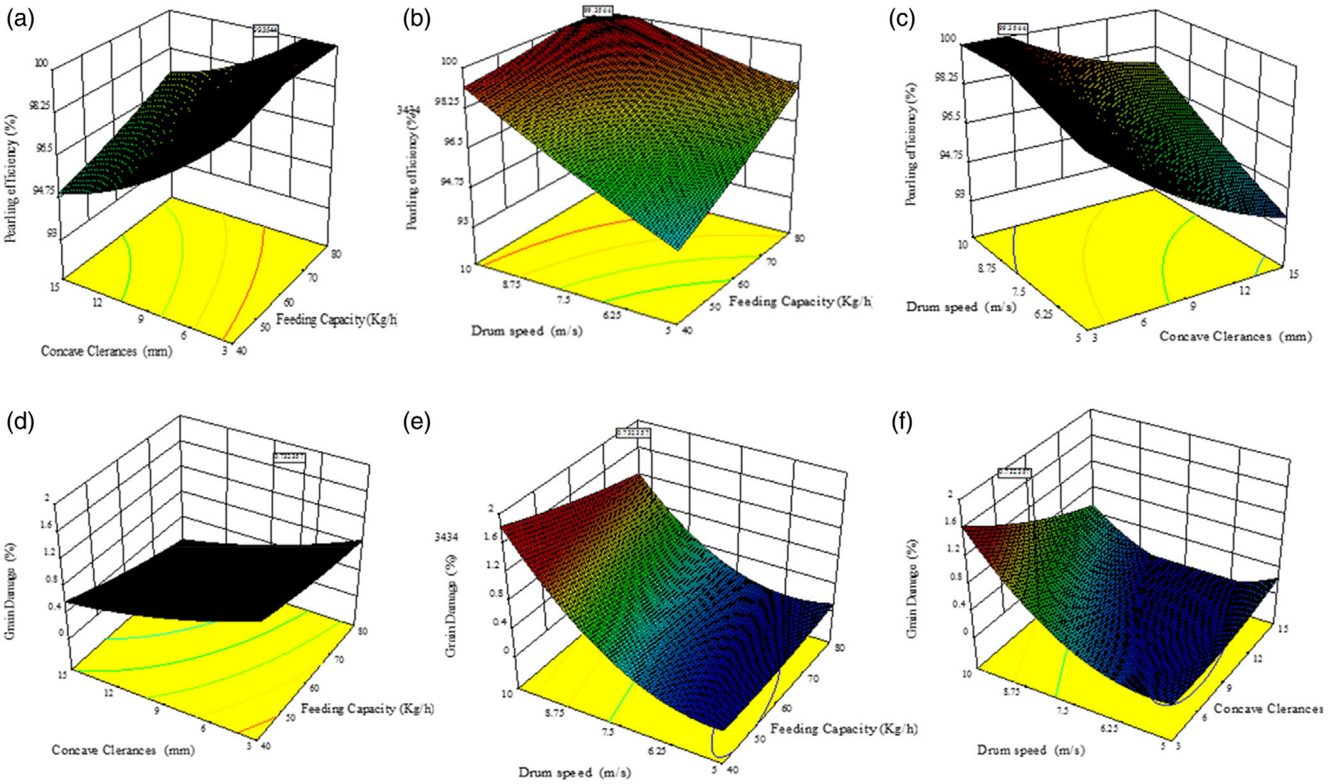

FIGURE 2 Response surface graphs representing the effect of independent parameters on the PE and GD (a) Effect of CC (mm) and FR (kg/h) on the PE (%) at optimum DS 7.13 m/s. (b) Effect of DS(m/s) and FR (kg/h) on the PE (%) at optimum CC 7.13 m/s. (c) Effect of DS (m/s) and CC (mm) on the PE (%) at optimum FR 71.89 kg/h. (d) Effect of CC (mm) and FR (kg/h) on the GD (%) at optimum DS 7.13 m/s. (e) Effect of DS (m/s) and FR (kg/h) on the PE (%) at optimum CC 5.43 mm. (f) Effect of DS (m/s) and CC (mm) on the GD (%) at optimum FR 71.89 kg/h

