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Application of Central Composite Design in Optimizing the Number and Angle of Pressure Plates in the Manufacture of Pelleted Chicken Feed

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Abstract. The response surface methodology (RSM) is used in conjunction with Central Composite Design (CCD) to construct a mathematical model and improve process parameters in the manufacture of chicken feed pellets utilizing a rotating press plate pellet system. The impacts of two process parameters, namely the number of pressure plates and the angle of the pressure plates, were investigated alone and in combination. ANOVA determines the relative relevance of process characteristics in the production of pelleted chicken feed. The angle of the press plate is more important than the number of press plates in enhancing production capacity, pellet durability, and machine efficiency. The Design-Expert program was used to construct a second-order regression model for predicting engine parameter optimization. Three press plates and a pressure plate angle of 60^0 provide the optimal circumstances for producing production capacity, pellet durability, and engine efficiency.

INTRODUCTION

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The growth and development of chickens while on the farm are influenced by the amount and type of chicken feed. Therefore, the productivity of chickens is highly dependent on the type of feed eaten. Several types of feed can be given to chickens. Pelleted feed is one of the most preferred types of feed by chickens. This type of pellet feed is more efficient and efficient given to chickens because it has high nutrition, and the growth rate of chickens is faster (1,2).

Pelletizing can be described as a phase change in the raw material by increasing the temperature to have a final phase in solid and capsule form. This final phase is formed after the raw material passes through the mold according to the desired shape. This final phase combines heat treatment during extrusion, moistening, and gelatinization of several components of the feed ingredients that function as binders. This binding effect prevents nutrient loss and slows down the disintegration of pellets in water (3–5).

Pelleting is a method of heat processing of feed raw materials. Pelleting aims to agglomerate smaller particles of feed raw materials using mechanical pressure, humidity, and heat. The initial step in pelleting is conditioning the mash through the addition of steam (3–6). Pellets are a sort of mechanical compaction that is aided by conditions such as humidity, heat, and pressure. Pellet stability is affected by the source material's moisture content, particle size, and temperature before processing. Additionally, these two parameters affect the durability, physical quality, and stability of pellets.

Preserving food in the form of pellets is beneficial because it increases the level of security in the supply of feed by ensuring that feed is available when it is needed (2). Creating pellets is the process of compacting feed materials into cylindrical forms or small bits of varying diameters, lengths, and degrees of hardness from raw ingredients. Pellet quality is influenced by a variety of factors, including starch, fiber, and fat content (2). Heat will cause gelatinization of starch when it is combined with water, and this process will impact the strength of the pellet. During the pellet creation process, fiber serves as a pellet mold, and fat serves as a lubricant to facilitate the process.

To develop a mathematical model and optimize process parameters in the production of chicken feed pellets using a rotating press plate pellet system rotating at 60 revolutions per minute, this paper employs the response surface methodology (RSM) approach and Central Composite Design (CCD) in conjunction with Central Composite Design (CCD). Previous researchers have published numerous studies on machining parameters (7–16), which have been widely disseminated.

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METHODOLOGY

Machine Specifications

(Fig. 1) is a chicken feed pellet machine using a rotating press plate. This pellet machine is used to measure the effect of the number and angle of the pressing plate on production capacity, machine efficiency, and pellet durability. The specifications of this machine are: machine dimensions (930 x 440 x 1130 mm), number of pressure plates (2, 3, and 4 pieces), pressure plate angle (30º, 45º, and 60º), dies plate (∅254x10 mm), diameter mold hole (5 mm), dynamo motor (1HP, 3 Phase, 1450 rpm), engine speed (50-70 rpm). (Fig. 2) shows the shape and number of pressure plates.

The machine's working principle is that the pressure plate rotates on the surface of the dies disk. The feed mixture enters through the hopper and cylindrical tube. Furthermore, the feed mixture is leveled and pressed into the mold hole. Pelleted chicken feed is formed after passing through the mold hole.

