Process optimization in Poultry Feed Mill

Sameh Amin (ssalaheldein@msa.edu.eg)
October University of Modern Sciences and Arts
Nahed Sobhi
October University of Modern Sciences and Arts

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Abstract

Poultry feed industry is a pretty much active in a lot of countries and it is achieved market acceptance. The final products are supposed to meet certain specifications to fulfill the nutritional need for animals at different life periods. The final product for poultry is shipped in the form of pelleted feed for the convenience of consumption. This paper focuses on improving production rates while maintaining quality specifications of the final products in an Egyptian poultry feed factory. The improvement approach is conducted by observing the main operating parameters of productivity; statistical analysis is conducted to observe the effect of those parameters on the production rate and the quality of the product. Comparison between parameters levels is done through analysis of variance to determine the significance of the tested parameters. The optimization of parameters was applied with Minitab and designed expert software to determine the best operating conditions. The obtained results showed that the downtime decreases by 16% monthly and the productivity increased by 35% and the pellet durability index increased by 0.8% after applying these parameters with total saving 2,160,000 LE.

Introduction

In a competitive market, customers are more likely to buy from the company that delivers their desired specifications and needs. Therefore, the companies focus on improving and optimize its production processes to be competitive in the market. Improving the process required understanding the modern technology that is the crucial key for a successful business. After identifying the root cause of the problem and highlighting the bottleneck then the process improvement can be achieved. The implementation of the solutions is connected with the form of weekly experiments, and multiple trials to eliminate variance for every experiment. This allows finding solutions to the problem with productivity without violating the general production constraints that can be done through optimizing equipment, or operating parameters. The feed industry must grow to meet the ever-growing demand by poultry farmers. The feed manufacturing industry faces enormous challenges and the demand for better quality feed is increasing gradually, it is becoming essential to improve the processes in a feed mill to increase the capacity while maintaining the required quality. With the growth of the poultry industry, old feeding methods as foraging were no longer capable of sustaining large farms and alternatives had to be found to sustain the ever-growing poultry population [1]. In order to raise a healthy poultry, a sufficient amount of protein and carbohydrates, vitamins, minerals, and suitable supply of water are required. The modern poultry industry aims to reduce the amount of time required to raise the chicken from a hatchling to an adult chicken (broiler) weighting around 2 kgs. The time required for this ranges from 4 to 14 weeks depending on the breed and the feed provided [2]. The influence of the feed is measured by the feed conversion ratio (FCR) which is the ratio of the livestock converts animal feed into weight [3]. Feed is considered the greatest cost item in broiler production representing (60–70) % of the total production cost, with the cost of ingredients accounting for the major portion of feed cost. Feed processing increase the cost of feed [4]. This is the main reason that farm owners aim to reduce the time required to bring the chick to the adolescence stage.

Background

Feed manufacturing processes

Feed goes through many processes before it packaged and sent off for the farms. The feed steps can be summarized in Fig. 1. The figure also shows the important quality checks to be carried out at each process.

The feed manufacturing processes can be summarized in the following steps [4]:

a. Crushing: It is the first step after receiving the raw materials. Any grains go through this process to undergo size reduction and increase the surface area for a greater nutritional value for the poultry [5]. The crushing process is mainly conducted by two types of machines, the hammer mills, and the roller mills:

- Hammer mills: in hammer mills, particle size reduction is accomplished by impacting slow moving ingredients with a set of hammers moving at high speed. Hammer mills generally produce spherical shaped particles with a polished surface [4]. Size distribution of particles produced in a hammer mill varies widely around the geometric mean, with some large and many small-sized particles.
- Roller mills: in roller mills, size reduction is accomplished through a compression force between the rotating roll pairs, producing more uniform particle size distribution with a low proportion of fine materials. Achieving a homogeneous mixture of ingredients is required.

b. Mixing: The main objective of mixing stage is started with a certain amount of ingredients having a certain weight then mixing them to an extent where they are homogenous. Any sample taken will have the same amounts of all ingredients. The mixing process can be conducted in many ways; the following are some of the most common methods in the feed industry (horizontal and vertical mixers).

