MODELING OF THE OPTIMAL PARAMETERS, IMPROVEMENT AND PERFORMANCE EVALUATION OF MARC ENGINE DRIVEN COMMON BEAN (PHASEOLUS Vulgaris L.) THRESHER IN ETHIOPIA

#11221

[1*]Biniam Zewdie, [2]Adesoji M. Olaniyan, [1]Amana Wako, [3]Dereje Alemu, [3]Tamrat Lema
[1*]School of Mechanical, Chemical, and Materials Engineering, Departments of Agricultural Machinery Engineering, Adama Science and Technology University, P.O. Box 1888, Adama, Ethiopia; [2]Department of Agricultural and Bioresources Engineering, Faculty of Engineering, Federal University Oye-Ekiti, Ikole-Ekiti Campus, Post Code 370001, Ikole-Ekiti, Nigeria; [3]Ethiopian Institute of Agricultural Research; Agricultural Engineering Research, Melkassa Agricultural Research Center, P.O. Box 436, Adama, Ethiopia
[*]e-mail: nzg2001nzg@gmail.com

ABSTRACT

This executive summary provides an overview of the research study conducted on modeling the optimal parameters, improvement, and performance evaluation of the engine-driven bean thresher developed by the Melkassa Agricultural Research Center (MARC) in Ethiopia. The study aimed to enhance the efficiency and productivity of the bean thresher, contribute to sustainable agricultural practices, promote technology adoption, and support the economic development of the agricultural sector. The research study employed a comprehensive approach involving data collection, modeling, experimentation, and performance evaluation. **Key steps** undertaken during the study included: **Literature Review**: A thorough review of existing literature related to bean threshing, agricultural machinery, and optimization techniques was conducted to establish a knowledge base and identify research gaps. **Data Collection:** Field surveys, interviews, and observations will be conducted to gather data on the existing bean thresher's performance, challenges faced by farmers, and specific requirements for improvement. **Modeling and Optimization**: Mathematical modeling and simulation techniques will be employed to identify the optimal parameters for the bean thresher. Parameters such as cylinder speed, concave clearance, and fan speed will be analyzed to determine their impact on threshing efficiency and grain quality. **Experimental Design**: Field experiments will be designed and conducted to evaluate the performance of the optimized parameters. The experiments involved comparing the modified thresher with the existing version, measuring key performance indicators, and assessing grain loss, power consumption, and processing efficiency. **Performance Evaluation**: The data collected from the experiments will be analyzed to evaluate the performance of the optimized bean thresher. The evaluation included metrics such as grain damage, threshing efficiency, fuel consumption, and processing capacity. The findings of the research study demonstrate the significance and potential impact of the modeled optimal parameters and improved bean thresher. The key **outcomes and recommendations** will include the following: **Improved Thresher Performance**: The optimized parameters resulted in a significant improvement in the thresher's performance. Threshing efficiency increased, grain damage was reduced, and fuel consumption was reduced. These improvements contribute to enhanced productivity and reduced post-harvest losses. **Sustainable Agriculture**: The optimized bean thresher exhibited improved resource efficiency, reducing fuel and energy consumption. This promotes sustainable agricultural practices and reduces the environmental impact of bean processing. **Economic Benefits**: The improved thresher reduces labor requirements, processing

time, and operational costs. Farmers can achieve cost savings of approximately, leading to increased profitability and economic benefits for bean producers. **Technology Adoption**: The research study provides evidence-based recommendations for the adoption of the improved bean thresher. Farmers, agricultural extension workers, and policymakers are encouraged to promote the use of this technology to enhance agricultural productivity and modernize farming practices. **Policy Implications**: The study's findings will have policy implications for the agricultural sector. Policymakers are advised to consider incorporating support mechanisms and incentives for the adoption of improved agricultural machinery, fostering local manufacturing, and promoting sustainable agricultural practices.

Keywords: RSM, Thresher, Threshing efficiency, Germination, and Grain Damage

INTRODUCTION

The common bean (*Phaseolus vulgaris L.),* according to (Joshi et al., 2022), is one of the main nourishments for both humans and livestock in Africa and the third most consumed legume worldwide. Its seed is high in carbohydrates and protein, and animal feed originates from the seed and its pod (Uebersax *et al*., 2023). With 560,191 hectares of cultivated land and 208,913 tons of beans produced in 2019, Ethiopia is the world's most significant producer of edible legumes. Among the most significant legumes are common beans (Bento *et al*., 2022).

After being harvested by hand, the common bean crop is threshed by a machine. The thresher uses impact force and pressure to remove grain from pod and stalk (Que *et al*., 2024). Grains sustain significant damage from the crop migrating between the thresher unit's stirring components and from inadequate clearance among static as well as moving portions (Lee et al., 2023). Grain that has been damaged has the lowest shelf life and is less resilient to pests and diseases (Adewoyin, 2023). Grain grading is the primary factor that determines its marketability; fragmented seeds result in a lower grain grade (Parker et al., 2022). In addition, damaged grains prevent seeds from germinating (Chandra et al., 2024).

The most qualitative parameters to determine the efficiency of a thresher operation consist of mixed chaff with the grain, loss from threshing, and damage to the grain. According to Ghebrekidan et al. (2024) analysis of a thresher apparatus's design features, the threshing performance was significantly influenced by the rate at which materials were fed into the device as well as technological factors including drum speed and concave-to-drum clearance. Additionally, Juraev *et al.* (2023) observed that the threshing process was influenced by the crop cultivar, moisture content, and biometrical indices.

