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Modeling and analysis of the effect of distances between hammers and sieves on some performance indicators of hammer mill machine

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Concave Clearance, Screen, Hammer-Mill Speed, Response Surface Methodology (RSM), Grinding Productivity

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ABSTRACT

This study was conducted to determine the effects of concave clearance and rotational speed on hammer-mill performance when grinding chickpeas. A response surface methodology (RSM) design approach was used to determine its suitability as a predictive approach for optimize chickpea flour production. The evaluation was performed using two parameters, concave clearance (6 mm, and 9 mm for the manufactured screen) and rotation speeds of (2154 rpm, 4339 rpm) as test factors, while Power Consumption (PC), Productivity (P), Specific Capacity (SC), Specific Energy (SE), Average Granules diameter (AG) and Grinding Fineness (GF) were used as test indicators. A quadratic regression combination test was designed and a mathematical model between the test indicators and the test factors was constructed. All models were statistically significant and were validated with two independent variables. The model R^2 for the responses was 0.87, 0.87, 0.71, 0.72, 0.91, and 0.93 for PC, P, SC, SE, AG, and GF, respectively. The results showed that the effect of concave clearance was significant for P, SC, SE, and AG; while PC, and GF were not significant. Furthermore, rotational speeds was significant for all indicators. The 9 mm concave clearance and the rotational speed of 4339 rpm were the most acceptable, so the new 9 mm concave clearance screen has a high productivity of 248.63 $kg.h^{-1}$ and reasonable power consumption of 1.82 kW, which is aprpperate in feed quality and preservation. After optimization the hammer mill showed the best operating performance meeting the requirements of precision grinding of chickpeas

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نمذجة وتحليل تأثير المسافات بين المطارق والغرابيل على بعض مؤشرات اداء ماكنة المجرشة المطرقية

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الخلاصة

اجريت هذه الدراسة لتحديد تأثير خلوص المقعر وسرعة الدوران على أداء المجرشة المطرقية عند جرش الحمص. تم استخدام أسلوب تصميم منهجية سطح الاستجابة (RSM) لتحديد مدى ملائمته كنهج تنبؤي لتحسين إنتاج مجروش الحمص. تم إجراء التقييم باستخدام معلمتين، الخلوص المقعر (6 ملم و 9 ملم للغربال المصنع) وسرعات الدوران (2154 دورة في الدقيقة، 4339 دورة في الدقيقة) كعوامل اختبار، بينما استهلاك الطاقة (PC)، الإنتاجية (P)، الانتاجية النوعية (SC)، الطاقة النوعية (SE)، متوسط قطر الحبيبات (AG) ودرجة نعومة الجرش (GF) كمؤشرات اختبار. وقد تم تصميم اختبار الانحدار التربيعي المركب وبناء نموذج رياضي بين مؤشرات وعوامل الاختبار. كانت جميع النماذج ذات دلالة إحصائية وتم التحقق من صحتها باستخدام متغيرين مستقلين. كان النموذج R^2 للاستجابات هو 0.87،0.87، 0.71، 0.72، 0.91، و0.93 ،للمؤشرات P، PC ،SC،SE، AG وGF، على التوالي. أظهرت النتائج أن تأثير خلوص المقعر كان معنوياً بالنسبة لـ P,SC,SE, AG، في حين لم يكن تأثيره معنويا لـ PC وGF ، في حين كانت سرعات الدوران معنوية لجميع المؤشرات. كان الخلوص 9 ملم وسرعة الدوران 4339 دورة في الدقيقة هو الأكثر قبولًا، لذا فإن خلوص الغربال المقعر الجديد 9 ملم يتميز بإنتاجية عالية تبلغ 248.63 كغم.ساعة$^{-1}$ واستهلاك للطاقة معقول يبلغ 1.82 كيلووات، وهو مناسب لجودة الأعلاف وحفظها. بعد التحسين أظهرت المجرشة المطرقية أفضل أداء تشغيل يلبي متطلبات الجرش الدقيق للحمص.

الكلمات المفتاحية: خلوص المقعر، الغربال، سرعة المجرشة المطرقية، منهجية سطح الاستجابة (RSM)، انتاجية الجرش.