TABLE 3 Effect of operational parameters on pearling efficiency

Source	Sum of squares	*df*	Mean square	*F* value	*p* value Prob > *F*	
Model	52.98	9	5.89	17.80	<.0001	Significant
A-FR	8.57	1	8.57	25.92	.0005	
B-CC	24.50	1	24.50	74.09	<.0001	
C-DS	18.64	1	18.64	56.36	<.0001	
AB	0.014	1	0.014	0.041	.8433	
AC	0.35	1	0.35	1.05	.3287	
BC	0.12	1	0.12	0.37	.5563	
A^2	0.041	1	0.041	0.12	.7316	
B^2	0.76	1	0.76	2.31	.1595	
C^2	0.041	1	0.041	0.12	.7316	
Residual	3.31	10	0.33			
Lack of fit	2.50	5	0.50	3.08	.1210	Not significant
Pure error	0.81	5	0.16			
Correction total	56.29	19				

fitted Equation (17) with a coefficient of determination (R^2) of 0.94 (ignoring the high error-generating factors, $p < .0001$). Similarly, the nonintercept model of PE is given by Equation (18).

$$\mathrm{PE} = 88.49 + 0.063\,\mathrm{FR} + 0.99\,\mathrm{DS} - 0.39\,\mathrm{CC} \tag{17}$$

$$\mathrm{PE} = 0.7199\,\mathrm{FR} + 6.24\,\mathrm{DS} + 0.57\,\mathrm{CC} \tag{18}$$

3.1.2 | Grain damage

It can be observed from Figure 2d that, at fixed DS (7.13 m/s), the maximum GD was observed up to 3–9 mm CC thereafter no GD was found for all FRs. The maximum GD (0.17%) was found at a 3 mm CC and 40 kg/h FR. Similarly, the GD increases with a decrease in FR at all drum speeds.

At a fixed value of CC of 5.43 mm, the GD increases with DS from 7 to 10 m/s at all FR. DS from 5 to 7.5 m/s there was no GD found (Figure 2e). At a fixed value of optimum FR of 71.89 kg/h, the GD increases with an increase in DS from 7 to 10 m/s at all CC and attaining maxima at GD of 1.6% at 10 m/s of DS with 3 mm CC (Figure 2f). Hanumantharaju et al. (2017) developed a motor-operated finger millet thresher having an output capacity of 65 kg/h. They checked the performance of the machine at set parameters such as DS 11 m/s, CC 4 mm, and threshing sieve size 3 mm. They reported the highest threshing efficiency of 94.15% and GD of 2.59%.

GD is caused by a decrease in CC, which increases the rubbing force between canvas strip-grains and concave bar-grains. It also occurs as a result of increased direct contact between the canvas strip-grains and the grain-concave bars of the drum. The seed damage was dependent upon concave clearance (CC). Reducing the CC tends to reduce the cylinder or threshing losses but increases the seed damage Similar trend was also reported by Kamble et al. (2003) for threshing pearl millet. The dominating impact force is observed at higher drum speed, this causes higher GD. Similar effect was also reported by Sudajan et al. (2002) for sunflower threshing.

According to the *F*-values in Table 4, the linear term of DS has a greater influence on GD than FR and CC. GD is significantly affected by DS ($p < .0001$) at the linear and ($p < .050$) quadratic levels, but no significant effect was seen at the interaction level, except for CC*DS ($p < .05$). Even at the 10% level of significance ($p < .1$), the interaction and quadratic terms of FR and CC did not affect GD. The numerical variation of GD (%) with different variables X_1, X_2, and X_3 was well fitted in Equation (19) with a coefficient of determination (R^2) of 0.94 (neglecting the high error-generating terms, $p < .0001$). Similarly, the nonintercept model of PE is given by Equation (20).

$$\mathrm{GD} = -06652 - 0.00717\,\mathrm{FR} + 0.219 - 0.033\,\mathrm{CC} \tag{19}$$

$$\mathrm{GD} = -0.0121\,\mathrm{FR} + 0.18\mathrm{DS} - 0.04\,\mathrm{CC} \tag{20}$$

Table 5 displays the anticipated values of responses for five ideal circumstances of independent variables determined by software. The optimal values of variables such as FR 71.89 kg/h, DS 7.13 m/s, CC 5.43 mm, PE 98.40%, and GD 0.12% were determined using the values given in the flagged region in Figure A5. The numerical optimization method's Serial no. 6 (Table 5) values were found to be closer to the graphical optimization method's values (Figure 2).