Grain damage, loss from threshing, and mingled the most prestigious are the particles with the grain metrics to assess a thresher's performance (Strecker *et al*., 2022). The velocity of material feeding into the device, along with technological aspects like drum acceleration and convex-to-drum aperture, had a substantial impact on the shredding performance, as per Ghebrekidan et al. (2024) analysis of the design elements of a thresher apparatus. The biometrical parameters, moisture level, and crop genotype were also found to have an impact on the threshing process by Jan et al. (2021).

Loss of grains, grain impairment, level of separation, as well as size of the pod decrease were all the parameters that Ejara et al. (2018) differentiated into standard bean threshing quality indices in an unusual investigation. In the process of threshing common beans, two important factors were identified to be the aperture along with the wire loop type drum and the convex, as well as drum peripheral velocity. Ghebrekidan et al. (2024) investigated the parameters of the typical mechanism used for separating beans. It was shown that the distance between the cylinder and the concaves and peripheral speed were the main parameters affecting crop quality. The findings of their experiment using the tangential threshing mechanism indicated that the rate of grain breakage improved from 3.8 to 6.01% when the cylinder perimeter speed was enhanced from 9.4 to 21.4 ms^{-1}.

Numerous threshing units were used by Umbataliyev *et al.* (2023) for common bean seeds. Using a multitude of sorts of drums, rates, as well as rate of feed, they assessed the thresher's performance in terms of throughput capacity, threshing effectiveness, damage to the grain, losses of the grain, differentiation, energy the threshold, as well as specific utilization of energy. They discovered that the apparent damage to the grain increased along acceleration as well as flow rate. Kidney bean threshers were examined by Wang and Cichy (2024) using variables such seed moisture level, clearance rates, and cylinder rpm. The outcomes demonstrated that moisture level, cyl speed, and convex level all had a major impact on the germination of threshed seeds.

Huertas et al. (2023) found that the feed rate, moisture content, and threshing drum beat all had a substantial impact on the success rate of threshing, output capacity, and grain damage and losses of a longitudinal flow barrier used in common beans. The impact of the moisture level, pod size, with the pace of the drum in a rasp-bean thresher were investigated in relation to the proportion of damaged grains and threshed pods (Lisciani et al., 2024). The findings showed that the pod size had the biggest impact on damage intensity, while the drum speed had the least. It was further suggested that the optimal circumstances for common bean threshing would be a water content ranging from 12 to 15% and a drum speed of 9.5 ms^{-1}. Although several studies have been conducted on the threshing of different agricultural crops, none have examined the response surface methodology's potential for optimizing the threshing of common beans with relation to machine-crop factors. To enhance technological parameters including cylinder acceleration, convex clearance levels, rate of feed, and level of moisture, the response surface approach is utilized, the principal aim of this investigation was to enhance threshing efficiency, minimize grain damage, and maximize seed germination when threshing common beans.

MATERIALS AND METHODS

Selected improved varieties of common beans from the Oromia regional State in Ethiopia were provided by the Awash Melkassa Research Center. A digital vernier caliper (TA, M5 0–300 mm, China) was used to measure the three primary axial dimensions of the beans: With an accuracy of 0.01 mm, the measurements are dimension (L, mm), (W, mm), and (T, mm). The experimental findings indicated that the average mean values for thickness (4.962 ± 0.50 mm), width (6.316 ± 0.502 mm), and length (9.848 ± 0.802 mm) were, accordingly. After common beans were harvested by hand, the threshing procedure was carried out using a laboratory wire loop/rasp type drum thresher. The assembled thresher and a collaborative assessment of it are depicted in Figure 1. With 33 teeth spaced 100 mm apart along each of the device's four axes, the drum measured 730 mm in length. The concave was made from 720 mm long steel sheets that had been rolled and perforated.

Experimental design

Based on the multifactorial experiment principle with three independent replications, the experiment utilized a split-split plot design. The main plot was assigned to the two varieties of crops levels, the sub plot was assigned to the three threshing drum speed levels, and the sub-sub plot was assigned to the three feeding levels, each with three replications (Table 1). The Response Surface Method was utilized to maximize the threshing performance, and statistical R-studio software was utilized to analyze all the data gathered during the laboratory and field performance evaluations.

Figure 1. MARC-Bean thresher schematic diagram and participatory evaluation assessment.

Response surface method (RSM)

Four independent parameters were considered for optimization: moisture content (5, 10, and 15% wb), convex aperture (25, 35, 45 mm), speed of cylinder (7.5, 9.17, 10.83 ms^{-1}), and rate of feeding (550, 650, 750 kgh^{-1}). Germination of seeds percentage, threshing efficiency, and damage to grain were the three dependent variables in the experimental method of optimization. To fit the experimental results, a polynomial equation of second order was thus developed using the method of response surfaces and central composite experiment design.

According to the findings of earlier research and the limitations of the manufactured thresher (Que *et al*., 2024) the levels of convex aperture, moisture level, and chamber rate were chosen (Savic *et al*. 2019). In the end, 54 experiments were conducted utilizing triplets of implementation for the independent variables in a CCD-type experimental design, as shown in Table 1. In a random order, the trials were carried out. In the latter half of the parameters with encode, three replications were conducted to determine the relationship model describing the two main parameters' sum of square errors and lack of fitness (Güvercin and Yıldız, 2018). Design-Expert 12 was used to optimize the several responses simultaneously.

