# EXPERIMENTAL EVALUATION OF BUCKWHEAT DEHULLING USING A NOVEL DEHULLING DEVICE WITH A ROTATING DRUM AND A SHAPE-ADAPTIVE PRESSURE DECK

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# *Эргэх хүрд ба сагаг будааны хэлбэрт тохируулсан шинэ хийцийн шахах дектэй хальслах төхөөрөмжөөр сагаг будааг хальсалсан туршилтын үр дүн*

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## ABSTRACT

*A novel buckwheat dehulling device consisting of a rotating drum and a pressure deck with an elastic contact surface was developed to eliminate the need for grain size classification prior to dehulling. The geometry of the pressure deck was designed to match the shape of buckwheat grains, ensuring stable contact and effective dehulling across the commercial grain size range of 3–5 mm. The performance of the device was experimentally evaluated using a three-factor rotatable central composite design. The effects of drum rotational speed, working gap, and grain moisture content on the dehulling degree were investigated, and a quadratic regression model was established. The results showed that the maximum dehulling degree of 66.08% was achieved at a drum rotational speed of 846 rpm, a working gap of 4.2 mm, and a grain moisture content of 13.86%. The developed device demonstrates that optimizing the geometry and elastic properties of the pressure deck can significantly improve buckwheat dehulling efficiency while eliminating the need for prior grain size classification.*

## ХУРААНГУЙ

*Сагаг будааг хэмжээний ангилалгүйгээр хальслах зорилгоор эргэх хүрд болон уян харимхай ажлын гадаргуутай, сагаг үрийн хэлбэрт тохируулан хийцлэгдсэн шахах декээс бүрдэх шинэ төрлийн хальслах төхөөрөмжийг боловсруулав. Шахах декний геометр хэлбэрийг сагаг үрийн хэлбэрт тохируулснаар 3–5 мм хэмжээтэй үрийг тогтвортой шахаж, үрийн гадаргууг жигд хальслах нөхцөлийг бүрдүүлсэн. Төхөөрөмжийн ажиллагааг гурван хүчин зүйлт төвийн зохиомжит ротатабель төлөвлөлтийн аргаар туршиж, хүрдний эргэлтийн давтамж, ажлын завсар, үрийн чийгийн агууламжийн хальслалтын зэрэгт үзүүлэх нөлөөг судлан шугаман бус регрессийн математик загвар байгуулсан. Туршилтын үр дүнгээр хүрдний эргэлтийн давтамж 846 эрг/мин, ажлын завсар 4.2 мм, үрийн чийгийн агууламж 13.86% байх үед хальслалтын зэрэг 66.08%-д хүрсэн. Судалгааны үр дүнгээс үзэхэд шахах декний геометр хэлбэр болон уян харимхай шинж чанарыг оновчтой сонгосноор сагаг будааг хэмжээний ангилалгүйгээр үр ашигтай хальслах боломжтой болохыг тогтоов.*

## INTRODUCTION

Various types of dehulling machines have been developed for cereal grain processing because differences in the anatomical structure and physical–mechanical properties of grains require different dehulling mechanisms. Grain shape, the adhesion strength between the hull and kernel, differences in the mechanical properties of the hull and kernel, and the elastic behavior of the grain determine the type and magnitude of the mechanical forces required during dehulling. Consequently, dehulling machines have been developed based on different operating principles to satisfy these technological requirements (*Chebotarev et al., 2004; Egorov et al., 2005; Tarasenko et al., 2017; Kent et al., 2018*). Experimental studies on roller-type dehulling machines have been reported by *Kamst et al. (2002)*, *Adisa et al. (2016, 2020)*, *Mar'in et al. (2020)*, *Itodo et al. (2023)*, and *Cheng et al. (2026)*.

According to their operating principles, dehulling machines can be classified as compression–friction, compression–impact, impact–inertia, and combined systems. Based on the mode of operation, they are categorized as mechanical, aerodynamic, or combined machines. According to the characteristics of the working surfaces, they are further classified into rigid, elastic, abrasive, and fluid- or gas-assisted types *(Chebotarev et al., 2004; Egorov et al., 2005; Tarasenko et al., 2017).*

Previous experimental studies have shown that dehulling machines operating on the principles of compression, friction, and impact provide high processing efficiency while being relatively simple to control and adjust *(Itodo et al., 2023; Kamst et al., 2002; Mar'in et al., 2020; Oidov et al., 2025; Shitanda et al., 2001; Solanki et al., 2018; Upreti et al., 2022; Zhang et al., 2025)*. Consequently, these machines are widely used in industrial buckwheat processing.