INTRODUCTION

Pulses or grain legumes have recently gained more attention from consumers as they are a good source of vegetable protein (Muhammed, 2023; Alatawi et al., 2024). Pulses have been used as food for a long time (Sabri & Dizayee, 2023; Rafaat, 2022). Rolling or coarse grinding can improve digestion and allows for better mixing in mixed complete rations (Lardy et al., 2022; Altaleb & Batkowska, 2023). Types of mills are used to reduce grain size, such as hammer, disc and roller mills (Jung et al., 2018). The hammer mill is the most common for crushing grains due to its ease of operation, maintenance and production (Manaye et al., 2019). A hammer mill is a size reduction machine consisting of high-speed swinging hammers mounted on a rotor that acts on the fed materials and crushes them into finer particles so that they can pass through the sieve holes (Saensukjaroenphon et al., 2017). Efficient grinding of a wide variety of grains and high production quality make the hammer mill the best choice for agricultural materials(Adejugbe et al., 2023). The increasing demand for food produced by mills and energy scarcity has led to an increased interest in energy in the world and providing a sustainable environment for it (Martin et al., 2022). Grinding consumes a lot of energy, which accounts for more than 70% of the total energy consumption for the production of animal feed (Shirshaab & Jassim, 2021). Studies were conducted with the aim of finding the clearance between hammers and sieves to crush pulses with the lowest energy consumption and highest efficiency. The energy required for grinding depends on the technical and geometric characteristics of the mill and the physical properties of the ground material (Dabbour et al., 2015). In a study on the design, manufacture and evaluation of the grinding performance of a mill, an increase in speed resulted in higher productivity and lower energy consumption (Dominguez, 2021). showed that the performance efficiency of the comminution machine (hammer mill) is based on productivity requirements, energy consumption, the size of the crushed particles and the degree of homogeneity of the materials (Basiouny & El-Yamani, 2016).

(Pereira, 1987) states that attempting to create a model helps to identify areas where knowledge and data are scarce. Also, compared to traditional methods, models generally make better use of the data; a model summarises large amounts of information. In order to achieve a realistic modelling of the mill, the material behaviour in the mill as well as the efficiency of the mill, the grinding result depends on the material properties associated with the comminution. These are usually determined in single-particle experiments (Toneva & Peukert, 2007). In addition, a realistic model can help to understand the milling process and the interaction of the individual process steps.

In developing countries, most farmers and peasants are poorly literate, making it difficult to apply the most advanced and modern agricultural food handling practices necessary to meet food safety requirements (Lamuka, 2014). In Iraq, the model is generally not used and there is no model. The reason for this is that the lack of interest in it causes a lack of future information and the importance of this issue in animal nutrition.

The objectives of the present study are: a) to evaluate the performance of the hammer mill for traditional and manufactured screens (sieves) with some technical and volumetric performance. b) to establish a highly accurate model to fill this gap by predicting according to the performance.

MATERIALS AND METHODS

Hammer mill

The experiment was conducted using a hammer mill Figure (1) with the specifications in Table (1) at Mosul University, College of Agriculture and Forestry,in Mosul,Iraq.

Table (1): specifications of the hammer mill and new locally manufactured screen

Parameters	value, unit	Parameters	value, unit	Parameters	Value, unit
No. of hammers	24	concave clearance	6 & 9 mm	screen area	109650 mm^2
dimensions of hammers	87 x 44.5 mm	screen opening	4.8 mm	No.holes of screen	330
hammer weighs	146.76 g	No. of blades blower	6	screen weight	1600 g
thickness of hammers	6 mm	size of hopper	72 x 41 x 35,5 cm	screen thickness	2 mm
electrical motor	5.5- 6.4 hp	distance between two sequential		hammers	41mm

Figure (1): Photograph of the hammer mill

Design and manufacture of the new screen

To evaluate the performance of the hammer with the screen,the new screen was manufactured by a local factory in Mosul.The performance of the whole machine depends on the grinding and screening performance and both (Chuanzhong et al., 2012; Toneva et al., 2011). The fabricated screen component is similar to the conventional component with the addition of a limited edge with a 3 mm larger gap between the tip of the hammer and the inner surface of the screen.The main parameters were determined according to the design method for a conventional screen. In addition, the performance of the new screen was compared with that of the conventional screen to validate and evaluate the new design. The determined parameters are listed with the specifications in Table 1. Figure 2 shows the newly fabricated screen.

The measurements of the screen were carried out based on the design diagram of the screen and the design was drawn. The properties of the fabricated metal were then tested for resistance to pressure and friction from the impact of the hammers.The fabricated material must have resistant properties to the operating conditions (Jiang, 2019). Some of the factors considered in the selection of materials for the design of the screen are based on the chemical composition and mechanical properties of the metal and are listed in Table (2).

Table (2): chemical composition and mechanical properties

Mechanical properties							
Tensile Strength (Mpa)		Yield Strength (Mpa)		Hardness (HR)		Elongation(%)	
421		245		67		22	
Chemical composition/(%)							
manu. Screen	Carbon	Manganese	Phosphoros	Sulfur	Chromium	Nickel	Molybdenum
AISI／1010	0.103	0.511	0.041	0.046	0.002	0.002	0.001


A


b

Figure (2): a- traditional screen b- new manufactured screen

Milling material

The products used to evaluate the performance of the mill are nutritional chickpeas. It was purchased from the local marketin at Mosul city and its specifications are given in Table (3).