Table 1. Randomization layout.

R1			R2			R3		
$S_1F_1M_1$	$S_2F_2M_2$	$S_3F_3M_3$	$S_1F_1M_3$	$S_2F_2M_1$	$S_3F_3M_2$	$S_1F_1M_2$	$S_2F_3M_3$	$S_1F_1M_1$
$S_3F_2M_1$	$S_1F_2M_2$	$S_2F_1M_3$	$S_3F_2M_3$	$S_1F_2M_1$	$S_2F_1M_2$	$S_2F_2M_2$	$S_1F_2M_3$	$S_2F_2M_1$
$S_2F_3M_1$	$S_3F_1M_2$	$S_1F_3M_3$	$S_3F_1M_3$	$S_2F_1M_1$	$S_2F_2M_2$	$S_3F_3M_2$	$S_3F_1M_3$	$S_3F_3M_1$
$S_3F_3M_1$	$S_2F_3M_2$	$S_1F_1M_3$	$S_3F_3M_3$	$S_2F_3M_1$	$S_1F_1M_2$	$S_3F_1M_2$	$S_2F_1M_3$	$S_3F_1M_1$
$S_2F_1M_1$	$S_1F_3M_2$	$S_2F_3M_3$	$S_2F_1M_3$	$S_3F_1M_1$	$S_2F_3M_2$	$S_3F_2M_2$	$S_3F_3M_3$	$S_2F_3M_1$
$S_1F_2M_1$	$S_3F_2M_2$	$S_3F_2M_3$	$S_1F_2M_3$	$S_1F_3M_1$	$S_3F_2M_2$	$S_1F_2M_2$	$S_1F_3M_3$	$S_1F_2M_1$
$S_1F_3M_1$	$S_2F_1M_2$	$S_3F_1M_3$	$S_1F_3M_3$	$S_3F_2M_1$	$S_3F_1M_2$	$S_1F_3M_2$	$S_2F_2M_3$	$S_1F_3M_1$
$S_2F_2M_1$	$S_3F_3M_2$	$S_1F_2M_3$	$S_2F_3M_3$	$S_3F_3M_1$	$S_1F_2M_2$	$S_2F_1M_2$	$S_3F_2M_3$	$S_3F_2M_1$
$S_3F_1M_1$	$S_1F_1M_2$	$S_2F_2M_3$	$S_2F_2M_3$	$S_1F_1M_1$	$S_1F_3M_2$	$S_2F_3M_2$	$S_1F_1M_3$	$S_2F_1M_1$

S = drum speed, F = feed rate, M =moisture content, & R = replications

Evaluation procedure

The chamber rate, flow rate, Level of moisture, and convex aperture width of the thresher were evaluated at three different levels on a firm surface after installation and adjustments. With regards to the trial, the consequence of their separate parameters on sprouting, threshing efficiency and grain damage was considered. Samples were randomly prepared and put into the thresher once it was turned on to obtain the thresher performance indices. According to Wang and Cichy (2024), the effectiveness of threshing (TE), the aptitude for threshing (TC), effective cleaning (CE), and proportional of losses were determined using the following relationships to assess the threshing machine's effectiveness.

RESULTS AND DISCUSSION

Threshing Efficiency

The figures 2a–c were prepared using optimal feeding amounts of 672 kg/h, 37.4cm concave clearance, and 8.25 ms^{-1} drum speed. Threshing efficiency improved together with concave geometry clearance and rate of feed, as Figure 2a presented. Threshing efficiency attained a highest of 98.7% at an average feed rate of 672 kg/h and a convex clearance of 37.4 cm. Figure 2b illustrates how increasing the rate of feed and speed of the drum led to an enhancement to the effectiveness of threshing. The most significant threshing efficiency (99.7%) was ascertained with an intake rate of 672 kg/h and a drum with a speed of 8.25 ms^{-1}. In contrast, the efficiency of threshing climbed in tandem with the drum speed improved and convex clearance dropped. The drum speed at which the highest efficiency (99%) was achieved was 8.25ms^{-1} and a concave clearance of 37.4mm (Fig. 2c). Threshing efficiency improved when the rubbing force between the bean and the canvas concave increased, corresponding with a decrease in convex clearance between the concave strip and the concave bar. As perimeter rate climbed, so did momentum and thrust of impact on the trembling, which in turn boosted threshing efficiency as drum speed climbed. When it came to bean threshers, Umbataliyev et al. (2023) discovered similar patterns.

The experimental findings are illustrated in Figures 2-d to -f. throughout the range of input components examined, the threshing efficiency varied between 95.1 and 99%. At the 1% confidence level, Table 2 illustrates that threshing efficiency was significantly impacted through the rate of feed, cylinder speed, level of moisture, and convex clearance. The impact of the chamber frequency on common bean effectiveness of threshing is illustrated in Figure 2-d. When cylinder speed was increased from 7.5 to 9.17 ms^{-1}, threshing efficiency climbed from 96.81 to 99.21% with a moisture level of 11.6%. Furthermore, as anticipated, the highest cylinder speed (10.83 ms^{-1}) produced the highest threshing efficiency rating (99.69%).