c. Pelleting: it is the process of transforming soft dusty feed into a hard pellet. This process is achieved through compression, extrusion, and adhesion. The process involves passing the feed mixture through a conditioning chamber where steam is added. The moisture from steam provides lubrication for compression and extrusion and in the presence of heat causes some gelatinization of raw starch present on the surface of vegetative ingredients, resulting in adhesion.

d. Cooling: this process aims to reducing the temperature of the pellets resulting from the pelleting process. The cooling of pellets also results in increasing the hardness of the pellet. The cooling process mainly uses vertical coolers or horizontal coolers.

e. Crumbling: this process aims to break down the pellets into small pieces that can be easily consumed by the chicks. It is used when producing starter feed for chicks. Otherwise, it can be bypassed.

f. Sieving: sifting is required when producing pellets. Usually small fragments (fine) are produced as a result when the hot, moist pellets are cut off from the die inside the pelleting chamber, and as produced pellets pass through the cooling and conveying processes. Fines should be returned to the pelleting machine for reprocessing or can be used as another product which is usually feed for fish.

g. Coating: fats and oils can be added in this process to further improve the nutritional value of the pellets. This aims to add the remaining amount of oils that could not be added before the pelleting process. This process can be done through spraying coaters, vacuum assisted coaters, or centrifugal coating machines.

Pelleting Process

The pelleting process consists of the following steps [5]:

A. Steam Conditioning:

Prior to the pelleting stage steam conditioning of mash is a big step. For conditioning process to be optimized, a balance between moisture and heat is required. Steam has ability to provide such balance for how easy to control and add, it became quite an important element in the pelleting process. The addition of heat in conditioning is to improve binding and to remove any pathogens in the feed.

B. Pelleting:

The process of producing pellets is considered a combining mechanical process with moisture, pressure, and heat an aggregation of small sized particles into larger sized particles [5]. This process is done by passing mash feed from the bin into the conditioner and feeder. Then steam is injected inside the conditioner to the feed, the conditioned mash flows the pelleting chamber. The formation of pellets occurs by passing the hot mash through the metal die then cooling comes after. The fine partials separated from the pellets can be collected in the sieve, and returned to the pellet chamber for reprocessing.

C. Cooling:

When pellets leave the chamber, it has a temperature of (80 to 90) degrees Celsius, carrying moisture between (150–170) g/kg. The temperature must be reduced to 8 degrees more than the ambient temperature and moisture should be adjusted between (100–120) g/kg. Heat and moisture are removed from pellets by ambient air.

D. Retention Time:

In the literature, ripening leads to positive effects, with or without steam, and it also points to better quality pellets. When retention time is more than 5 minutes more moisture or other liquids can be added followed by steam injection and has no loss effects on productivity or feed quality. However, modern feed manufacturers use a great number of different animal diets that must be produced in short timespans. Therefore, the equipment with small hold period (less than two minutes) will have a favorable effect on the quality of nutrition.

E. Physical quality of pellets:

The quality of the pellet is measured by its ability to withstand abrasion and fragmentation during pneumatic and mechanical movement, storage, or bagging without breaking to reach the feeders without generating of high amount of fines. Pellets are easily fractured from the time they are manufactured until it reaches the chicken, so it creates fines in the feed. The pellet durability test is used to determine the amount of solid pellets that remains in manufactured pellets withstanding the attrition stresses due to mechanical process. Pellet durability can be evaluated to estimate quality of pellets. Quality of pellet is defined through pellet durability index (PDI) [6].

Roller and Die Dimensions

In feed manufacturing, pellet presses use the ring die design. In different designs usually two or three rollers are used. In most designs, the die rotates around the centered rollers. A few are designed as flat-die presses in which the die does not move, and the horizontal rollers revolve while pushing the feed through the die plate.

To generate Pressure in the die-hole of the pellet press it depends on the coefficient of friction between the die wall and feed mash, moisture content, die temperature, relaxation time of the plastic deformable portion in the mash and compressibility of the material [6].

Effects of Raw Material Constituents

The constituents include materials such as protein, starch, sugar, and fat, non-starch polysaccharides (NSP), fiber, inorganic matter, and water. The matrix structure in which the different components are arranged is very complex and it may lead to prevent the expression of a single constituent on the quality of pellet [5]. The diet inclusion of fats is a well-known example; free fats that are added into the mixer affect the durability and hardness of the pellet negatively but will improve the capacity of press in terms of tons produced per hour. This is attributed to the effect of lubricating fat added on the mash-die interface in pelleting process. A description of the feeds constituents' functionality can be given, this description can vary between different types of grains.