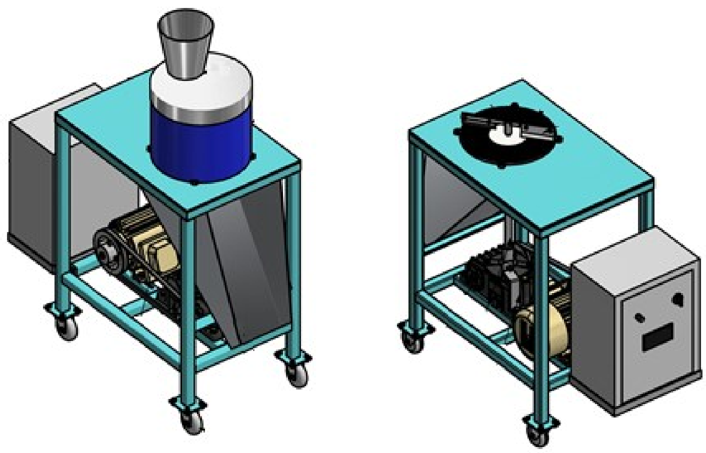

FIGURE 1. The chicken feed pellet machine uses a pressing plate.

(a) (b) (c)

FIGURE 2. Pressure plate models: two pressure plates (a), three pressure plates (b), and four pressure plates (c).

Stage of Testing Method

The feed mixture is formed on a press plate system pellet machine. The test aims to obtain the optimal number, and angle of pressure plate parameters at 60 rpm engine speed, 500 grams of feed ingredients, 25 grams of adhesive, and 400 water are prepared. The test parameters are the number of pressure plates 2, 3, and 4 pieces with pressure plate angles of 30º, 45º, and 60º. Equations (1), (2), and (3) are used to calculate pellet production capacity and durability, and machine efficiency.

$$\text{Production Capacity} = \frac{weight\ of\ pellet\ (Kg)}{Times\ (Hour)} \quad (1)$$

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$$\text{Pellet Durability} = \frac{Weight\ of\ durablitiy\ pellet\ (Kg)}{Weight\ of\ broken\ pellet\ (Kg)} \text{ x } 100\% \quad (2)$$

$$Machine\ efficiency = \frac{Weight\ of\ feedmix\ (Kg)}{Weight\ of\ pellet\ (Kg)} \text{ x } 100\% \quad (3)$$

Experimental design and statistical analysis.

The Central Composite Design method on Software Design of Expert (DOE) is used to explore the influence of operational factors on response in the investigation area. The independent factors selected were the number of pressure plates (pcs, A) and the angle of the pressure plates (degree, B). The ranges of values and levels of factor codes are given in (Table 1). The polynomial equation (Equation 4) was used to predict the response based on the independent factors and their interactions [11]. In this work, there are two independent factors; therefore, the response for a quadratic polynomial becomes:

TABLE 1. Independent factors and their levels for DOE of chicken feed pellets process.

Independent Factors	Unit	Level		
		-1	0	1
Number of pressure plates (A)	(pcs)	2	3	4
Pressing plate angle (B)	(Degree)	30	45	60

$$Y = \beta_0 + \sum \beta^i x^i + \sum \beta^i x_i^2 + \sum\sum \beta^{ii} x^i x_j \quad (4)$$

Where b0, bi, bii, and bij denote the constant, linear, square, and interaction coefficient terms, respectively, and xi and xj denote the independent variables (A and B). Multiple regression analysis, analysis of variance (ANOVA), and analysis of ridge maximum of data in the response surface regression (RSREG) technique were performed using the Design of Expert 6 program. R2 determined the model's quality, and the F-test determined its statistical significance.

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Result and Discussion

This study analyzed the effect of the number and angle of the pressure plate on the optimization of pelleted chicken feed production and engine efficiency. The design was used to obtain 11 design points across the two-factor range for the experiment. After the experiment, the response surfaces were analyzed by Central Composite Design. (Table 2) shows the design, and the responses are given.