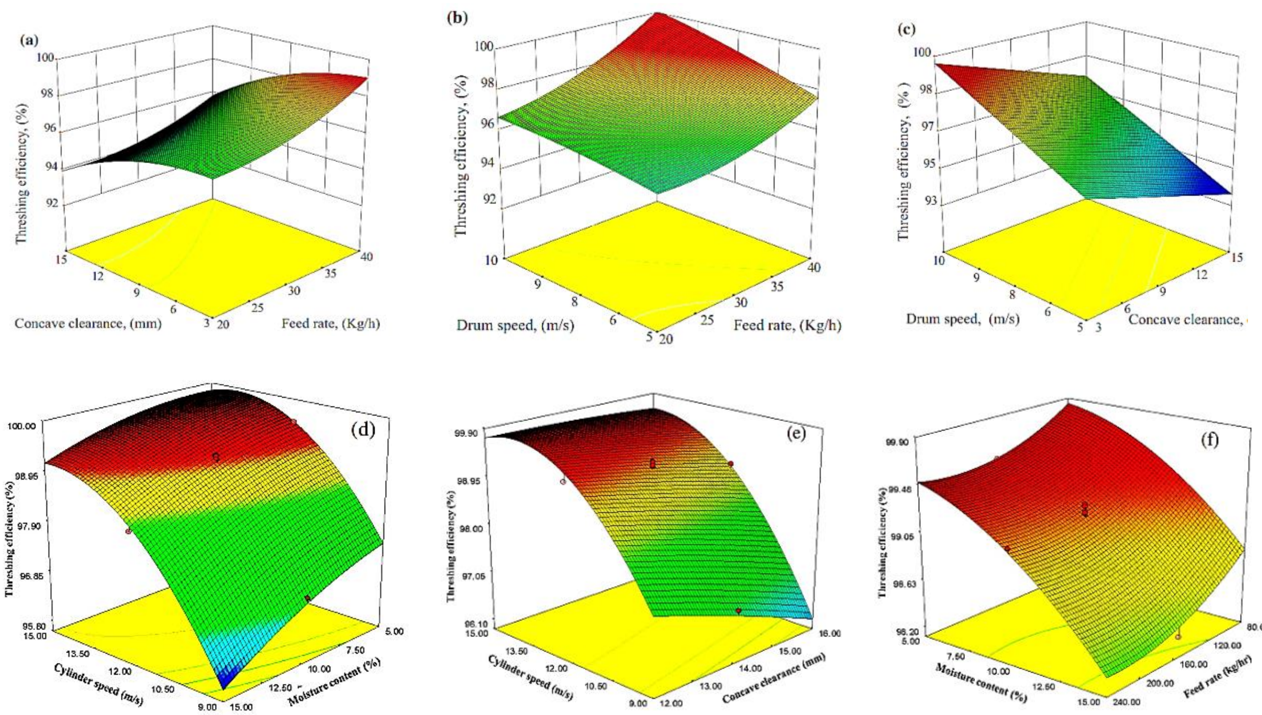

Figure 2. The implications of those parameters on the threshing efficiency: (a) feed rate and concave clearance; (b) drum speed and feed rate; (c) drum speed and concave clearance; (d) cylinder speed and moisture content; (e) cylinder speed and concave clearance; and (f) moisture content and feed rate.

As concave aperture increased, threshing efficiency decreased, as Figure 2-e illustrates. Considering improvements in convex aperture from 35 to 45 mm, the threshing efficacy reduced from 97.45 to 96.16% at 7.5 ms^{-1} with the chamber's frequency. Convex space did not significantly influence performances at speed of drum exceeding 9.17 ms^{-1}. The higher cylinder speed resulted in refined threshing efficiency because of an increased impact force. The rationale for lowest threshing efficiency at the highest concave clearance was the insufficient force exerted on the pods, which caused them to fall out without separating the seeds. At the 1% confidence level, the concave clearance and cylinder speed influences on the threshing efficiency interacted significantly. There was a negative correlation between the feed rate and threshing efficiency.

As the feed consumption rate went up from 550 to 750kgh^{-1}, the average threshing efficiency reduced from 99.52 to 99.09% in (Figure 2f). Outcomes of the investigation indicated that the detrimental impact of cylinder speed on crop threshing was mitigated as the rate of feed escalated due to an increase in the width of the trim slice between the cylinder and concave. For every drum speed level, Huertas et al. (2023) found that as feed rate climbed the effectiveness of threshing decreased.

The efficiency of threshing dramatically dropped as the input material's level of moisture escalated, shown in Figure 2-f. There was a correlation between the highest (99.52%) and minimum (98.31%) effectiveness of threshing and the amounts of water of 5% and 15%, within that sequence. At increasing levels of water content, there was a greater impact of moisture content on threshing efficiency. Que *et al*. (2024) also reported a similar outcome. Pods and seeds are more easily split because there is less tension holding the pod together and the pods are more brittle due to reduced seed moisture concentrations. Threshing efficiency dropped because of increased pod cohesion brought on by the plant materials' increased flexibility at higher moisture contents.

