OPTIMIZATION OF MELKASSA AGRICULTURAL RESEARCH CENTER (MARC) BEAN THRESHER PARAMETERS USING RESPONSE SURFACE METHOD (RSM) /

የምላሽ ወለል ዘዴን (RSM) በመጠቀም የመልካሳ ግብርና ምርምር ማዕከል (MARC) የቦሎቄ መውቂያ ማሽን መለኪያዎችን ማመቻቸት

Biniam ZEWDIE[1*], Adesoji M. OLANIYAN[2], Amana WAKO[1], Dereje ALEMU[3], Tamrat LEMA[3]

[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

Tel: +2519-1040-8218/+2519-1582-8327; email: nzg2001nzg@gmail.com

Corresponding author: Biniam Zewdie Ghebrekidan

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ABSTRACT

In this study, the Agricultural Research Center of Melkassa examined the performance of a laboratory loop type bean thresher. As a function of different drum speeds (450, 550, and 650 rpm), concave apertures (25, 35, and 45 mm), feed rates (550, 650, and 750 kg/h), and moisture levels (5, 10, and 15%), the extent of grain deterioration, threshing efficiency, and rate of implantation were examined. Utilizing response surface techniques, the experimental design for optimization was developed. The response variables were significantly impacted by each independent variable. With a cylinder speed increase of 7.5 to 10.83 ms^{-1}, the percentages of grain damaged, threshed, and germination decreased from 45.98 to 47.97%, 96.81 to 99.69%, and 85.75 to 55.98%, respectively. Despite an increase in seed germination, damaged grain and threshing efficiency decreased as the moisture content increased. Grain deterioration and threshing efficiency decreased, however seed sprouting improved in tandem with an increase in feed rate and convex aperture. The cylinder speed of 8.25 ms^{-1}, the concave clearance of 37.4 mm, the feed rate of 672 kg/h, and the moisture content of 11.6% (db) were found to be the ideal parameters. In this case, the ideal ranges for seed sprouting, threshing efficiency, and grain impairment were found to be 3, 98.3, and 84.29%, respectively.

አኅፅሮተ-ጥናት

በዚህ ጥናት የመልካሳ ግብርና ምርምር ማዕከል የላብራቶሪ ሉፕ አይነት የቦሎቄ መፈልፈያ አፈጻጸምን መርምሯል። እንደየተለያዩ የሲሊንደር ፍጥነት (450, 550 እና 650 rpm), ሾጣጣ ቀዳዳዎች (25, 35 እና 45 ሚሜ)፣ የምግብ መጠን (550, 650 እና 750 ኪ.ግ. በሰዓት) እና የእርጥበት ደረጃዎች (5, 10, እና 15%) ፣ የእህል መበላሸት መጠን, የመውቂያ ቅልጥፍና እና የመትከል መጠን ተፈትሸዋል. የምላሽ ወለል ቴክኒኮችን በመጠቀም፣ ለማመቻቸት የሙከራ ንድፍ ተዘጋጅቷል። የምላሽ ተለዋዋጮች በእያንዳንዱ ገለልተኛ ተለዋዋጭ ጉልህ ተጽዕኖ አሳድረዋል. የሲሊንደር ፍጥነት ከ 7.5 ወደ 10.83 ms^{-1} በመጨመር የተጎዳ፣ የተወቃ እና የበቀለው እህል በመቶኛ ከ45.98 ወደ 47.97%፣ ከ96.81 ወደ 99.69% እና ከ85.75 ወደ 55.98% ቀንሷል። የዘር ማብቀል ቢጨምርም የእርጥበት መጠኑ እየጨመረ ሲሄድ የተበላሸ እህል እና የመውቂያው ውጤታማነት ቀንሷል። የእህል መበላሸት እና የመውቂያ ቅልጥፍና ቀንሷል፣ ነገር ግን የዘር ማብቀል ከአመጋገብ ፍጥነት እና ከኮንቬክስ ክፍት ቦታ ጋር ተያይዞ ተሻሽሏል። የሲሊንደሩ ፍጥነት 8.25 ms^{-1}፣ የሾለ 37.4 ሚሜ ማጽጃ፣ የምግብ ፍጥነቱ 672 ኪ.ግ በሰአት እና 11.6% (db) የእርጥበት መጠን በጣም ጥሩ መለኪያዎች ሆነው ተገኝተዋል። በዚህ ሁኔታ ለዘር ማብቀል፣ የመውቂያ ቅልጥፍና እና የእህል እክል ተስማሚ ክልሎች 3፣ 98.3 እና 84.29% በቅደም ተከተል ተገኝተዋል።

INTRODUCTION

According to *Joshi et al*. (2022), the common bean (*Phaseolus vulgaris* L.) is the third most consumed legume globally and one of the primary sources of nutrition for both people and animals in Africa. The seed and pod are used to make animal feed, and the seed has a high protein and carbohydrate content (*Uebersax et al., 2023*).