TABLE 2. Design layout and experimental results.

Run	Number of the pressure plate (pcs)	Pressing plate angle (^{O})	Coded		Production Capacity ($Kghr^{-1}$)	Pellet Durability (%)	Machine Efficiency (%)
			A	B			
1	2	30	-1	-1	5.1	87.0	57.1
2	4	60	1	1	7.0	87.1	57.2
3	3	60	-1	1	7.7	87.6	57.7
4	3	30	0	-1	6.1	86.9	57.0
5	3	45	0	0	6.8	87.3	57.5
6	3	45	0	0	6.7	87.1	57.1
7	2	60	-1	1	7.0	87.4	57.5
8	4	30	1	-1	5.5	86.9	56.7

Run	Number of the pressure plate (pcs)	Pressing plate angle (^{O})	Coded A	Coded B	Production Capacity (Kghr^{-1})	Pellet Durability (%)	Machine Efficiency (%)
9	2	45	-1	0	6.2	87.1	57.0
10	3	45	0	0	6.9	87.5	57.5
11	4	45	1	0	6.4	87.1	57.1

Production Capacity

The findings of the production capacity at the pressure plate and the angle of the pressure plate indicate that it fits the quadratic model. The ANOVA for the data on manufacturing capacity is given in (Table 3). With a Prob>F value of significantly less than 0.01, the quadratic model is viable. In terms of coefficients, the number of pressure plates and their angle were deemed significant.

TABLE 3. ANOVA with CI = 95% for model and factors of the production capacity.

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	5.39	5	1.08	85.76	<0.0001	significant
A	0.060	1	0.060	4.78	0.0805	
B	4.17	1	4.17	331.70	<0.0001	
A^2	1.01	1	1.01	80.45	0.0003	
B^2	2.526E-003	1	2.526E-003	0.2	0.6726	
AB	0.040	1	0.040	3.18	0.1344	
Residual	0.063	5	0.013			
Cor Total	5.45	10				

The obtained empirical equation of the production capacity in the form of an actual factor is as stated in equation (5),

$$\text{Production capacity} = 6.85 + 0.1 * A + 0.83 * B - 0.63 * A^2 - 0.032 * B^2 - 0.10 * A * B \quad (5)$$

Where A is the number of the pressure plate (pcs.), and B is the angle of the pressure plate (degree). Based on quadratic equation (5), the pressure plate angle is the most influential parameter in increasing production capacity. For convenience, the equation can be displayed as response surface contour and three-dimensional surfaces, as shown in (Fig. 3).

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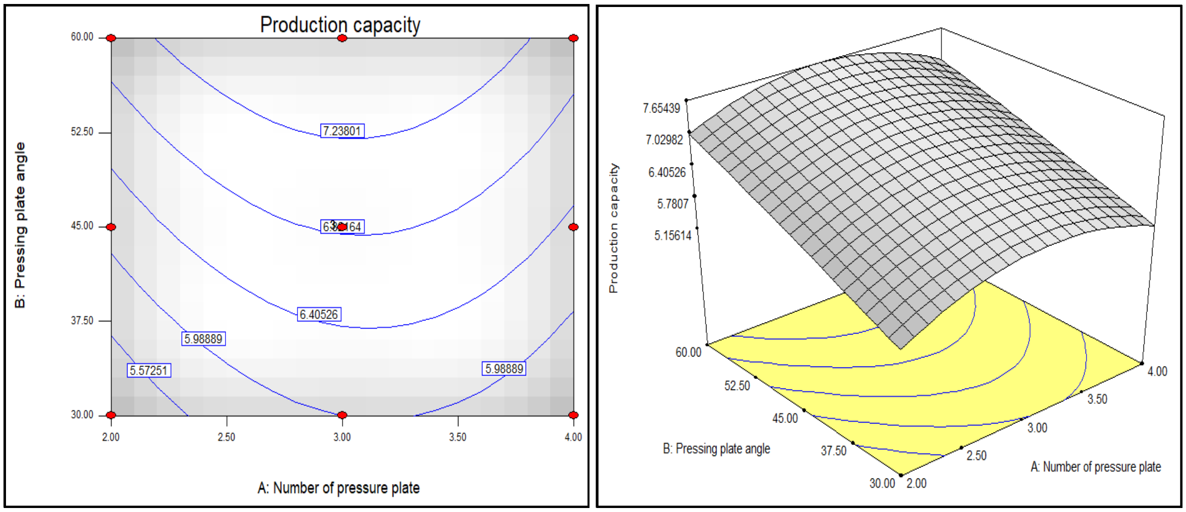