The ANOVA illustrated in Table 2 ($p<0.001$) implies that the predicted value of F (19.81) is high, indicating that a model with quadratic parameters could be a good fit for the outcomes of the experiment. Table 2 illustrates the F-values that demonstrate the significant impact of the rate of feed, convex clearance, and speed of drum in terms of linear regression on the effectiveness of shredding at the 1% significance level. In a similar manner at the 5% significance level, the interaction terms between the drum speed x convex clearances and the drum speed a quadratic term exhibited an important impact on the threshing effectiveness. The remaining interactive and graphs had no discernible effect on the threshing effectiveness while not even at the 10% threshold of significance.

Detects the proportion of noise to signal with adequate precision; A value more than four is preferred. In this case, the ratio changed to 16.577, indicating a strong pulse. Savic and Savic-Gajic (2021) assert that this framework can be used for maneuvering within the realm of design. This model's predicted R^2 (0.81) and adjusted R^2 (0.89) agreed. Using polynomial form fitting, the regression model illustrating the threshing efficiency change with regard to the independent parameters ($feed\ rate, F_r$), ($drum\ speed, v_s$) and ($concave\ clearance, C_c$) was produced. The simplified polynomial model was obtained by removing terms from the quadrilateral model that are not significant (Savic *et al*. 2019)

Grain Damage

The variation among the investigation's outcomes illustrated that the convex aperture, chamber rate, rate of feeding, and levels of water content are all exhibited a significant impact on the amount of grain damage (Table 2). The most significant factors were determined to be the cylinder speed, which was followed by rate of feeding, moisture level, and convex aperture. First-order interactions were prioritized according to relevance: chamber frequency × level of moisture, feed rate × level of moisture, chamber frequency × convex aperture, and cylinder speed × cylinder speed. The implications of convex clearance and speed of cylinder on the percentage of grain damage are shown in Figure 3a. This figure illustrates how the rotational frequency at which the drum is threshed enhances the amount of grain impairment.

Damage of grains escalated from 4.98 to 47.97% at the convex of 35 mm when the drum speed increased from 7.5 to 10.83 ms^{-1}. When cylinder speed was raised from 7.5 to 10.83 ms^{-1}, Grain breakage escalated from 1.71 to 33.29% at a convex aperture of 35mm. During threshing, the common bean was subjected to higher impact levels, which increased damage. However, as concave clearance improved, grain damage drastically decreased.

Table 2. Response surface quadratic model-based analysis of variance for common bean threshing.

Source of variation	df[a]	Grain damage	Threshing efficiency
Model	54	164.62**	99.73**
Cys	1	1437.46**	930.83**
Fr	1	78.75**	21.01**
Cc	1	70.63**	60.35**
Mc	1	232.06**	144.55**
Cys× Fr	1	15.69**	13.34**
Cc ×Fr	1	0.83ns[b]	0.082ns
Fr ×Mc	1	1 5.46*	0.92ns
Cc ×Cys	1	1 24.03**	35.36**
Cc ×Mc	1	3.59ns	0.78ns
Cys× Mc	1	94.68**	21.16**
$(\mathrm{Mc})^2$	1	5.38*	2.51ns
$(\mathrm{Cys})^2$	1	93.47**	52.46**
$(\mathrm{Fr})^2$	1	0.46ns	1.60ns
$(\mathrm{Cc})^2$	1	1.45ns	0.090ns
Res.	15		
Pe	5		
Corr. total	69		

*Significant at the 5% level; **highly significant at the 1% level; [a] Degrees of freedom, [b] Non-significant, Fr = Feed rate, Cs = Drum speed, Cc = Convex aperture, Mc = Level of moisture, Res. = Residual, Pe = pure error, Corr. = Correlation total

Grain damage and rate of feeding interacted inversely with each other across independent variables. Since the crop was subjected to more intense contact at the lower feed rate, the reduction in grain damage was approximately 50% (Figure 3b) when the concave clearance of 37.4mm was attained while upgrading the intake rate from 550 to 750 kg/h. Additionally, according to Ghebrekidan et al. (2024)), grain damage increased as feed rate diminished.

When the amount of moisture escalated, the proportion of grain damage dropped dramatically, as shown in Figure 3c. On the other hand, grain loss went from 33.42 to 57.79% when the amount of moisture decreased at a speed of 10.83 m/s, from 15% to 5%. At lower cylinder speeds, the impact of moisture content on grain damage was minimal. When moisture content was reduced from 15% to 5%, grain damage increased from 5.52 to 10.51% at a cylinder speed of 7.5m/s. Grain elastic behavior increased with increasing moisture content; hence, more energy was needed to crack the grain. Moisture content has also been identified by several researchers as a significant factor influencing grain impairment (Huertas et al., 2023; Chandra et al., 2024).

A 672 kg/h rate for feeding, a concave clearance of 35cm, and a drum speed of 8.25m/s were the optimal parameters for preparing the Fig. 3g–i. As illustrated in Fig. 3g, the greatest damage to the grain appeared at 35–45 mm convex clearance at rates of feed varied from 650–750 kg/h. There was no evidence of damage to grains within the 35–38 mm convex clearance range at 650–675 kg/h amount of intake. The greatest amount of grain impairment has been observed to be 3.5% at 25 cm convex spacing and 750 kg/h amount of intake. Figure 3h showed the proportion of damaged grains emerged in tandem with raised rate of feed and drum rpm. With an amount of intake 750 kg/h and a drum rate of 10.83 m/s, the ultimate breakdown of grain was achieved, at 3.3%.