3.2 | Validation of the performance of pearling drum

With the above-optimized settings, the performance of the pearling drum was tested, and it was found that PE was 99% versus expected 98.40%, and no GD was found versus predicted 0.12%, respectively. The operating parameters of the pearling drum, such as DS, CC, and pearling sieve size, are optimized by Powar et al. (2019a) and (2019b). The authors reported that the ideal operating settings for the pearling drum were 7.25 m/s DS, 3 mm CC, and 2 mm pearling sieve size, which indicated a maximum PE of 98.95% and GD of 0.73%. In comparison

TABLE 4 Effect of operational parameters on grain damage

Source	Sum of squares	*df*	Mean square	*F* value	*p* value Prob > *F*	
Model	2.37	9	0.26	19.15	<.0001	Significant
A-FR	0.10	1	0.10	7.32	.0221	
B-CC	0.22	1	0.22	16.12	.0025	
C-DS	1.47	1	1.47	107.08	<.0001	
AB	1.250E-003	1	1.250E-003	0.091	.7693	
AC	0.031	1	0.031	2.27	.1628	
BC	0.10	1	0.10	7.36	.0218	
A^2	3.345E-003	1	3.345E-003	0.24	.6327	
B^2	0.016	1	0.016	1.13	.3119	
C^2	0.44	1	0.44	31.82	.0002	
Residual	0.14	10	0.014			
Lack of fit	0.078	5	0.016	1.29	.3921	Not significant
Pure error	0.060	5	0.012			
Correction total	2.51	19				

TABLE 5 Solution for optimization condition

S. no	FR	CC	DS	PE	GD	Importance
1	71.89[a]	5.43[a]	6.68[a]	98.16[b]	0.050[c]	1
2	71.89[a]	5.43[a]	6.68[a]	98.16[b]	0.050[c]	2
3	71.89[a]	5.43[a]	6.69[a]	98.16[b]	0.051[c]	3
4	71.89[a]	5.43[a]	6.68[a]	98.16[b]	0.050[c]	4
5	71.89[a]	5.43[a]	6.68[a]	98.16[b]	0.050[c]	5
6	71.89[a]	5.43[a]	7.13[a]	98.40[b,d]	0.1227[c,e]	-

[a] Goal in range.
[b] Goal maximum.
[c] Goal minimum.
[d] Five importance.
[e] Three importance.

to this study, the level of CC was raised by 45%. This is advantageous for reducing GD and boosting the capacity of the pearling drum.

4 | CONCLUSION

According to the research, if the same drum is used for pearling and threshing, the capacity of the pearling drum is twice that of the threshing drum. The FR of 71.89 kg/h, CC of 5.43 mm, and DS of 7.13 m/s were found to be optimal for pearling drum performance. The corresponding PE was 99% versus the projected 98.40%, and no GD was found versus the predicted 0.12%. According to the foregoing findings, the pearling drum presented in this study is ideal for the construction of a finger millet thresher-cum-pearler. This removes the disadvantages of the manual pearling method.

AUTHOR CONTRIBUTIONS

Ranjit Powar: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; software; validation; visualization; writing-original draft; **Vijay Aware**: Conceptualization; funding acquisition; project administration; supervision; **Prasad Chavan**: software; statistical analysis; article writing; writing-review and editing. **Amit K. Jaiswal**: writing-review; technical check; editing and revision.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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APPENDIX