Table (3): Specifications of the chickpeas

Parameters	Value, unit	Parameters	Value, unit
Hectoliter weight	78.3 kg/hL	Width grain	6.64 mm
1000 grain weight	243.12g	Thickness grain	6.18mm
Grain length	8.86mm	Sphericity	80.53%

Measurement of moisture content

Moisture content was calculated using a Steinlite SL95 NTEP moisture meter and the moisture content of the sample (fodder chickpeas) was determined according to (Zhang et al., 2013) The moisture content was determined to be 11.2 %. The device reads the moisture content in percent (8 to 10) seconds.

Experimental procedures

This was performed by comparing the clearance between hammer and screen (6 mm traditional screen, 9 mm manufactured screen) at hammer speeds (2154 , 4339 rpm) in terms of effects on PC, P, SC SE, AG and GF.The samples were divided into smaller samples. Each sample containing approximately two kilograms of grain. It was used for every replication.

Once the machine has reached the desired operating speed, grains of known weight and moisture content are poured into the feed hopper and the chip is opened at the hopper opening at a predetermined feed rate (which is regulated via the feed opening). After grinding each sample, the time required for grinding was calculated, the ground mass was weighed, and the mass of the crushed sample was measured and recorded. To measure voltage and current, a voltmeter and ammeter were used, with grinding continued to ensure the cut-off time. The grains were milled in separate batches to obtain three replicates per treatment. Treatments were arranged in a 2 × 2 factorial arrangement with the main effects of concave screen clearance (6 mm conventional screen , 9 mm manufactured screen) and hammer speed in steps (2154 , 4339 rpm).

Particle size distribution

A sample of 200 grams of the milled product was characterized from each treatment and sifted using a mechanical sieve shaker and a multi-diameter sieve arranged from the largest to the smallest opening according to (ASAE, 2012).The sieve sizes used in the experiment were (nominal openings of 3.35, 2.36, 2.00, 1.18, 0.85, 0.30 and 0.15 mm, respectively) for successive sieving. The duration of the sieving was 10 minutes according to (Ghorbani et al., 2010). After sifting, the particles retained by each sieve were collected and weighed using an electronic compact balance (SF-400C). The Fineness modulus is expressed the coarse, medium and fine particles (Senthilkumar et al., 2015). The sifting of the ground material was repeated three times and the average values were given.

Figure (3): photo during separation on different sieve sizes of the flour sample

The studied indicators Power Consumption (PC), Productivity (P), Specific Capacity (SC), Specific Energy (SE), Average Diameter of Granules (AG), Grinding Fineness (GF)were calculated as follows:

$PC = I.V.1{,}73\,.PF/1000$ .... (1)

Where, PC - power consumption (kW), I - electric current consumed (A), V - voltage rating of the electrical source (V). equal 220V., and PF - power factor = 0.93, (Payne, 1997).

$P = MG/T$ ....………(2)

Where, P - productivity ($kg \cdot h^{-1}$), MG - mass of ground experimental matter (kg), T- duration of grinding one trial material (h), (Basiouny & El-Yamani, 2016).

$SC = P/PC$ ....……..... (3)

Where, SC - specific capacity ($kg \cdot kw^{-1}.h$), P - productivity ($kg \cdot h^{-1}$), PC - power consumption (kw), (Pfost & Headley, 1971)

$SE = PC/P$ ....……......(4)

Where, SE - specific energy ($kw \cdot h\ kg^{-1}$), PC - power consumption (kw), P - productivity ($kg \cdot h^{-1}$), (Khudher et al., 2021).

$AG = \sum_{i}^{k} Xi.fi$ ....……......(5)

AG - Average Granules Diameter (mm), Xi - average math of the upper and lower sieve,
i- sieve series number, k - number of sieves, fi - weight percentage of fines given in the sieve (mm), (Istvan, 1980).

Grinding Fineness: It was calculated after weighing the samples with a digital balance according to:

$$GF = 1F1 + 2F2 + 3F3 + \cdots + 7F7 \qquad \text{............} (6)$$

Where, GF - grinding fineness (%), F1- weight percentage for the last entry, F2- weight percentage for the penultimate entry, 1, 2, 3- constants, (Dabbour et al., 2015).

Response Surface Method(RSM)

The experimental design was carried out using the statistical software Design Expert 13 (Stat-Ease Inc., USA) and regression equations were created. The machine performance was determined for two factors, namely concave clearance in stages (6 mm,9 mm) and speeds in stages (2154 rpm, 4339 rpm) and their effects on the characteristics to determine power consumption, productivity, specific capacity, specific energy, Average Diameter of Granules and fineness of grinding was predicted using the Design of Experiments and Modeling program. For optimization and modeling, comprehensive data were recorded based on the number of trial runs represented by the number of independent parameters and their levels using Response Surface Methodology.