Despite their effectiveness, conventional buckwheat dehulling machines require the grains to be classified into several size fractions before processing. Typically, buckwheat is separated into six size fractions (4.5, 4.2, 4.0, 3.8, 3.6, and 3.3 mm), and each fraction is processed using a different working clearance. Although this approach improves dehulling efficiency, it increases processing time, equipment complexity, energy consumption, and production costs.

To overcome these limitations, a new dehulling device has been developed that is capable of processing unsorted buckwheat within the commercial size range of 3–5 mm without preliminary size classification. The device consists of a rotating drum and a newly designed pressure deck whose geometry is adapted to the shape of buckwheat grains. During operation, the elastic contact surface of the pressure deck continuously presses the grains into the rotating drum while accommodating variations in grain size. The abrasive surface of the rotating drum then removes the hull without causing excessive grain breakage.

The successful operation of this device depends primarily on the elastic properties of the pressure deck material. If its elastic stiffness is lower than that required to generate sufficient contact pressure, larger grains cannot be properly compressed and effective dehulling cannot be achieved. Therefore, selecting an appropriate elastic material for the pressure deck makes it possible to maintain stable contact between grains and the rotating drum over a wide range of grain sizes, thereby eliminating the need for preliminary size classification.

The objective of this study was to experimentally evaluate the dehulling performance of the newly developed rotating drum–pressure deck device and to determine its optimal operating conditions using a three-factor rotatable central composite design. The effects of drum rotational speed, working gap, and grain moisture content on the degree of dehulling were investigated, and a quadratic regression model describing the dehulling process was established.

## MATERIALS AND METHODS

The objective of this experimental study was to verify the theoretical model previously developed by the authors *(Oidov et al., 2025).* Under practical operating conditions and to evaluate the dehulling performance of unsorted buckwheat using a newly designed dehulling device consisting of a rotating drum and a pressure deck with an elastic contact surface (elastic coefficient ($k_m \approx 10\ N/mm$)). The study focused on identifying the operating conditions that maximize the degree of dehulling while preventing excessive grain damage.

Based on the theoretical analysis and previous studies, three operating parameters were selected as the main independent variables because they have the greatest influence on the dehulling process: drum rotational speed ($X_1$), working gap between the rotating drum and the pressure deck ($X_2$), and buckwheat moisture content ($X_3$). The response variable was the degree of dehulling ($y$), which was used as the optimization criterion.

The experimental material consisted of common buckwheat (*Fagopyrum esculentum* Moench) with a moisture content ranging from 9 to 16% (wet basis) and a grain size ranging from 3.2 to 5.0 mm. The selection of the experimental material and evaluation of its physical and mechanical properties were based on the methods and the engineering principles reported by *(Bonafaccia et al., 2003; Mohsenin., 1986; Altuntas et al., 2007; Rao et al., 2005).* The upper limit of 5 mm was used as the equivalent grain diameter in the design calculations because it represents the largest grain fraction processed by the machine and therefore corresponds to the most critical operating condition. The experimental apparatus consisted of a rotating drum and a newly developed pressure deck with an elastic contact surface, as illustrated in Fig. 1.

To investigate the combined effects of the selected factors while minimizing the number of experiments, a three-factor, second-order Central Composite Rotatable Design (CCRD) was employed. This experimental design enables the development of a quadratic regression model describing the relationship between the operating parameters and the degree of dehulling, while also allowing evaluation of interaction and quadratic effects. The design matrix comprised 20 experimental runs, including factorial, axial, and center points. For each experimental run, a sample of 100 buckwheat grains was processed, and the degree of dehulling was determined experimentally. The resulting data were subsequently analyzed using regression analysis and analysis of variance to determine the optimum operating conditions.