FIGURE 3. Response surface graph of contours (a) and 3D Surface for production capacity (b).

In (Fig. 3), it is known that the number of pressure plates affects the production capacity. Production capacity increased from 2 pressure plates to 3 pressure plates. However, there is a decrease in production capacity at four pressure plates. Suppose analyzed by linear regression, the more pressure plates, the greater the production capacity.

In (Fig. 3) it can also be analyzed the effect of the pressure plate angle on the production capacity. The greater the angle of the pressure plate, the higher the production capacity. Based on the analysis results of the effect of the number and angle of the pressure plate, the highest production capacity (7.7 Kg/hour) occurred in parameter 3 of the pressure plate, and the angle of the pressure plate was 60º. The pellet production capacity in this machine is lower than the previous test results [2, 6, 11]. However, the engine speed used in this test (60 rpm) is lower.

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Pellet Durability

The results for the durability pellet at the pressure plate and the angle of the pressure plate reveal that it is consistent with the linear model of durability pellet. The results of the ANOVA for the pellet durability data are presented in (Table 4). The linear model is viable since it has a probability >F that is much less than 0.01. In terms of coefficients, both the pressure plate and the angle at which the pressure plate was applied were determined to be statistically relevant factors. Pellet durability was not affected by the angle of the pressure plate or the change in the pressure plate's size.

TABLE 4. ANOVA with CI = 95% for model and factors of pellet durability.

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	0.31	2	0.15	4.97	0.0395	significant
A	0.027	1	0.027	0.86	0.3808	
B	0.28	1	0.28	9.08	0.0167	
Residual	0.25	8	0.031			
Cor Total	1.56	10				

The obtained empirical equation of pellet durability in the form of an actual factor is as stated in equation (6),

$$\text{Pellet durability} = 87.18 - 0.067 * A + 0.22 * B \quad (6)$$

Where A is the number of the pressure plate (pcs.), and B is the angle of the pressure plate (degree). Based on the linear regression equation (6), the most influential parameter in increasing pellet durability is the angle of the pressure plate. For convenience, the equation can be displayed as response surface contour and three-dimensional surfaces, as shown in (Fig. 4).