RESULTS AND DISCUSSION

The factors were optimized to result the level of responses of power consumption, productivity,specific capacity,specific energy, Average Granules Diameter and grinding fineness by using design expert 13 software. The data was statistically analyzed using the response surface methodology. Analysis of variance (ANOVA) was utilized to check the significance of the model and independent variables.ANOVA is a statistical technique used to draw conclusions based on the analysis of the experimental data. In Table (4), the results of the significance test for each regression coefficient are presented.The results of the significance test for each of the rating index regression models are all highly significant.

The analysis of variance of the quadratic models has shown that the model (p-value) reflects high significance for the regression model, as can be seen from the F test values of 24.78, 25.97, 8.97, 9.35, 40.37, and 53.43 for PC, P,SC,SE, AG and GF , respectively (Table 4 ($p<0.01$)) for all response models. The following model terms, independent variable concave clearance (A), are remarkably significant and have very strong effects on SE followed by SC, AG, and P, whereas PC and GF show no significant difference.

It was also found that the independent variable term rotational speed (B) significantly affected all indicators at the 5% level, responsible for higher significant effects in the sequences were PC, P, AG, GF, SC and SE. The interaction effect of A×B is not less than 0.05. Thus, there is a non-significant interaction effect. For the squared terms (A^2), (B^2), the squared effect is less than 0.05.There is therefore a significant indication of a quadratic effect, with the linear term (A^2) being the most significant term in the model. The lack of fit values affected all responses ($p < 0.05$), except for PC(0.333) and the response values were 0.0001, 0.01, 0.0197, 0.0006, and 0.0001 for P,SC,SE, AG and GF, respectively.

Table (4): ANOVA for quadratic model data

Response	Source	Model	A	B	AB	A^2	B^2	Lack of Fit
PC	F.val.	24.78	2.3	88.56	0.77	31.89	4.75	1.23
	p.val.	0.0001	0.146*	0.0001	0.391*	0.0001	0.0429	0.333*
P	F.val.	25.97	5.77	62.86	0.73	59.04	22.56	16.21
	p.val.	0.0001	0.0274	0.0001	0.403*	0.0001	0.0002	0.0001
SC	F.val.	8.97	13.6	7.08	1.18	21.31	11.28	5.41
	p.val.	0.0002	0.0017	0.0159	0.292*	0.0002	0.0035	0.01
SE	F.val.	9.35	17.7	6.92	0.05	21.58	8.19	4.47
	p.val.	0.0002	0.0005	0.017	0.822*	0.0002	0.0104	0.0197
AG	F.val.	40.37	8.76	116.7	0.89	75.36	15.47	10.53
	p.val.	0.0001	0.0084	0.0001	0.356*	0.0001	0.001	0.0006
GF	F.val.	53.43	4.22	163.1	0.22	99.28	18.87	27.35
	p.val.	0.0001	0.054*	0.0001	0.639*	0.0001	0.0004	0.0001

Note: *denotes not significant effect at *p.value* >0.05

Thus, there is evidence that the model adequately explains the variation in responses. The statistically significant effect of the lack of fit indicated that the model was adequate for prediction (Oluwole et al., 2019).

The equations relating to the true factors can be used after analysis to make predictions about the response for specific levels of each factor. By adopting the quadrature technique, the regression equation for the model was obtained, which explains the relationships between two factors and six scoring indicators, including the following:

$$PC = -4.35347 + 1.26492A + 0.000735B - 0.000018AB - 0.082132A^2 - 5.97403E{-}08B^2 \quad (7)$$

$$P = -1283.47251 + 315.18585A + 0.169926B + 0.003302AB - 21.22582A^2 - 0.000025B^2 \quad (8)$$

$$SC = -390.89154 + 109.11772A + 0.053956B + 0.002416AB - 7.35343A^2 - 0.000010B^2 \quad (9)$$

The linear regression in equations (7,8,9) shows that the regression terms of A and B had a positive effect on PC,P and SC, while equations (10,11,12) show that the terms of A and B had a negative effect on SE, AG, and GF. The interactive effect of increasing AB led to an increase in P,SC,AG and GF, while PC and SE decreased with an increase in AB as shown in the regression equation.

$$SE = +49.92422 - 8.74818A - 0.004377B - 0.000038AB + 0.553537A^2 + 6.42866E{-}07B^2 \quad (10)$$

$$AG = +20.73228 - 3.98031A - 0.002162B + 0.000038AB + 0.250630A^2 + 2.14054E{-}07B^2 \quad (11)$$

$$GF = +50.85587 - 9.46921A - 0.004801B + 0.000041AB + 0.612871A^2 + 5.03745E{-}07B^2 \quad (12)$$

Table (5) shows that quadratic models represent the responses of PC, P, SC, SE, AG and GF. The coefficient of determination of the model R^2 for PC was (0.8731), indicating that the model can explain 87.31% of the total variance, which is very close to 1 and can explain up to 87.31% of the response variance. This means that the performance of the model is acceptable and good for grinding. Table (5) shows that the predicted values of PC within the range of the experimental operation were consistent with the observed values. The observed R^2 squared effects and adjusted R^2 values range between 0.8731 and 0.8379 and are therefore significant and good.