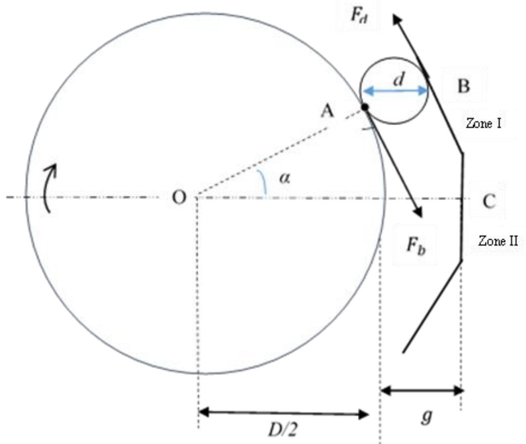


**Fig. 1 - Schematic diagram of the rotating drum-pressure deck dehulling system and force analysis of a buckwheat grain**

*O - drum center; A – contact point between the drum and grain; B – contact point between the pressure deck and grain; $F_b$– friction force between the drum and grain; $F_d$ – friction force between the pressure deck and grain; $d_{eq}$- equivalent grain diameter; $D$- drum diameter; $g$-working gap, $\alpha$ – grain position angle (measured from the horizontal centerline of the rotating drum).*

### *Calculation of the Rotating Drum Diameter and Pressure Deck Length*

The geometric parameters of the experimental dehulling device were determined from the kinematic conditions governing the entry of a buckwheat grain into the working gap between the rotating drum and the pressure deck Fig. 1. At contact point **A**, the rotating drum exerts a friction force $F_b$ on the grain, whereas at contact point **B**, the pressure deck exerts a friction force $F_d$. In addition, normal reaction forces are generated at both contact points due to the elastic deformation of the grain. Owing the tetrahedral geometry of buckwheat grains, their rotational motion during feeding was assumed to be negligible, and the grains were therefore considered to undergo pure translational motion. This assumption is consistent with the principles of contact mechanics described by *Johnson., (1985),* and with the mechanical behaviors of biological materials reported by *Mohsenin., (1986).*

For the grain to be drawn into the working gap, the friction force generated by the rotating drum must exceed that generated by the pressure deck:

$$F_b > F_d \tag{1}$$

where $F_b$ is the friction force between the rotating drum and the grain, and $F_d$ is the friction force between the pressure deck and the grain.

The condition for grain entry can also be expressed in terms of the nip angle:

$$\tan\alpha < (f_b - f_d) \tag{2}$$

where $\alpha$ is the grain position angle, $f_b$ is the coefficient of friction between the rotating drum and the grain, and $f_d$ is the coefficient of friction between the pressure deck and the grain.

The friction coefficients were experimentally determined using the inclined-plane method described in our previous study *(Oidov et al., 2025)*. The measured values were $f_b = 0.47$ for the rotating drum and $f_d = 0.36$ for the pressure deck.

From the geometric relationship between the drum, grain, and working gap, the minimum drum diameter is determined by

$$D = \frac{d_{eq}cos\alpha - g}{(1 - cos\alpha)} \tag{3}$$

where $D$ is the drum diameter, $d_{eq}$ is equivalent diameter of the buckwheat grain, $g$ is the working gap.

The equivalent diameter of the buckwheat grain was experimentally determined in our previous study *(Oidov et al., 2025)* by measuring the grain height of 100 randomly selected grains and converting it to the equivalent diameter using $d_{eq} = 4h/3$. Statistical analysis yielded an average equivalent diameter of $5.00 \pm 0.48\,mm$. The equivalent diameter is widely used for the engineering characterization of agricultural processing equipment because it provides a representative geometric for irregularly shaped biological materials (*Mohsenin, 1986; Rao et al., 2005*). Since the experimental material included grains with equivalent diameters of up to $5.0$ mm, this value was adopted in the present design calculations as the representative grain size corresponding to the most critical operating condition for determining the minimum drum diameter. The working gap was selected as $g = 4$ mm.

Substituting these values into Equation (2),

$$\tan\alpha < (0.47 - 0.36) = 0.11$$

thus,

$$\alpha = \arctan(0.11) = 6.3^0$$

Using Equation (3),

$$D_{min} = \frac{5 \cdot cos(6.3^0) - 4}{1 - cos(6.3^0)} = 95 \text{ mm}$$

Accordingly, the selected drum diameter of 152 mm satisfies the design requirement: $D_{min} < D = 152\,mm$

The drum width was selected as 60 mm.