Pellet Mill Die and Roller Design

The pellet dies plays a vital role in the pelleting process. Moreover, the type of rollers used to spread and deliver the mash to the die to be formed affects the pelleting process as the following parameters:

A. Die design features:

The die physical characteristics are determined by its performance by specifying the overall thickness, correct blank, hole size and type of relief. The strength of the die is determined by the blank thickness. Resistance to deflection caused by pelleting process between the die and rolls is increased when the die is thicker. The work of the die material is determined by the effective thickness, therefore affecting pellet quality. If the die material is changed, the effective thickness should be changed as well to maintain good pellet quality and production capacity. To determine the correct (L/d) ratio length of the hole is compared with the hole diameter [7].

B. Die-hole inlets:

Hole inlet of the die can be tapered or with an enlarged hole diameter. Tapered inlets act as a chamber for pre-compression, they allow for practical machining techniques to be used and keep the cost of die lower. Recessed face dies with high grain ratio, in easy running applications which are conditioned extremely well and contain a lot of heat and moisture. This type of feed takes the path of the least resistance and will get squeezed between the die and rolls at outside edge, this prevents the material from escaping and makes sure the die face working width is used effectively. The specifications of the die are identical to the standard die, so the quality of pellet is the same. When recessing the die face the inside of the die is increased as well as the die's face area [7].

C. Die-hole patterns:

Three types of patterns are used for die holes: standard, heavy-duty, and close-hole patterns. Standard pattern is suitable for general feed applications with normal hole count, where many formulas are pelleted on the same die and machine. It maintains an average performance but affects the quality and production capacity of the pellets, while also affecting the overall die life. Heavy-duty pattern has less than normal number of die holes, making the die stronger, and increases the ligament thickness between the die. Production capacity is reduced, when this pattern is used because of reduced hole-count, as well as cost is increased. Close-hole pattern has a number of die-holes more than that of standard pattern by 25%. Using close-hole pattern results in an increased pellet quality and production capacity, better die wear, and efficient energy use, and less average cost per ton [8].

D. Roller shells:

Roller shells have many configurations. If maximum performance is expected, the correct design must be chosen accordingly to suit that application. Each design is geometrically engineered to give highest production of feed through a die while making sure the traction on the die face is reliable. Different designs for different requirements or applications [9] are presented below:

1) Open-end corrugated shells: it have narrow corrugations and runs horizontally over roller-shell face. It has the most corrugations than any other shell, so it is ideal for any applications that are troubled with chronic roll slip. It, used for manufacturing high-fiber materials such as dairy for cattle feeds [9].

2) Closed-end corrugated shells: its corrugations shape is gently sloping and closed off at the end of the shell to support effective use of outside rows of die-holes. Close ends allows the feed material to be trapped on the face of the die. Close end roller shell assist in a greatly die face wear by holding back on the natural characteristics of some of the feed formulations; it works to the grooves of each side of die face [10]. The close-end shells are available in different depths and widths and suits many applications but is generally used with poultry feed manufacturing for a well-conditioned, high-grain rations.

3) Helical closed-end corrugated shells: have two helices and can be used as a pair by creating opposition using one helix. Because of the helix design, the feed material tends to be pushed to the outer edges across the die face, that way they are helpful for dies that are experiencing problems of feed disruption of die face. Corrugations pass throughout the contour in the form of a curve of the roller shell face, due to being cut at a helical angle. Thus, ensuring that corrugations are in proximity with the die face and leading to smoother operation than when using straight corrugated shells [11].

4) Dimpled shells: have good wear characteristics because of its increased surface area. They are available with deep or shallow dimple based on which application they are used for. Roller face surface has a series of holes specifically designed for it.

5) Tungsten carbide shells: used for extremely abrasive applications when no other type of shells could handle and would wear out quickly. They pose greater wear resistance and longer life. They are used for pellet materials that either contain ground crops like sand and dirt or with high mineral such as cattle feed materials. When adjusting the rollers, greater care should be considered with this shell fitted. If adjusted too tight towards die face, the surface of the tungsten of shell will cause rapid wear [10].