Ethiopia is the world's largest producer of edible legumes, with 560,191 hectares of farmed land and 208,913 tons of beans produced in 2019 (*Delelegn T., 2022*). Common beans are among the most important legumes (*Bento et al., 2022*). The common bean crop is threshed by a machine after being harvested by hand. Grain is separated from the pod and stalk by the thresher using pressure and impact force (*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*).

Grain damage, threshing loss, and mingled chaff with the grain are the most qualitative indicators of a thresher operation's effectiveness. In their examination of the design features of a thresher apparatus, *Ghebrekidan et al. (2024)* found those technological parameters such as drum speed and concave-to-drum clearance, as well as the rate at which materials were fed into the device, had a substantial impact on the threshing performance. Furthermore, the crop cultivar, moisture content, and biometrical indices all had an impact on the threshing process, according to *Juraev et al. (2023*). In order to assess a thresher's performance, the most prestigious particles are combined with grain damage and threshing loss (*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*).

Ejara et al. (2018) conducted an interesting inquiry in which they distinguished several criteria into conventional bean threshing quality indices: loss of grains, grain impairment, level of separation, and size of the pod decrease. The aperture, the wire loop type drum, the convex, and the drum peripheral velocity were shown to be two crucial elements in the threshing of common beans. *Ghebrekidan et al. (2024)* looked at the parameters of the common bean separation mechanism. It was demonstrated that the primary factors influencing crop quality were peripheral speed and the distance between the cylinder and the concaves. 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 m/s. 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, 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 as seed moisture level, clearance rates, and cylinder rpm. The outcomes demonstrated that moisture level, cylinder speed, and convex level all had a major impact on the germination of threshed seeds.

The success rate of threshing, output capacity, and grain damage and losses of a longitudinal flow barrier utilized in common beans were all significantly impacted by the feed rate, moisture content, and threshing drum beat, according to *Huertas et al. (2023*). The percentage of damaged grains and threshed pods in a loop-type bean thresher was investigated in relation to the impact of the drum's speed, moisture level, and pod size (*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}. The potential of the response surface methodology for optimizing the threshing of common beans in respect to machine-crop factors has not been investigated, despite the fact that several studies have been carried out on the threshing of various agricultural crops. The main objective of this study was to increase threshing efficiency, reduce grain damage, and maximize seed germination when threshing common beans. To achieve this, the response surface approach is used to improve technological parameters such as cylinder acceleration, convex clearance levels, feed rate, and moisture level.

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 dimensions (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 Fig.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.

Fig. 1 – MARC Bean thresher schematic diagram and participatory evaluation assessment

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.

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

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.

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 taken into account. Samples were randomly prepared and put into the thresher once it was turned on in order 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 in order to assess the threshing machine's effectiveness.

RESULTS

i) Threshing Efficiency

The figures 2a–c were prepared using optimal feeding amounts of 672 kg/h, 37.4 cm concave clearance, and 8.25 ms^{-1} drum speed.