The minimum length of the pressure deck (working gap) is calculated from:

$$\alpha = arccos\frac{D_{min}+\delta}{D_{min}+d} \quad (4)$$

and

$$L_{min} = 2 \cdot \frac{\pi D_{min}}{360} \cdot \alpha \quad (5)$$

Substituting $D_{min} = 95\,mm$

$$\alpha = arccos\frac{95+4}{95+5} = 8.1^0;$$

$$L_{min} = 13.4\,mm$$

For the selected drum diameter $D = 152\,mm$,

$$L_{min} = 13.26\,mm$$

For the selected drum diameter of $D = 152\,mm$, the calculated minimum working gap length was $L_{min} = 13.26\,mm$. To ensure complete contact between the buckwheat grain and the abrasive surface during dehulling, the working section of the pressure deck was designed with a length of 15 mm. Based on these calculations, the experimental dehulling device was constructed with a drum diameter of 152 mm, a drum width of 60 mm, a working gap of 4 mm, and a pressure deck working length of 15 mm. These parameters were adopted in all subsequent experiments.

***Mathematical Processing of Experimental Data***

To evaluate the performance of the proposed dehulling device, the experiments were conducted according to a three-factor central composite rotatable design (CCRD). This design enables the effects of the main operating factors and their interactions to be evaluated efficiently while providing a quadratic regression model suitable for process optimization.

The response variable was the degree of dehulling (%), which was used as the optimization criterion. Based on previous studies *(Itodo et al., 2023; Kamst et al., 2002; Mar'in et al., 2020; Oidov et al., 2025; Shitanda et al., 2001; Solanki et al., 2018; Upreti et al., 2022; Zhang et al., 2025; Zhen et al., 2022)* and the theoretical analysis presented in this work, three independent variables were selected:

- $\boldsymbol{X_1}$– drum rotational speed, $n$ (rpm);
- $\boldsymbol{X_2}$ – working gap between the rotating drum and the pressure deck, $g$ (mm);
- $\boldsymbol{X_3}$ – buckwheat grain moisture content, $w$ (%).

The coded and actual levels of the experimental factors are presented in Table 1, while the corresponding experimental design matrix is given in Table 2.

**Table 1**

**Experiment factors and their coded levels**

| № | Real factors and units of measurement | Marking | The rate at which factors change | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | -1 | 0 | +1 | Δ | +1,68 | -1,68 |
| 1 | Drum rotational speed, $n$ (rpm) | $X_1$ | 700 | 800 | 900 | 100 | 968 | 632 |
| 2 | Working gap between the rotating drum and pressure deck, $g$ (mm) | $X_2$ | 3 | 3.8 | 4.6 | 0.8 | 5.14 | 2.5 |
| 3 | Buckwheat grain moisture content, $w$ (%) | $X_3$ | 11 | 13 | 15 | 2 | 16.36 | 9.64 |

**Table 2**

**Central composite rotatable design matrix and experimental results**

| Experimental types | № | $X_1$ | $X_2$ | $X_3$ | $X_1X_2$ | $X_1X_3$ | $X_2X_3$ | $X_1X_1$ | $X_2X_2$ | $X_3X_3$ | $y_i$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Full factorial experiment | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 65 |
| | 2 | 1 | 1 | -1 | 1 | -1 | -1 | 1 | 1 | 1 | 62 |
| | 3 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | 1 | 1 | 61 |
| | 4 | 1 | -1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 60 |
| | 5 | -1 | 1 | 1 | -1 | -1 | 1 | 1 | 1 | 1 | 64 |
| | 6 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | 1 | 1 | 61 |
| | 7 | -1 | -1 | 1 | 1 | -1 | -1 | 1 | 1 | 1 | 60 |
| | 8 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | 1 | 58 |
| Experiment on star points | 9 | 1.68 | 0 | 0 | 0 | 0 | 0 | 2.8224 | 0 | 0 | 65 |
| | 10 | -1.68 | 0 | 0 | 0 | 0 | 0 | 2.8224 | 0 | 0 | 56 |
| | 11 | 0 | 1.68 | 0 | 0 | 0 | 0 | 0 | 2.8224 | 0 | 64 |
| | 12 | 0 | -1.68 | 0 | 0 | 0 | 0 | 0 | 2.8224 | 0 | 55 |
| | 13 | 0 | 0 | 1.68 | 0 | 0 | 0 | 0 | 0 | 2.8224 | 64 |
| | 14 | 0 | 0 | -1.68 | 0 | 0 | 0 | 0 | 0 | 2.8224 | 56 |
| Experiment on the planning center | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 64 |
| | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |
| | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 61 |
| | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 62 |
| | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 58 |
| | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 63 |

The experimental data were analyzed using response surface methodology (RSM). A second-order polynomial regression model was developed to describe the relationship between the degree of dehulling and the operating factors. The homogeneity of the experimental variance was evaluated using Cochran's test, the statistical significance of the regression coefficients was determined using Student's t-test, and the adequacy of the regression model was verified using Fisher's F-test.