Analysis of Variance

A factorial experiment is an experiment, which extracts information on several design factors more efficiently than can be done by the classical approach. A classical experiment is one where, generally, one factor is varied while others are held constant [11]. The Analysis of variance is based on the following statistical property. When several sources of variation are acting simultaneously on a set of observations, the variance of the observations is the sum of the variances of the independent sources. This property makes the application of the analysis of variance particularly useful in factorial experiments. By this method, the total variation within an experiment can be broken down into variations due to; each main factor, interacting factors, and residual error. The significance of each variation is then tested. An ANOVA test is a way to find out if experiment results are significant or not. In other words, they help us to figure out if needed to reject the null hypothesis or accept the alternate hypothesis. The groups are tested to see if there is a difference between them. Groups or levels are different groups within the same independent variable [12]. Multiple research studies focus on studying the different parameters and the effect of each other on the overall quality of the pellet. In order to reach the best production rates, improvement of the parameters must take place within the factory through experimentations. The factors to be considered for improvement include feed rate; conditioning time; temperature; mash feed size.

Method

Each organization has its exclusive constraints and problems that hinder achieving the required productivity. Studying all data and parameters to find the root cause of the problems and defining the bottleneck it is the first step for problem solving. In this study, the feed manufacturing production line has different processes of feed manufacturing as show in Fig. 1. The line has a bottleneck in the pelleting machine. This bottleneck decreases the rate of production and increase the total downtime in the production line. Defining the pelleting machine operating parameters are very important. Analyzing the effect of different parameters on the overall quality of the pellet is also important. There are no set parameters to use as the parameters are recipe specific, meaning they change from one recipe to another. To reach the best production rates, improvement of the parameters must take place within the factory through experimentations. The parameters to be considered for improvement include feed rate; conditioning time; temperature; mash feed size.

Data collection and analysis

Stoppages of the production line:

The most frequent stoppage in the production line is called jamming of the pelleting machine, where the die can no longer pass the mash feed and therefore, it is clogged and no pellets are being produced. This specific stoppage is representing 58% of the total stoppages. The frequency of the jamming contributed is 44 hours per Month (20 working days). In this duration, the production of the machine was reduced from the average 11.58 tons per hour to zero, as the machine produces no feed when it is clogged. The cost of feed is an average of 6000 L.E per ton. The organization loses 26.6 Ton production per day with total loss of 3,196,080 L.E per month.

Experimenting with the 4 mm dies

One of the possible solutions to the jamming problem would be the change of the hole size of the dies. This factory use of 3 mm dies. According to the literature review, some researcher uses dies of hole sizes larger than 3 mm with better quality also. Therefore it important to study experiment with dies having a larger die hole size and compare the results and repeat the experiment with another feed type. The following data was collected from pelleting machine it shows the different PDI and production rates for the two different die size holes.

Effect of different Die holes size on PDI

The study was carried out on two types of feeds, the grower and the finisher. The PDI ratio is calculated for the different types of feeds for the two die hole sizes. The obtained results on feed type showed the PDI for the 3 mm die hole size was 87.31% with a variance of 0.00014 while the average PDI for the 4 mm die hole size was 88.3% with a variance of 0.00011 as shown in Fig. 2. In Fig. 3 the average of the PDI for the 3 mm die hole size was 87.27% with a variance of 7×10^{-5} while the average PDI for the 4 mm die hole size was 88.01% with a variance of 9×10^{-5} with finisher type of feed.

a) The Productivity at different Die hole size:

The collected data shows the productivity of the machine in Tons/Hr. for the two die holes sizes. The study was conducted on finisher feed, as it was the main type of feed. Figure 4 show that the average productivity for the 3 mm die hole size is 13.3 Tons/Hr. with a variance of 5.136 while, the average productivity for the 4 mm die hole size is 15.35 Tons/Hr. with a variance of 1.397.