Likewise, there was an increase in damage to grains when the drum speed climbed, and the convex clearance diminished. At a chamber inclination of 10.83 m/s and a convex space of 25 mm, the highest possible 3.8% loss of grain was seen (Figure 3i). The reduction in convex clearance led to an increase in the contacting action between the grains and the covering stripe, degrading the grains. Moreover, it happened because there was more intimate interaction among the beans and the canvas strip and the segments of the chamber that convex. Significant forces from impacts were detected when the drum was moving faster. The maximum grain damage was caused by those maximal impact forces. At lower drum speeds, the maximum grain damage is caused by these maximum impact forces, and vice versa. Grain damage was found to be decreased at higher feed rates because maximum feed rates share the power of collision and contacting force produced by drums in rotation, whereas minimum feed rates handle the greatest the power of collision and contacting force, which results in highest degree of scratches. Similar findings with respect to the multi-threshing machine (Huertas et al., 2023; Chandra et al., 2024) published their findings. The greater feed that was shared by the impact and rubbing power of the revolving drum resulted in less degradation of grain when the degree of feeding escalated.

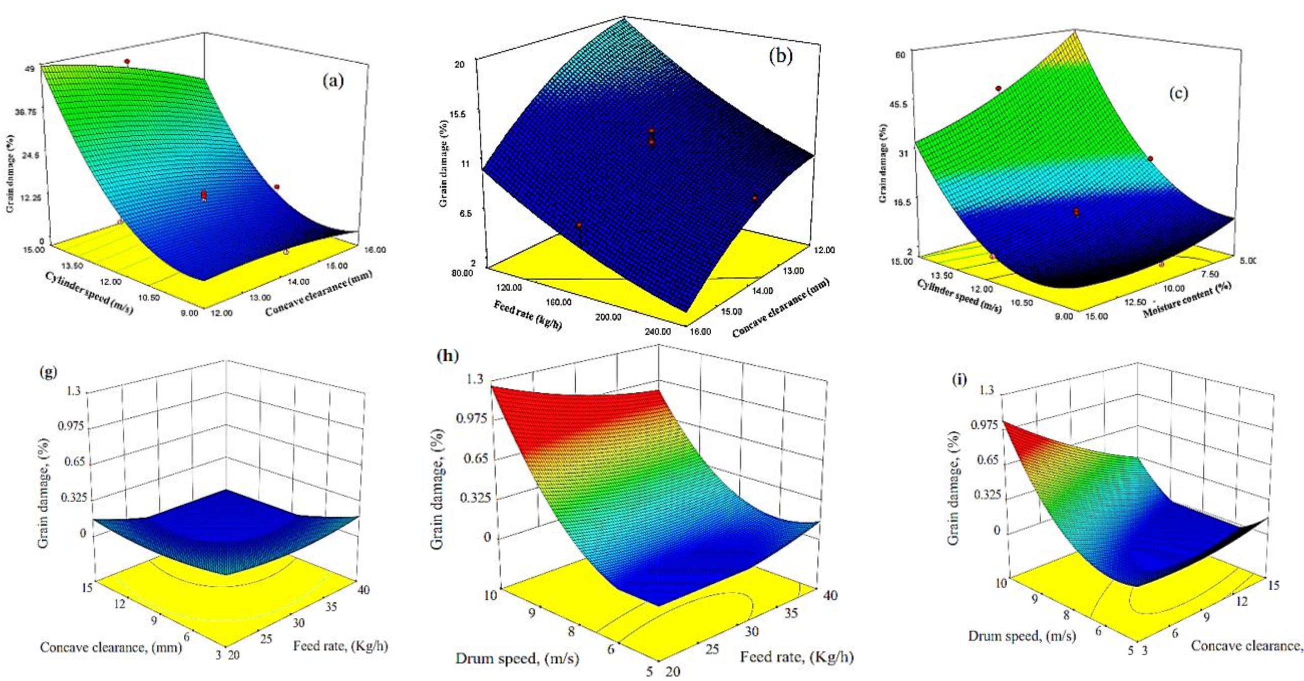

Figure 3. The implications on grain damage percentage of (a) cylinder speed and concave clearance, (b) feed rate and concave clearance, (c) cylinder speed and moisture content, (g) concave clearance and feed rate, (h) drum speed and feed rate, and (i) drum speed and concave clearance.

The influence of the rate of feeding (kg/h), speed of the drum (m/s), and convex clearance (mm) on common bean damage was investigated using the implementation of the ANOVA described in

Table 2. It is evident from emulate F's considerable value (44.34) ($p < 0.001$) that an equation with quadratic might correspond to the empirical information efficiently. The linear parameters of rate of feeding, drum speed, convex space, interaction coefficient curvature space x speed of drum, and nonlinear term convex clearance all had a significant impact on grains damage at the 1% level of significance, based on Table 2's F-values.

At the 5% significance level, the rate feed x drum speed interaction term also significantly influenced the degree of grain impairment. The damage to the beans was not significantly impacted by the relationship between the terms flow rate x concave aperture or the quadrilateral in relation to convex geometry and intake rate variables, irrespective of the significance threshold of 10% ($p < 0.1$).