To homogeneity of variance was evaluated from six replicated experiments performed at the center point of the design.

$$G_t = \frac{maxS_i{}^2}{\sum_i^n S_i{}^2} \tag{6}$$

where, $G_t$ is the calculated Cochran statistic, $S_i{}^2$ is the variance obtained from the $i-th$ replicated experiment, $maxS_i{}^2$ is the maximum variance among all experimental conditions, $n$ is the number of replicated experiments.

The experimental variance at the center point was determined from

$$S_i^2 = \frac{\sum_i^{N_0}(y_i-\bar{y})^2}{N_0-1} \tag{7}$$

where $S_i^2$ is the experimental variance, $N_0$ is the number of replicated center-point experiments, $y_i$ is the measured degree of dehulling, and $\bar{y}$ is the mean response.

The constants required for calculating the regression coefficients are presented in Table 3.

**Table 3**

**Determinants and Constants for Rotatable Central Composite Design**

| Parameter | Symbol / Description | Value |
|---|---|---|
| Number of factors | n | 3 |
| Total number of experiments | N | 20 |
| Number of center-point experiments | N₀ | 6 |
| Calculation constant | A | 0.4537037 |
| Calculation constant | B | 0.8571429 |
| Calculation constant | C | 1.4285714 |

The auxiliary sums used for estimating the regression coefficients were calculated as

$$S_0 = \sum_{i=1}^{n} y_i \quad (8)$$

$$S_i = \sum_{i=1}^{n} (X_{\boldsymbol{i}} \cdot y_i) \quad (9)$$

$$S_{ij} = \sum_{i=1}^{n} (X_{\boldsymbol{ij}} \cdot X_{\boldsymbol{ji}} \cdot y_i), \qquad (i \neq j) \quad (10)$$

$$S_{ii} = \sum_{i=1}^{n} (X_{ii}^2 \cdot y_i) \quad (11)$$

where, $S_0$ is the sum of the response values, $S_i$ is the weighted sum for the linear terms, $S_{ij}$ is the weighted sum for the interaction terms, $S_{ii}$ is the weighted sum for the quadratic terms.

The regression coefficients were calculated using Equations (12) - (15).

$$b_0 = \frac{2AB}{N}\left[S_0 B(n+2) - C\sum_{i=1}^{n} S_i\right] \quad (12)$$

$$b_i = \frac{CS_i}{N} \quad (13)$$

$$b_{ij} = \frac{C^2 S_{ij}}{BN} \quad (14)$$

$$b_{ii} = \frac{AC}{N}\left[S_{ii}C[B(n+2-n) + C(1-B)\sum_{i=1}^{n} S_{ii} - 2BS_0\right] \quad (15)$$

The variances of the regression coefficients were calculated using Equations (16) - (19).

$$s_{b_0}^2 = \frac{2AB(n+2)}{N} \cdot S_y^2 \quad (16)$$

$$s_{b_i}^2 = \frac{S_y^2}{N-N_0} \quad (17)$$

$$s_{b_{ij}}^2 = \frac{C^2}{N} \cdot S_y^2 \quad (18)$$

$$s_{b_{ii}}^2 = \frac{AC^2}{N}[B(n+1) - (n-1)] \cdot S_y^2 \quad (19)$$

The statistical significance of the regression coefficients was evaluated using Student's *t*-test.

## RESULTS AND DISCUSSION

### Statistical Analysis of the Regression Model

The calculated Cochran statistic was:

$$G_t = 0.47,$$

whereas the critical value was:

$$G_{cr} = 0.616.$$

Since:

$$G_t < G_{cr},$$

the experimental variances were considered homogeneous, confirming the reproducibility of the experimental data.

The calculated center-point variance was:

$$S_y^2 = 4.67$$

The results of the variance calculations are presented in Table 4.