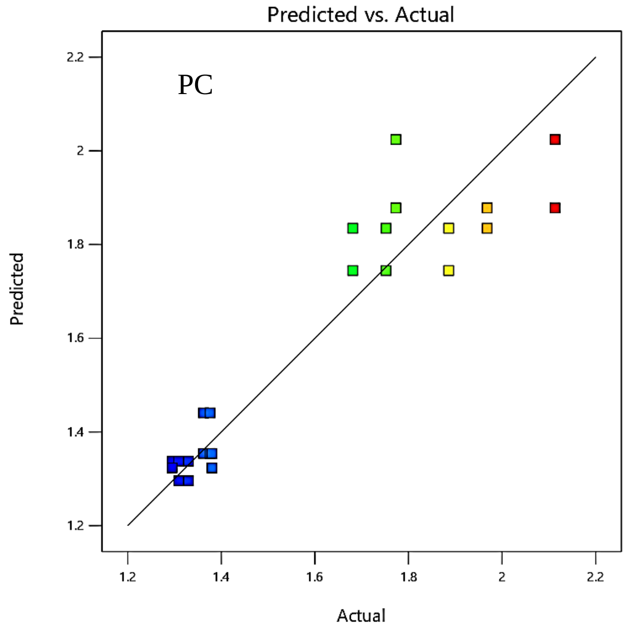
Consistent and acceptable the predicted R^2 value of 0.7707 with the adjusted R^2 value of 0.8731. It is desirable that the Adeq precision value is greater than 4 (Myers et al., 2016). The adequate precision value of 12.6183 indicates a sufficient signal and indicates that the model can be used to navigate the design space. Figure(4) shows that the actual response values are in good agreement with the predicted response values.

The coefficients of determination (R^2) for P, SC, SE, AG and GF were 0.8782, 0.7136, 0.7220, 0.9181, and 0.9369 respectively. In addition, the adjusted R^2 was 0.8444 for P, 0.6340 for SC, 0.6448 for SE, 0.8954 for AG, and 0.9193 for GF. This means that the model can predict and explain many changes in the observed response values, as evidenced by high values of (R^2) and adjusted R^2 (Pasandide et al., 2017).

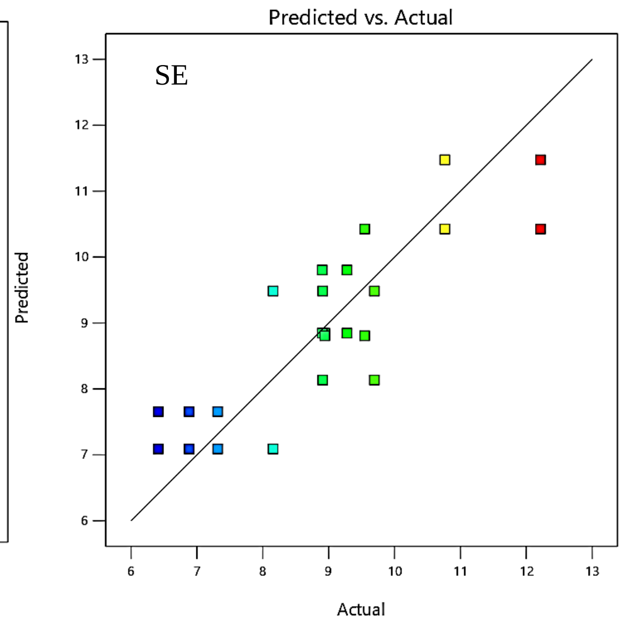
Furthermore, the coefficient of variation (CV) for all responses ranged from 7–13%, with a value of less than 13% indicating reasonable accuracy of the experiments and models Table (5). The reliability and accuracy of the data values is well established (Zhu & Liu, 2013).

Table (5): quadratic models

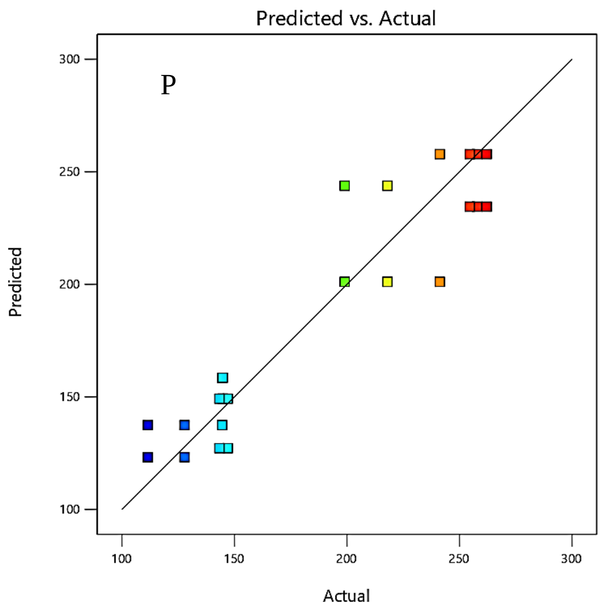
Parametr	**R^2**	**Adjusted R^2**	**Predicted R^2**	**Adeq Precision**	**Std. Dev**	**Mean**	**C.V. %**
PC	0.8731	0.8379	0.7707	12.6183	0.1155	1.60	7.21
P	0.8782	0.8444	0.7773	12.2788	21.93	187.64	11.69
SC	0.7136	0.6340	0.4861	8.8819	12.65	115.61	10.94
SE	0.7220	0.6448	0.5006	9.2704	0.9460	8.92	10.61
AG	0.9181	0.8954	0.8475	15.8220	0.2292	1.89	12.13
GF	0.9369	0.9193	0.8832	17.7433	0.4883	6.83	7.15