Sufficient accuracy is used to measure the signal to noise proportion. Therefore, the ratio should be higher than four. In this instance, the ratio changed to 22.74, indicating a strong signal. To navigate the design space, one can apply this model (Savic *et al*. 2019; Savic and Savic-Gajic, 2021). This model's predicted R^2 (0.89) and adjusted R^2 (0.95) agreed. Polynomial form fitting was used to generate the regression equation that shows a variation of the percentage of grain damage (GD, %) with respect to the independent parameters $(feed\ rate, F_r)$, $(drum\ speed, v_s)$ and $(concave\ clearance, C_c)$. The exponential model's insignificant terms had been eliminated to create the simplified multiplication framework (Savic *et al*. 2019)

Optimization of MARC bean thresher

The graphical optimization and optimal outcomes are shown in Figure 4. The machine's independent design parameters, which are connected to these outcomes, establish the optimal ranges of cleaning efficiency, threshing efficiency, and grain damage. The predicted percentages for cleaning efficiency, grain damage, and threshing efficiency were 85%, 0.086%, and 97.94%, respectively. By using graphical optimization, the optimal values of several variables were found, including concave clearances of 25 – 45mm with 87.94% efficiency of threshing, 85% cleaning effectiveness, and 0.086% fractures.

The marked region of Figure 4a–c displays the collective outcomes of this optimization. The same values were obtained by the numerical and graphical optimization techniques (Benaseer et al. 2018; Umbataliyev et al., 2023). These optimal features guided the development of the drum, which was then finished and its performance assessed to validate the chosen parameters. The findings indicated that the percentage of cleaning, detrimental to the grain and spinning was 86% compared to 85%, 99%, and 0.1%, respectively, compared to predictions of 97.94% and 0.086%. As a result, a cylinder speed of 8.25 ms^{-1}, convex aperture of 37.4mm, rate of feed 672kgh^{-1}, and level of moisture 11.6% were recommended for threshing common beans.

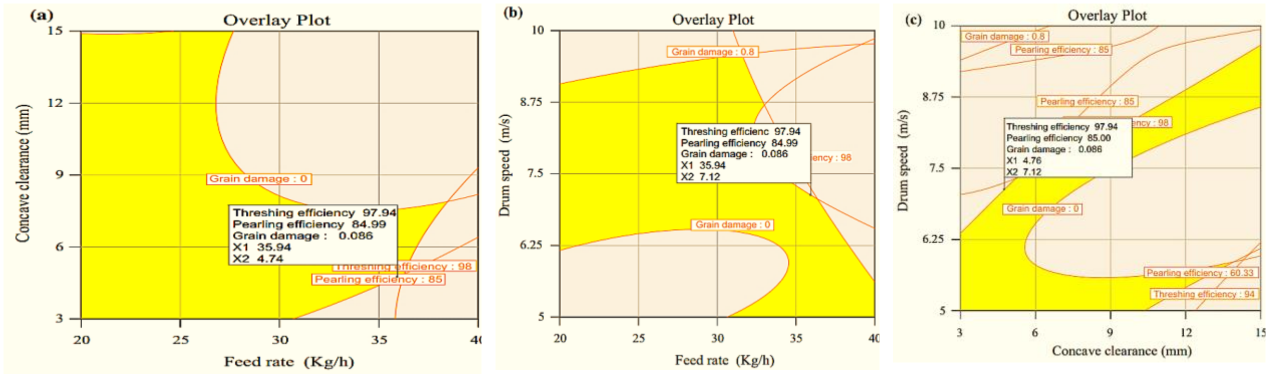

Figure 4. Graphical optimization of the operating parameters of the threshing drum; (a) Superimposed contours for threshing efficiency, pearling efficiency, and damage to bean at varying feed rates and concave clearance; (b) Superimposed contours for threshing efficiency, pearling efficiency, and speed of the drum at varying feed rates; and (c) Superimposed contours for threshing efficiency, drum speeds, and concave clearance at varying feed rates.

CONCLUSIONS

The threshing drum of the MARC bean thresher is one of its essential parts and its performance is depending on its operational parameters. Important variables influencing grain damage, threshing efficiency and cleaning efficiency in common bean threshed seed quality are rate of feed, moisture level, convex aperture, and drum speed. The most significant crop and machine measurement was cylinder speed, which was subsequently the moisture level. The percentage of damaged grain improved from 45.98 to 47.97% and the overall threshing efficiency elevated from 96.81 to 98.69% when the speed of drum was varied from 7.5 to 10.83 ms^{-1}. Increased moisture content was associated with increased grain damage, efficiency of threshing and rates of seed germination. The proportion of grain impairment, and threshing efficiency were all significantly ($P<0.01$) impacted by concave clearance. Within the 550–750 kg h^{-1} rate of feed range, there was variation in the average value of damage to grain (16.65–7.67%) and threshing efficiency (96.52-28.09%). As a result, a cylinder speed of 8.25 ms^{-1}, convex aperture of 37.4mm, rate of feed 672kgh^{-1}, and moisture level of 11.6% were recommended for threshing common beans.

REFERENCES

Adewoyin, O. B. (2023). Pre-Harvest and Postharvest Factors Affecting Quality and Shelf Life of Harvested Produce. In New Advances in Postharvest Technology. IntechOpen. 42, 28-420

Benaseer, S., Masilamani, P., Albert, V. A., Govindaraj, M., Selvaraju, P., & Bhaskaran, M. (2018). Impact of harvesting and threshing methods on seed quality: A review. Agricultural Reviews, 39(3), 183–192.