**Table 4**

**Evaluation of Variance at the Center Point of the Design**

| № | $y_i$ | $(y_i - \bar{y})$ | $(y_i - \bar{y})^2$ | $S_i^2$ |
|---|---|---|---|---|
| 15 | 64 | 2.67 | 7.11 | 3.55 |
| 16 | 60 | -1,33 | 1.78 | 0.89 |

| № | $y_i$ | $(y_i - \bar{y})$ | $(y_i - \bar{y})^2$ | $S_i^2$ |
|---|---|---|---|---|
| 17 | 61 | -0.33 | 0.11 | 0.05 |
| 18 | 62 | 0.67 | 0.44 | 0.22 |
| 19 | 58 | -3.33 | 11.11 | **5.55** |
| 20 | 63 | 1,67 | 1.78 | 1.39 |
| | 61.33 | | 23.33 | 11.67 |

The statistical significance of the regression coefficients is presented in Table 5. Only statistically significant were retained in the final regression equation.

**Table 5**

**Significance of Regression Coefficients**

| $\lvert b_i \rvert$ | $b_i =$ | t-criterion | Significant (Yes/No) |
|---|---|---|---|
| $\lvert b_0 \rvert$ | 64.88 | 2.45 | Y |
| $\lvert b_1 \rvert$ | 1.58 | 1.48 | Y |
| $\lvert b_2 \rvert$ | 2 | 1.48 | Y |
| $\lvert b_3 \rvert$ | 1.6 | 1.48 | Y |
| $\lvert b_{12} \rvert$ | 0.12 | 1.77 | N |
| $\lvert b_{13} \rvert$ | 0.12 | 1.77 | N |
| $\lvert b_{23} \rvert$ | 0.36 | 1.77 | N |
| $\lvert b_{11} \rvert$ | 1.71 | 1.43 | Y |
| $\lvert b_{22} \rvert$ | 2.04 | 1.43 | Y |
| $\lvert b_{33} \rvert$ | 1.87 | 1.43 | Y |

The adequacy variance of the regression equation was calculated from

$$S_{ad}^2 = \frac{\sum_{i=1}^{n}\left(y_i - y_i^t\right)^2 - S_{\bar{y}}^2 (N_0 - 1)}{N - \frac{(n+2)(n+1)}{2} - (N_0 - 1)} \tag{20}$$

where, $S_{ad}^2$ is the adequacy variance, $y_i$ is the experimental value, $y_i^t$ is the value predicted by the regression model.

The Fisher criterion was determined as:

$$F_p = \frac{S_{ad}^2}{S_y^2} \tag{21}$$

The calculated value was:

$$F_p = 4.70$$

whereas the critical value was:

$$F_{cr} = 5.05$$

Since:

$$F_p < F_{cr}$$

the developed regression model was considered statistically adequate for describing the buckwheat dehulling process.

The comparison between the experimental and predicted values is presented in the Table 6.

**Table 6**

**Variance Evaluation of the Regression Equation**

| № | Output parameter | | $(y_i - y_i^t)^2$ | № | Output parameter | | $(y_i - y_i^t)^2$ |
|---|---|---|---|---|---|---|---|
| | Experimental, $y_i$ | Calculation, $y_i^t$ | | | Experimental , $y_i$ | Calculation, $y_i^t$ | |
| 1 | 65 | 64.45487 | 0.297168 | 11 | 64 | 61.49649 | 2.260531 |
| 2 | 62 | 61.24915 | 0.563769 | 12 | 55 | 55.74769 | 0.559046 |
| 3 | 61 | 60.43773 | 0.316152 | 13 | 64 | 62.28906 | 2.927326 |
| 4 | 60 | 57.23201 | 7.66176 | 14 | 56 | 56.90346 | 0.816235 |

| № | Output parameter | | $(y_i-y_i^t)^2$ | № | Output parameter | | $(y_i-y_i^t)^2$ |
|---|---|---|---|---|---|---|---|
| | Experimental, $y_i$ | Calculation, $y_i^t$ | | | Experimental , $y_i$ | Calculation, $y_i^t$ | |
| 5 | 64 | 61.29487 | 7.317736 | 15 | 64 | 64.18 | 0.0324 |
| 6 | 61 | 58.08915 | 8.473022 | 16 | 60 | 64.18 | 17.4724 |
| 7 | 60 | 57.27773 | 7.410776 | 17 | 61 | 64.18 | 10.1124 |
| 8 | 58 | 54.07201 | 15.42909 | 18 | 62 | 64.18 | 4.7524 |
| 9 | 65 | 61.72482 | 5.176442 | 19 | 58 | 64.18 | 38.1924 |
| 10 | 56 | 57.41602 | 2.005114 | 20 | 63 | 64.18 | 1.3924 |
| Σ | | | | | 1219 | 1216.465 | 133.1686 |