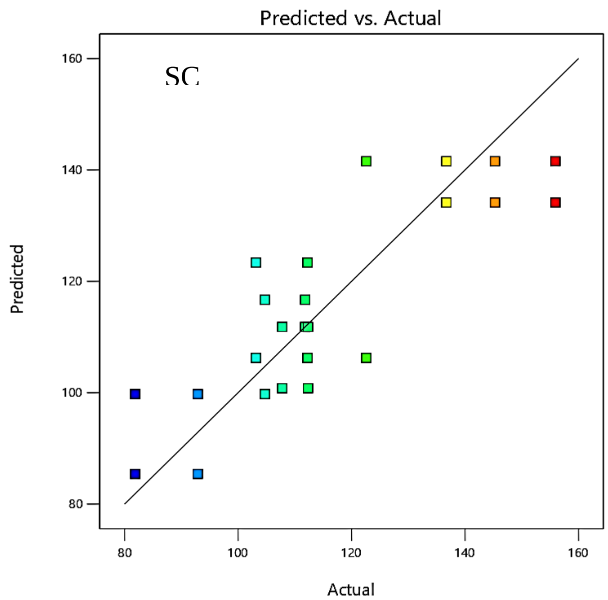
a-Power consumption



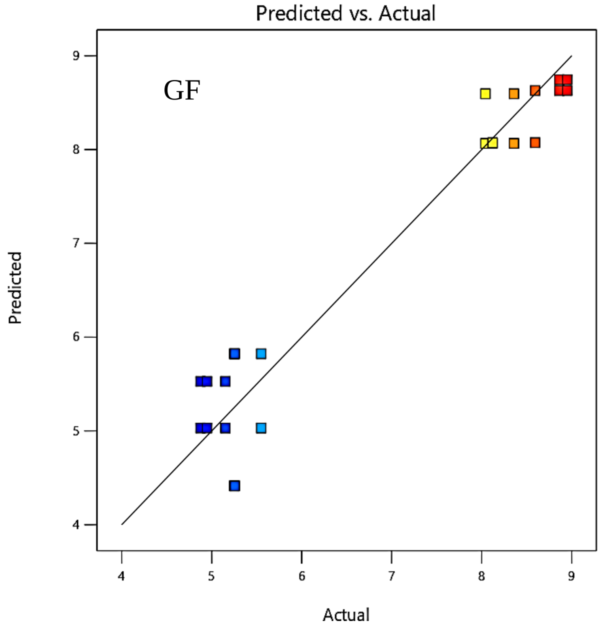
b-specific energy

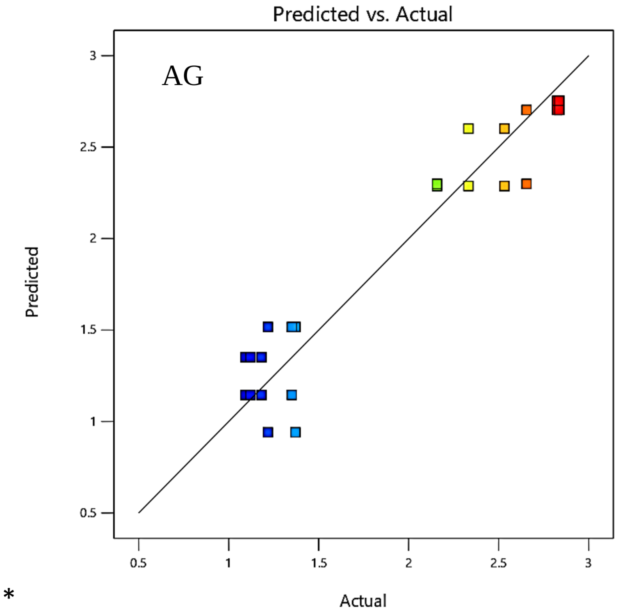


c-productivity



d-specific capacity





e- grinding fineness f- Average Diameter of Granules

Figure (4): Plots of Observed actual response values versus predicted response values.