Bento, J. A. C., Gomes, M. J. C., Bassinello, P. Z., Martino, H. S. D., de Souza Neto, M. A., & Oomah, B. D. (2022). Benefits of Carioca Beans (Phaseolus vulgaris) Molecular Mechanisms to Human Health and Nutrition. Molecular Mechanisms of Functional Food, 112-141.

Chandra, R. J., Masilamani, P., Suthakar, B., Rajkumar, P., Sivakumar, S. D., & Manonmani, V. (2024). Effect of Moisture Content on Combine Harvested Seed Crop and its Quality. Journal of Experimental Agriculture International, 46(3), 114-138.

Ejara, E., Mohammed, W., & Amsalu, B. (2018). Genetic variability, heritability and expected genetic advance of yield and yield related traits in common bean genotypes (Phaseolus vulgaris L.) at Abaya and Yabello, Southern Ethiopia. African Journal of Biotechnology, 17(31), 973-980.

Ghebrekidan, B. Z., Olaniyan, A. M., Wako, A., Tadesse, A. G., Alemu, D., & Lema, T. (2024). Gravimetric characteristics and friction parameters of common bean (Phaseolus vulgaris L.). Turkish Journal of Agricultural Engineering Research, 5(1), 76-93.

Güvercin, S., & Yıldız, A. (2018). Optimization of cutting parameters using the response surface method. Sigma Journal of Engineering and Natural Sciences, 36(1), 113-121.

Huertas, R., Karpinska, B., Ngala, S., Mkandawire, B., Maling'a, J., Wajenkeche, E., & Foyer, C. H. (2023). Biofortification of common bean (Phaseolus vulgaris L.) with iron and zinc: Achievements and challenges. Food and Energy Security, 12(2),e406.

Jan, S., Rather, I. A., Sofi, P. A., Wani, M. A., Sheikh, F. A., Bhat, M. A., & Mir, R. R. (2021). Characterization of common bean (Phaseolus vulgaris L.) germplasm for morphological and seed nutrient traits from Western Himalayas. Legume Science, 3(2), e86.

Joshi-Saha, A., Sethy, S. K., Misra, G., Dixit, G. P., Srivastava, A. K., & Sarker, A. (2022). Biofortified legumes: Present scenario, possibilities and challenges. Field Crops Research, 279,108467

Juraev, D. T., Dilmurodov, S. D., Kayumov, N. S., Xujakulova, S. R., & Karshiyeva, U. S. (2023). Evaluating Genetic Variability and Biometric Indicators in Bread Wheat Varieties: Implications for Modern Selection Methods. Asian Journal of Agricultural and Horticultural Research, 10(4), 335-351.

Lee, G. H., Moon, B. E., Basak, J. K., Kim, N. E., Paudel, B., Jeon, S. W., ... & Kim, H. T. (2023). Assessment of Load on Threshing Bar During Soybean Pod Threshing. Journal of Biosystems Engineering, 48(4), 478-486.

Lisciani, S., Marconi, S., Le Donne, C., Camilli, E., Aguzzi, A., Gabrielli, P., & Ferrari, M. (2024). Legumes and common beans in sustainable diets: nutritional quality, environmental benefits, spread and use in food preparations. Frontiers in Nutrition, 11,1385232.

Parker, T. A., Gallegos, J. A., Beaver, J., Brick, M., Brown, J. K., Cichy, K., & Gepts, P. (2022). Genetic resources and breeding priorities in Phaseolus beans: Vulnerability, resilience, and future challenges. Plant breeding reviews, 46, 289-420.

Que, K., Tang, Z., Wang, T., Su, Z., & Ding, Z. (2024). Effects of Unbalanced Incentives on Threshing Drum Stability during Rice Threshing. Agriculture, 14(5),777.

Savic, I. M., & Savic Gajic, I. M. (2021). Optimization study on extraction of antioxidants from plum seeds (Prunus domestica L.). Optimization and Engineering, 22, 141-158.

Savic, I. M., Nikolic, I. L., Savic-Gajic, I. M., & Kundakovic, T. D. (2019). Modeling and optimization of bioactive compounds from chickpea seeds (Cicer arietinum L). Separation Science and Technology, 54(5), 837-846.

Strecker, K., Bitzer, V., & Kruijssen, F. (2022). Critical stages for post-harvest losses and nutrition outcomes in the value chains of bush beans and nightshade in Uganda. Food Security, 14(2), 411-426.

Uebersax, M. A., Cichy, K. A., Gomez, F. E., Porch, T. G., Heitholt, J., Osorno, J. M., ... & Bales, S. (2023). Dry beans (Phaseolus vulgaris L.) as a vital component of sustainable agriculture and food security—A review. Legume science, 5(1), e155.

Umbataliyev, N., Smailova, G., Toilybayev, M., Sansyzbayev, K., Koshanova, S., & Bekmukhanbetova, S. (2023). Optimization Of The Technological Process Of Threshing Combine Harvester. Eastern-European Journal of Enterprise Technologies, 124(1).

Wang, W., & Cichy, K. A. (2024). Genetic variability for susceptibility to seed coat mechanical damage and relationship to end-use quality in kidney beans. Crop Science, 64(1), 200-210.