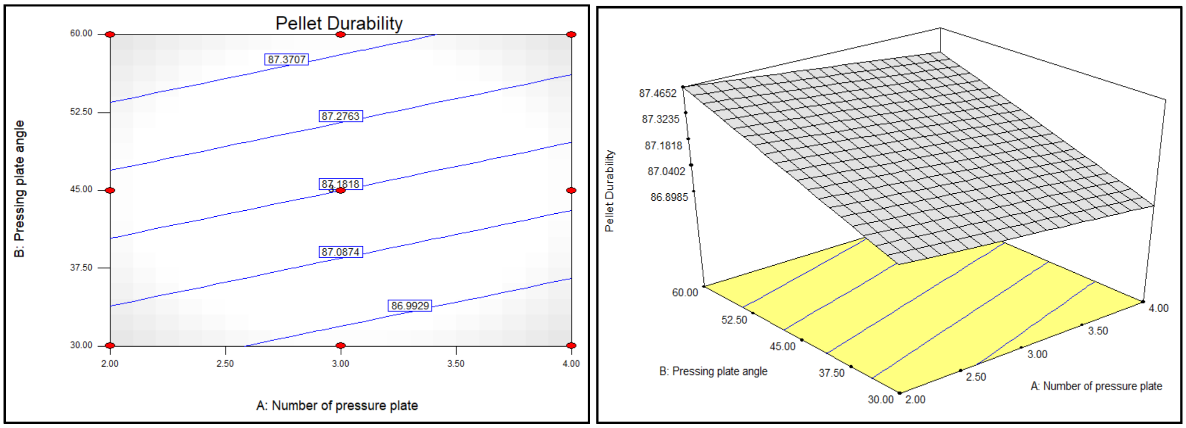

FIGURE 4. Response surface graph of contours (a) and 3D Surface for pellet durability (b).

(Fig. 4) shows the effect of the number and angle of the pressing plate on Pellet Durability. Pellet durability decreases with the increasing number of pressing plates, and pellet durability increase with increasing pressure plate angle. The best pellet durability (87.6%) occurred at three pressure plates, and the angle of the pressure plate was 60^o.

Machine Efficiency

This model is well-suited to the data obtained for machine efficiency at different numbers of pressure plates and angles of pressure plates. The results of the ANOVA for the data on machine efficiency are presented (Table 5). The linear model is valid because its probability>F is significantly less than 0.01. About the coefficients, it was determined that both the number of pressure plates in use and the angle at which they were used were statistically significant factors. Increased machine efficiency did not appear to be affected by changes in the number of pressure plates or the angle at which each pressure plate was positioned.

TABLE 5. ANOVA with CI = 95% for model and factors of the machine efficiency.

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	0.49	2	0.24	5.00	0.0391	significant
A	0.082	1	0.082	3.20	0.2993	
B	0.082	1	0.082	3.20	0.0182	
Residual	0.39	8	0.049			
Cor Total	0.88	10				

The obtained empirical equation of machine efficiency in the form of an actual factor is as stated in equation (7),

$$Machine\ Efficiency = 57.22 - 0.100 * A + 0.27 * B \qquad (7)$$

Where A is the number of the pressure plate (pcs.), and B is the angle of the pressure plate (degree). Based on linear equation (7), the most influential parameter in increasing engine efficiency is the angle of pressure plates. For convenience, the equation can be displayed as response surface contour and three-dimensional surfaces, as shown in (Fig. 5).

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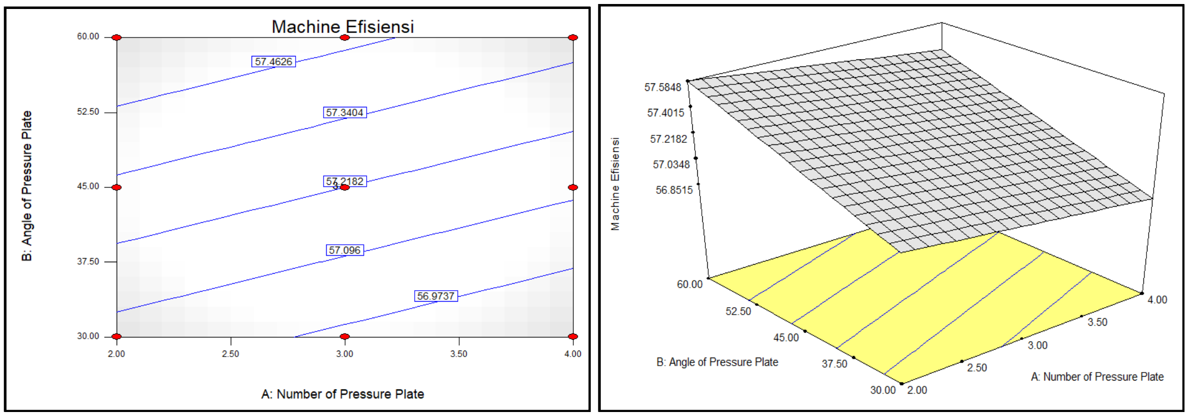

FIGURE 5. Response surface graph of contours (a) and 3D Surface for machine efficiency (b).