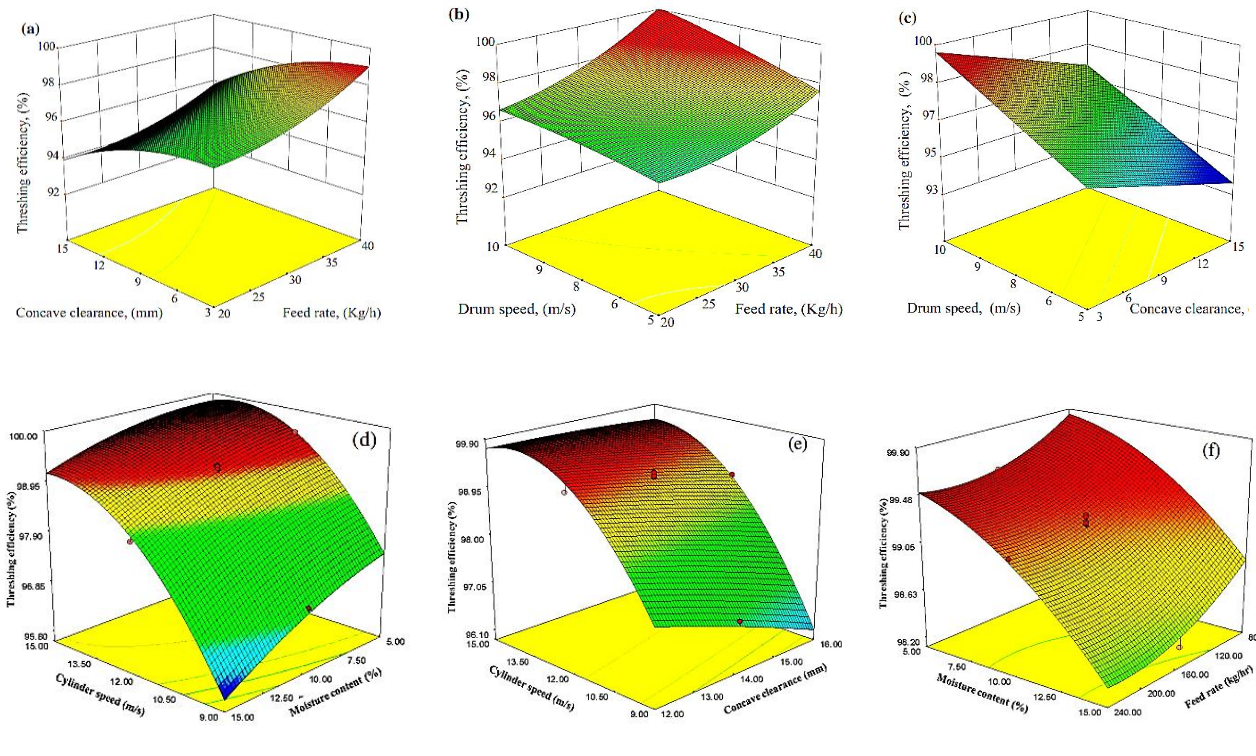

Fig. 2 - The implications of those parameters on the threshing efficiency

(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.

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 8.25 ms^{-1} and a concave clearance of 37.4 mm (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 Fig. 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 cylinder speed on common bean effectiveness of threshing is illustrated in Fig. 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%).

As concave aperture increased, threshing efficiency decreased, as Figure 2-e illustrates. In light of 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 750 kgh^{-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, as shown in Fig. 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 as a result 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 feed rate, convex clearance, and drum speed in terms of linear regression on the effectiveness of shredding at the 1% significance level. 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). 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*)

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**
$(Mc)^2$	1	5.38*	2.51ns
$(Cys)^2$	1	93.47**	52.46**
$(Fr)^2$	1	0.46ns	1.60ns
$(Cc)^2$	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. = Total Correlation*

ii) Grain Damage

The variation among the investigation's outcomes illustrated that the convex aperture, chamber rate, rate of feeding, and levels of water content 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: cylinder speed × level of moisture, feed rate × level of moisture, and cylinder speed × convex aperture. The implications of convex clearance and speed of cylinder on the percentage of grain damage are shown in Fig. 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 35 mm. During threshing, the common bean was subjected to higher impact levels, which increased damage. However, as concave clearance improved, grain damage drastically decreased.

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% (Fig. 3b) when the concave clearance of 37.4 mm 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 Fig. 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*).