The graphical representation of the quality of the models can be seen in Figure (4). The predicted values compared to the experimental values show that the quadratic model fits are appropriate, with R^2 -values for PC, P,SC,SE, AG and GF of 0.8731,0.8782, 0.7136, 0.7220, 0.9181, and 0.9369, respectively.These R^2 values show that only 12.69% of PC variation and 12.18% of P variation and 28.64%,27.80%,8.19%, 6.31% for SC,SE, AG and GF, respectively were not explained by the models. As can be seen in Figure (4), the actual values were relatively close to the values predicted by the model. Thus, the model can predict the values better.

Figure (5-a) and Table (4) show that the speed of the hammer mill and the concave clearance have a significant effect on the power consumption of hammer mill. In this study, the effect for concave clearance was quadratic, while speed had a linear and quadratic effect on hammer mill power consumption. Equation (7) shows that speed and concave clearance have a positive linear trend for the hammer-mill.

Figure (5-a) shows the interaction between hammer mill speed and concave clearance on power consumption. The response surface plots show affirmative power consumption with rotational speed, this show a slight increase and improvement with an increase in concave clearance, where it can be observed that the lowest value of power consumption of 1.27 kw at 2154 rpm besides 6 mm clearance and the highest value of power consumption of 1.82 kW was found at 4339 rpm with 9 mm clearance. In 6 mm clearance the power consumption rised from 1.27 to 1.79 kw when the speed increased from 2154 to 4339 rpm. The boost in power due to higher motor load, achieved by increasing the rotor speed with basically only a marginal increase in torque. This is consistent with the observations of (Bitra et al., 2009; Alkhoury et al., 2022).

The independent variables used influenced the hammer mill productivity. Rotational speed and concave clearance had a significant linear and quadratic effect on hammer mill productivity Table (4). on the other hand, speed and concave clearance showed a positive linear and quadratic correlation with hammer mill productivity (equation 8).

The response surface plots of productivity in Figure (5-b) a show an increase in productivity with an increase in speed and concave clearance. At a constsnt clearance, raising the speed from (2154 – 4339) rpm boosted productivity from (120.51 - 205.74) $kg\cdot h^{-1}$, as the hammers impact force on the grain increased as a result of gradual increase in rotor speed. (Wang et al., 2021; Khudher & Mishaal, 2022) observed the effect of increasing rotor speed on productivity. It is clear that the highest productivity of 248.63 $kg\cdot h^{-1}$ was observed at the maximum interaction of rotation speed and concave clearance and the lowest value at 120.51 $kg\cdot h^{-1}$.

Table (4) shows that the model created is significant with an F-value of 8.97. The two factors we have a significant effects on the specific capacity of hammer mill ($p<0.05$). As illustrated in figure (5-c) the specific capacity rises from 95.05 to 106.65 $kg.kw^{-1}h$, under 9 mm clearance at 2154 rpm, and similarly at 4339 rpm, the specific capacity increased from 115.13 to 136.74 $kg\cdot kw^{-1}h$. The lower grinding time resulted in higher productivity as the power consumption is relatively low due to the inverse relationship between power consumption and specific capacity (Al-Shamiry & Abbas, 2023; Akbar Ali et al., 2024).

The relationship between hammer mill speed and concave clearance to the specific energy requirement was shown in Figure (5-d). It was found that the increase in hammer mill speed and concave clearance leads to a reduction in specific energy, which is due to the fact that the machine capacity has increased more than the power requirements. This is probably because of an inverse relationship between the productivity and specific energy (El-Sharabasy & Soliman, 2021; Ali et al., 2024). The lowest value of specific energy (7.36 $kW\cdot h\cdot kg^{-1}$) was achieved at a speed of 4339 rpm and a concave clearance of 9 mm.

Figures (5-e)and(6-f) show the opposite behavior of average granules diameter and grinding fineness, as well as the interaction with hammer speed and concave clearance. Increasing the concave clearance to 9 mm at 4339 rpm reduces the average granules diameter from 2.75-1.21 mm and improves grinding fineness from 8.77-5.31%. Its 9 mm clearance, ample grinding space, and available processing time make it ideal for the material's size and characteristics (Toneva & Peukert, 2007). Thus, the grain size and comminution decrease due to the high impact velocity of the hammer, which leads to a reduction in the average granules diameter and grinding fineness (Ezurike et al., 2018). On the other hand (Zahra Ghorbani et al., 2013), a direct correlation between average granules diameter and specific energy was demonstrated in alfalfa milling.