Based on the experimental data, a second-order regression model describing the relationship between the degree of buckwheat dehulling and the operating parameters of the developed dehulling device was obtained:

$$y = 64.88 + 1.58X_1 + 2X_2 + 1.6X_3 - 1.71X_1^2 - 2.04X_2^2 - 1.87X_3^2. \quad (22)$$

The adequacy of the developed model was confirmed by Fisher's test ($F_p = 4.70 < F_{cr} = 5.05$), indicating that the regression equation provides adequately descries the experimental data. The maximum predicted degree of dehulling was $66.08\ \%$, obtained at the coded factor levels of $X_1 = 0.46$, $X_2 = 0.49$ and $X_3 = 0.43$. These values correspond to a drum rotational speed of 846 rpm, a working gap of 4.2 mm, and a buckwheat moisture content of 13.86%.

The optimum moisture content obtained in this study (13.86%) is consistent with the moisture range reported by *(Solanki et al., 2018)* for efficient buckwheat dehulling and is also in agreement with the experimental findings of *(Upreti et al., 2022).* Although *(Zhang et al., 2025)* employed a grinding-disc dehuller operating on a different mechanical principle, they similarly reported that grain moisture content significantly influences dehulling performance.

The results further demonstrate that the dehulling efficiency is governed by the combined influence of drum rotational speed, working gap, and grain moisture content. The optimum operating conditions were located near the center of the experimental region rather than at its boundaries, indicating that excessive or insufficient values of the operating parameters reduce the degree of dehulling. Similar relationships between operating parameters and dehulling efficiency have also been reported for roller-type rice hullers *(Shitanda et al., 2001; Cheng et al., 2026)* and buckwheat dehulling machines *(Zhen et al., 2022)*.

**Response Surface Analysis**

The influence of the operating factors was further analyzed using response surface and contour plots generated from the regression model.

To illustrate the interaction between factors, one variable was fixed at its central coded level while the remaining two variables were varied.

Fig. 2, shows the response surface for the combined effect of drum rotational speed ($X_1$) and working gap ($X_2$) at the central moisture content ($X_3 = 0$).

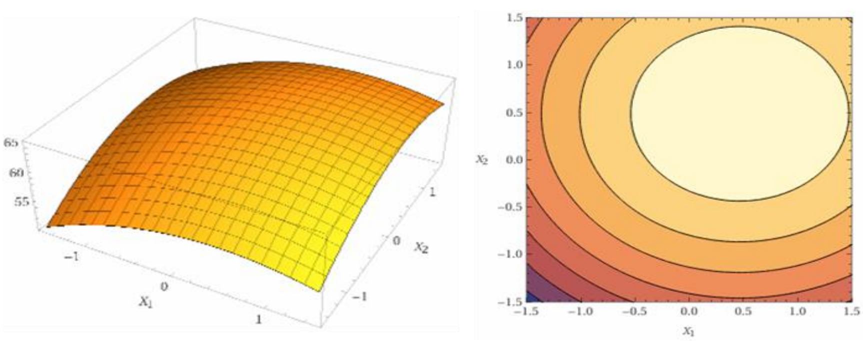


**Fig. 2 - Response surface and contour plot of the degree of dehulling as a function of drum rotational speed and working gap ($X_3 = 0$)**

Fig. 3, illustrates the interaction between drum rotational speed ($X_1$) and grain moisture content ($X_3$) while maintaining the working gap at its central level ($X_2 = 0$).