EFFECT OF OPERATING PARAMETERS ON PERFORMANCE OF PEARLING DRUM

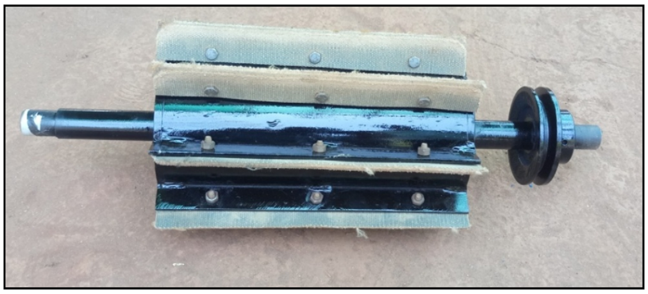

FIGURE A1 Pearling cylinder with canvas belt

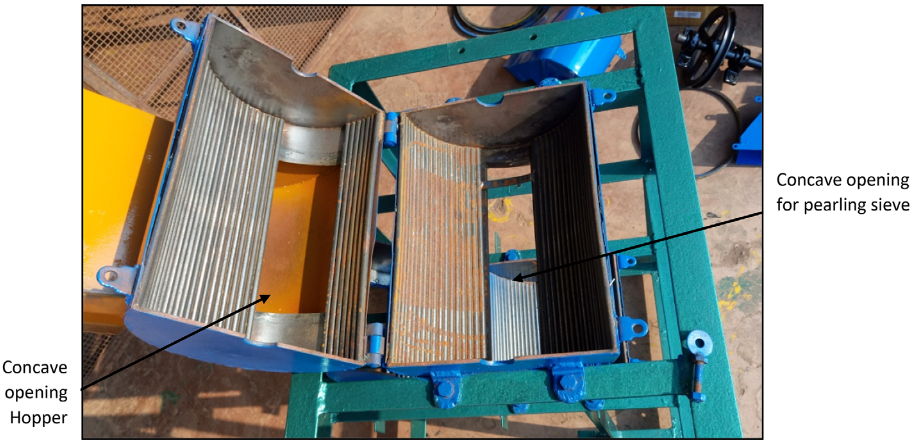

FIGURE A2 Concave for pearling operation

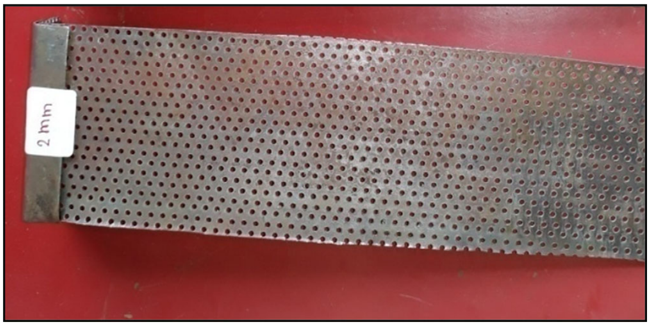

FIGURE A3 Pearling sieve size

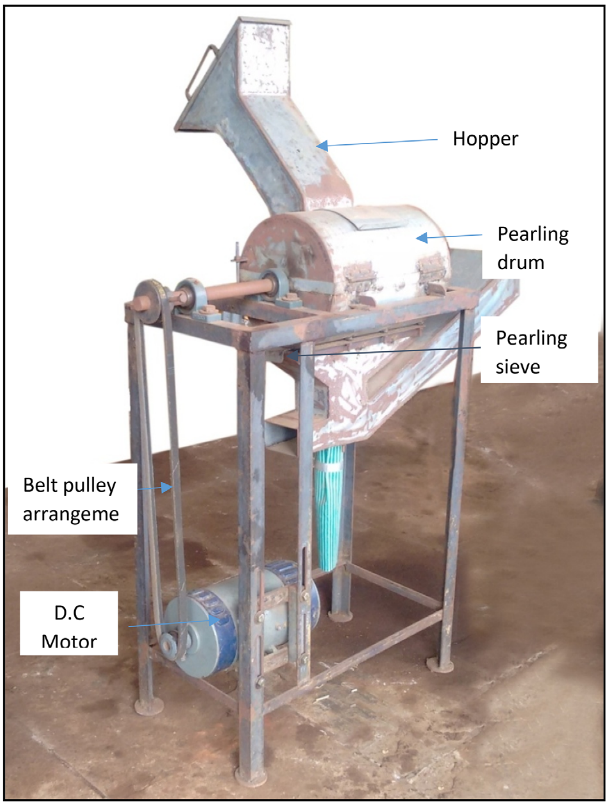

FIGURE A4 Pearling machine

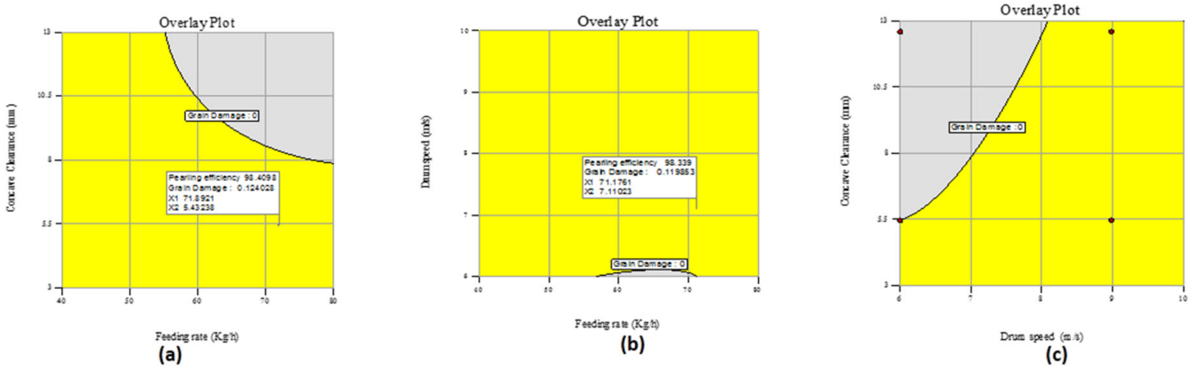

FIGURE A5 Superimposed contours for PE (%) and GD (%): (a) at varying FR (kg/h), and CC (mm) at fixed DS of 7.14 m/s. (b) at varying FR (kg/h), and DS (m/s) fixed of 5.43 CC (mm). (c) At varying CC (mm) and DS (m/s) at fixed FR of 71.89 kg/h