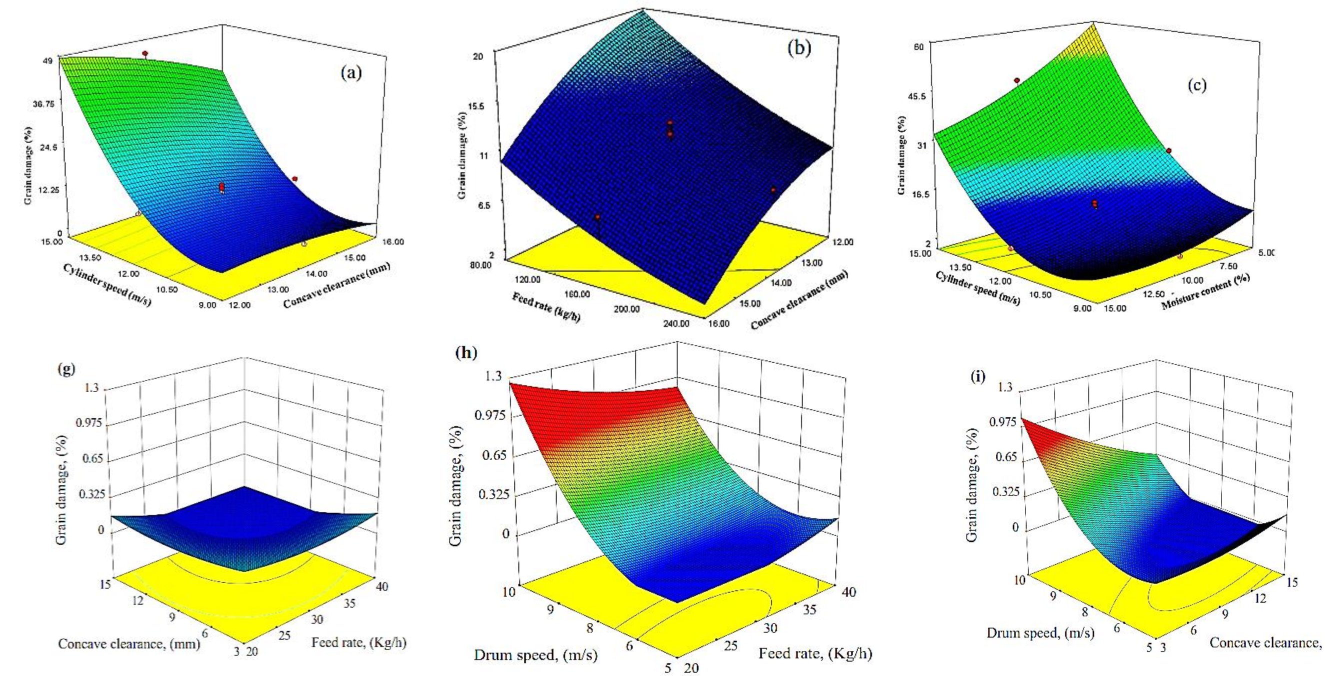

Fig. 3 - The implications on grain damage percentage of (a) cylinder speed and concave clearance, (b) feed rate and concave clearance, (c) cylinder speed and moisture content, (g) concave clearance and feed rate, (h) drum speed and feed rate, and (i) drum speed and concave clearance

A 672 kg/h rate for feeding, a concave clearance of 35 cm, and a drum speed of 8.25 m/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 (Fig 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 are 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 were published in *Huertas et al., (2023), Chandra et al., (2024)*. 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.

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. 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 the F-values in Table 2. 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). 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*).

iii) 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 25-45 mm with 87.94% efficiency of threshing, 85% cleaning effectiveness, and 0.086% fractures.

The marked region of Fig 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 672 kgh^{-1}, and level of moisture 11.6% were recommended for threshing common beans.

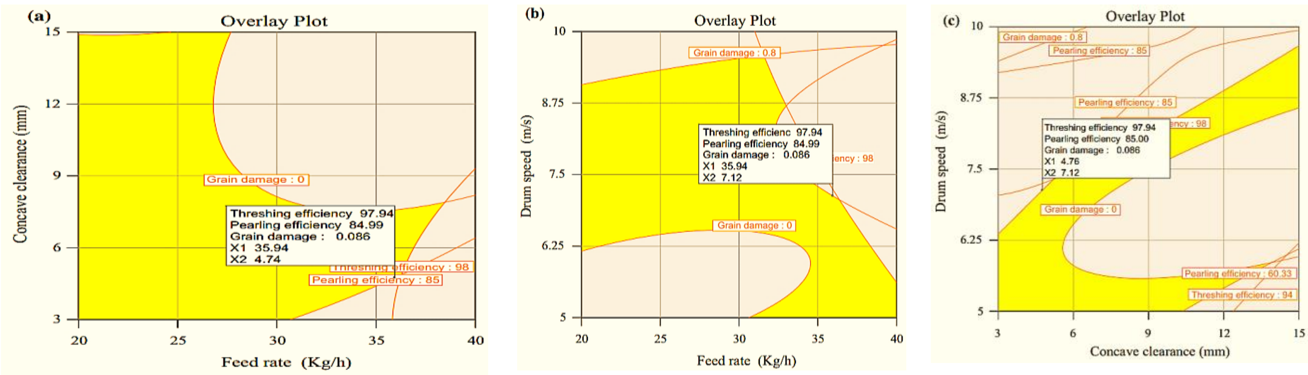

Fig. 4 - Graphical optimization of the operating parameters of the threshing drum

(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 the feed rate, 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 37.4 mm, rate of feed 672 kgh^{-1}, and moisture level of 11.6% were recommended for threshing common beans.

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