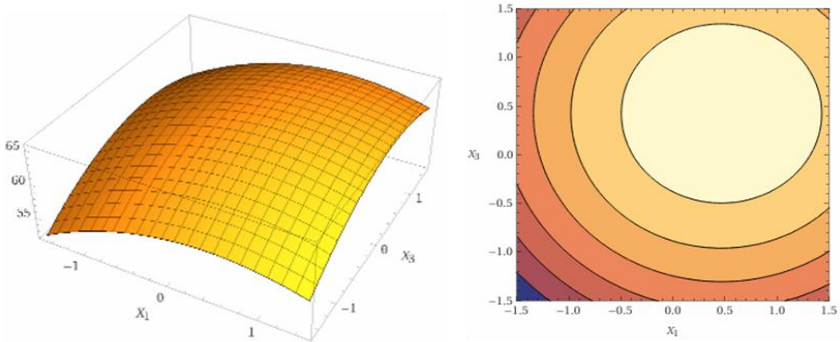


**Fig. 3 - Response surface and contour plot of the degree of dehulling as a function of drum rotational speed and grain moisture content ($X_2 = 0$)**

Fig. 4, presents the combined influence of working gap ($X_2$) and grain moisture content ($X_3$) at the central drum speed ($X_1 = 0$).

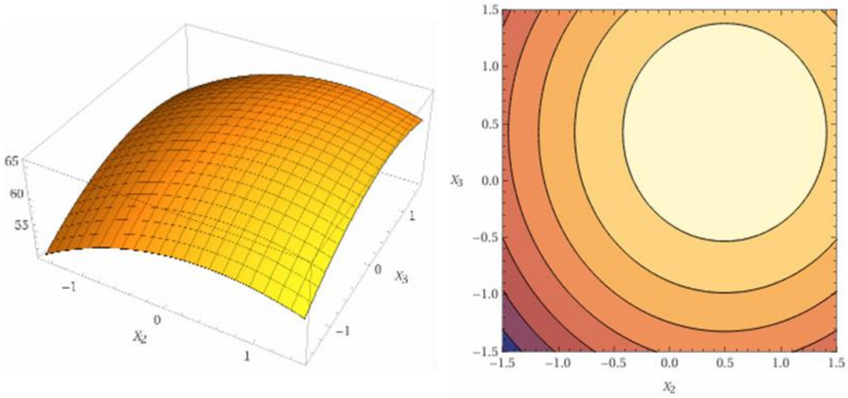


**Fig. 4 - Response surface and contour plot of the degree of dehulling as a function of working gap and grain moisture content ($X_1 = 0$)**

The response surface analysis demonstrated that drum rotational speed, working gap, and grain moisture content all had significant effects on the degree of buckwheat dehulling. The response surface indicate that the dehulling degree is governed by the combined interaction of these operating parameters, with the highest values occurring in the vicinity of the optimum conditions predicted by the regression model. Similar relationships between operating parameters and dehulling efficiency have been reported for roller-type rice hullers (*Shitanda et al., 2001; Cheng et al., 2026*) and buckwheat dehulling machines (*Solanki et al., 2018; Zhen et al., 2022*). The agreement between the response surface analysis and statistical optimization results confirms the reliability of the developed regression model for predicting the operating conditions that maximize the degree of dehulling.

Compared with conventional rubber-roll and impeller-type hullers reported by *(Shitanda et al., 2001*; *Solanki et al., 2018; Upreti et al., 2022),* the proposed rotating drum-pressure deck system achieves comparable dehulling performance while eliminating the need for preliminary grain size classification.

## CONCLUSIONS

Experimental investigations of buckwheat dehulling using the developed dehulling device consisting of a rotating drum and a pressure deck with an elastic contact surface ($k_m \approx 10\ N/mm$) were successfully carried out using a three-factor central composite rotatable experimental design.

The main conclusions are as follows:

1. A statistically adequate second-order regression model describing the influence of drum rotational speed, working gap, and grain moisture content on the degree of buckwheat dehulling was developed and verified using Cochran's, Student's, and Fisher's statistical tests.
2. The optimum operating conditions predicted by the regression model were:
   - drum rotational speed: 846 rpm;
   - working gap: 4.2 mm;
   - buckwheat moisture content: 13.86%.

3. Under these operating conditions, the maximum predicted degree of dehulling reached 66.08**%**.
4. Response surface analysis demonstrated that the interaction of the operating factors significantly affects the dehulling performance. The use of an elastic pressure deck enables effective dehulling of buckwheat grains over the investigated size range without preliminary size classification.
5. The obtained results confirm the feasibility of the proposed dehulling principle and provide a basis for further optimization of the mechanical properties of the elastic pressure deck and the operating parameters of the dehulling device.

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