(Fig. 5) shows the effect of the number and angle of the pressure plate on the machine efficiency. The highest engine efficiency (57.7%) occurs at three pressure plates, and the angle of the pressure plate is 60°.

Optimization

Empirical models have been obtained for all chicken feed pellet manufacturing process responses due to the number and angle of pressure plates. Selection of the optimal number and angle of pressure plate parameters can be made. The expected range can be adjusted from each chicken feed pellet manufacturing process response. The range of the number and angles of the press plates as expected for all pellet manufacturing process responses can be determined. For example, to get production capacity, pellet durability, and machine efficiency, the number and angle of pressure parameters must be selected in the range of the number of pressure plates 2, 3, or 4 pieces and pressure plate angles of 30°, 45°, and 60°. To achieve this criterion, the range of number and angle of pressure plates must be within the yellow plot of the overlay (Fig. 6) of all the responses to making chicken feed pellets.

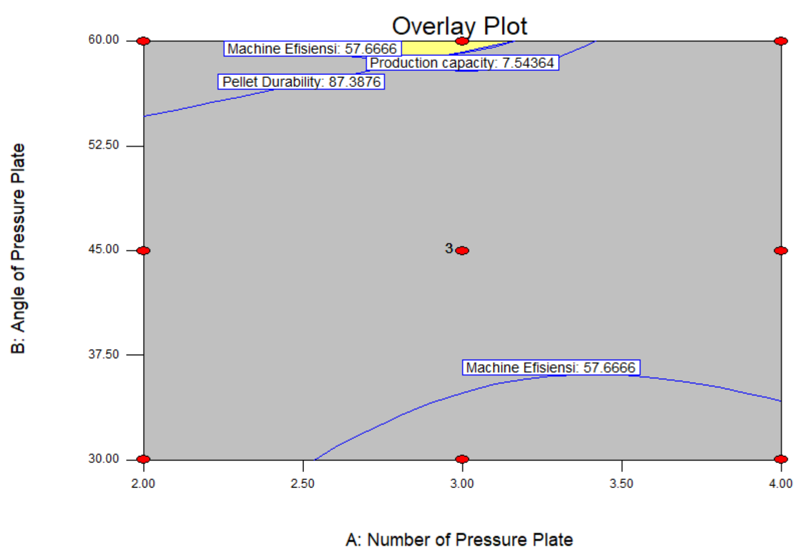

FIGURE 6. Overlay plot of the input factors for the predetermined response criteria of pellet production and machine efficiency.

In (Fig. 6), we can see the Overlay plot of the input factors for the predetermined response criteria. The response criteria that have been determined are the production capacity of 7.54364 Kg/hour, pellet durability of 87,3876%, and engine efficiency of 57.6666%. Based on the optimal response criteria, the best parameters obtained are the number of pressure plates 3, and the angle of the pressure plate is 60°.

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CONCLUSION

The optimization of the number and angle of pressure plate parameters in the manufacture of chicken feed pellets has been investigated using a rotating press plate pellet system machine. The conclusions of this study are the highest pellet production capacity (7.7 Kg/hour), the highest pellet durability (87.6%), and the highest machine efficiency (57.6%). Analysis of variance (ANOVA) shows the relative significance of the process parameters in making pelleted chicken feed. Press plate angle is more significant in increasing production capacity, pellet durability, and machine efficiency than the number of press plates. Design-Expert software was used in developing a second-order regression model to predict the optimization of engine parameters. Optimal production capacity, pellet durability, and engine efficiency are found in the number of 3 pressing angles and 60^{o} pressure plate angles.

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