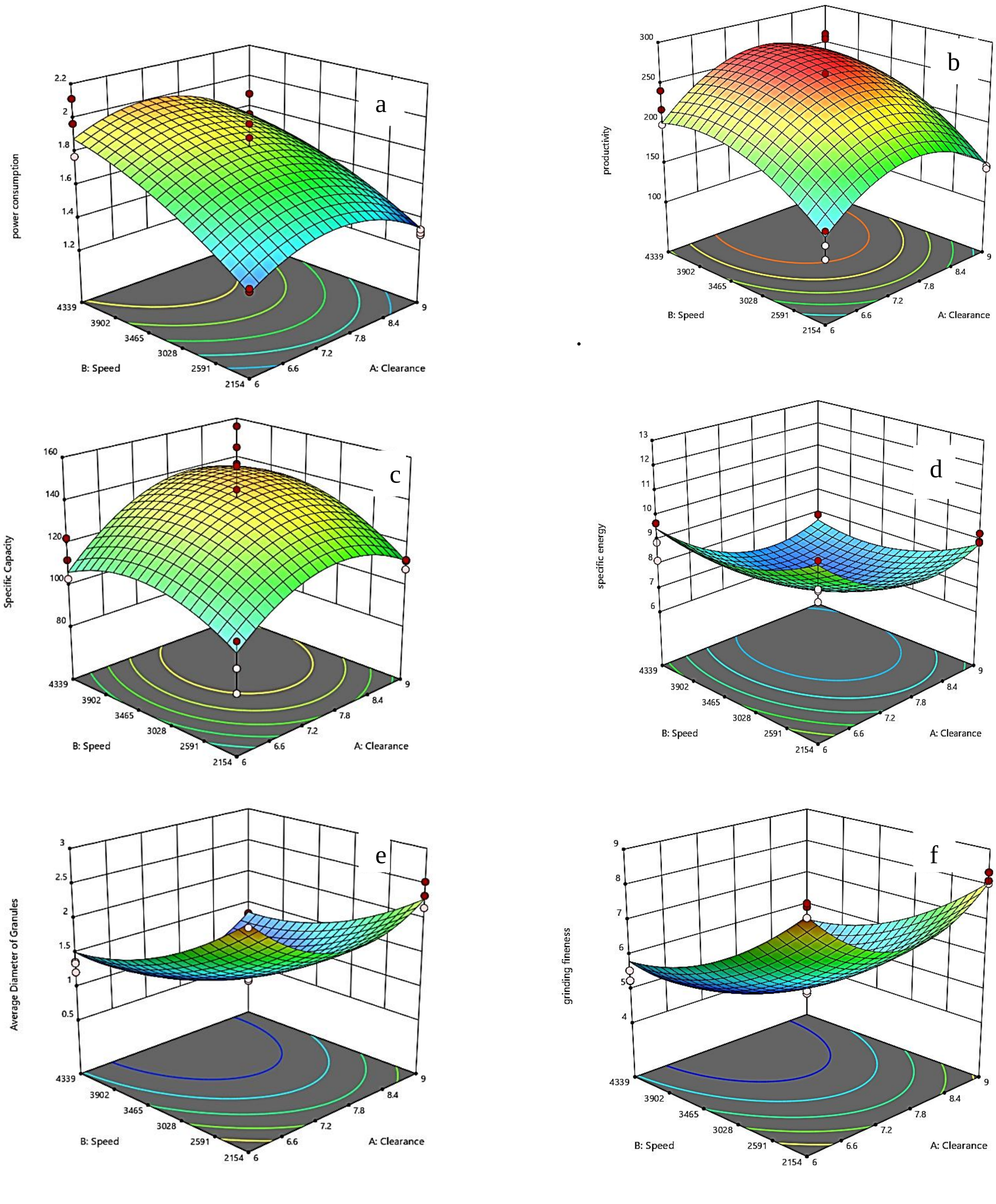


Figure (5): 3D surface plots explain the effect concave clearance and rotational speeds on power consumption-a, productivity-b, specific capacity-c, specific energy-d, average granules diameter -e and grinding fineness-f.

CONCLUSIONS

The technical characteristics of hammer mill and physical properties of ground chickpeas were influenced by the independent variables of rotation speed and concave clearance on the quality of ground chickpeas and had a significant effect on PC, P, SC, SE, AG and GF. The results showed 1.82 kW power consumption, 248.63 kg·h^{-1} productivity, 136.74 kg/kW·h specific capacity, 7.36 kW·h·kg^{-1} specific energy, 1.21 mm average granules diameter, and 5.13% grinding fineness under ideal conditions of 4339 rpm rotation speed and 9 mm concave clearance. Speed increases from 2154 to 4339 rpm increased specific capacity (95.05 to 115.13 kg·kW^{-1}h), productivity (120.51 to 205.74 kg·h^{-1}), and power consumption (1.27 to 1.79 kW). At higher speeds, however, specific energy, average granules diameter, and grinding fineness all declined. The influence of concave clearance on P, SC, SE and AG was significant ($p<0.05$). The experimental values were close to the predicted values in the validation. milling generally proved to be effective in improving the functional and nutritional properties of foods.

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CONFLICT OF INTEREST

The researchers declare that there is no conflict of interest in publishing this work.

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