While the current situation looks to favor the use of 4 mm dies. A decision cannot be taken until further analysis is conducted. Therefore, some statistical tests will be conducted to see if there is a significant difference regarding the PDI and productivity at different die hole sizes. One way Analysis of variance is used to determine whether the die hole size is significant or not. In case it is significant, post ANOVA analysis will be conducted to point out the better option for both the PDI and productivity.

b) Analysis of Variance for the PDI:

Minitab software is used to determine whether, the hole size of the die is a significant parameter for the quality or not. A confidence level of 95% was used for the calculations and the null hypothesis is no significant difference. The obtained results showed that the null P-value is less than the 'α' level (0.008 < 0.05), therefore, the null hypothesis is rejected shown in Table 1. Then a significant difference to the quality occurs when different die sizes are used.

Table 1
One way ANOVA table for grower feed

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.001010	0.001010	7.93	0.008
Error	40	0.005096	0.000127		
Total	41	0.006106			

It can be seen in Fig. 5that the PDI for the 4 mm die hole size tends to be higher with a higher mean. For the grower feed type, since a significant difference exist, it is apparent that the use of the 4 mm die will result in better quality product. The next study is conducted to compare between the uses of the two dies hole sizes using a different type of feed. The date in the following table is for the finisher feed type.

Table 2
One way ANOVA table for finisher feed

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.002186	0.002186	26.56	0.000
Error	154	0.012677	0.000082		
Total	155	0.014863			

The variance is unknown but assumed equal that the study is implemented on the same machine with the same feed type. A confidence level of 95% is used for the calculations and the null hypothesis was that there is no significant difference. In this case, it is observed that the null P-value is less than the α level (0.000 < 0.05) as shown in Table 2. Therefore, the null hypothesis is rejected, a significant difference to the quality occurs when different die sizes are used. It is worth mentioning that the actual P-value is not equal to an absolute zero. However, computer software usually rounds the actual value to zero for simplicity. It can be seen in Fig. 6 that the PDI for the 4 mm die hole size tends to be higher with a higher mean. For the finisher feed type, since a significant difference exist, it is apparent that the use of the 4 mm die will result in better quality product.

c) Analysis of Variance for the productivity

The next step is to compare the productivity for the two die hole sizes to study the significance of the die hole size. The study was conducted only on the finisher type. The following table is the ANOVA table for the productivity at the two die holes sizes for the finisher feed. For the calculations in Table 3, the variance is unknown but assumed equal the study is implemented on the same machine with the same feed type. A confidence level of 95% is used for the calculations and the null hypothesis was that there is no significant difference. In this case, it is observed that the null P-value is less than the α level ($0.000 < 0.05$). Therefore, the null hypothesis was rejected, a significant difference to the productivity occurs when different die sizes are used. Once more, it is worth mentioning that the actual P-value is not equal to an absolute zero. However, computer software usually round the actual value to zero for simplicity. It can be seen in Fig. 7 that the use of the 4 mm dies results in a larger productivity with a higher mean for the finisher feed type.

Table 3
ANOVA table for the productivity of finisher feed at the two die hole sizes

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	228.2	228.167	107.32	0.000
Error	148	314.7	2.126		
Total	149	542.8			

Study the operating parameters

A proposed solution for limited productivity of the factory is to study the different parameters of operation and then find the optimum level for each parameter. Then these parameters would be standardized. In order to do so, experiments are carried out on the pelleting machine. A machine was checked by the factory to ensure that it is in suitable conditions for the experiments to take place. The proposed parameters for the experiments are pressure and temperature. The productivity will be measured at different levels of these two parameters. Two-way ANOVA will then be conducted to determine the significance of each parameter. Finally, software will be used to select the optimum operation parameters. The data was collected through many trials. The number of replications for each level is three replications after removing the failed trials or interrupted trials. There are four levels of the pressure parameter; 1.5, 1.7, 2 and 2.2 bar. The temperature consisted of three levels; these levels are intervals rather than individual values. These intervals are 75–77, 78–79 and 80–81°C. The selected levels of the parameters are going to show the trend of what levels of each parameter are best. The obtained results from the experiments by using the ANOVA test to identify the significance of each parameter and the significance of the interaction between the two parameters are presented in Table 4. These observations can be used in the optimization process later where the best parameters will be identified to be later on standardized. Each of the interactions between the two parameters has 3 replications. These observations are entered into Minitab software so the ANOVA calculations and the suitability of the model to this case can be measured.

Minitab was used to understand the significance of the parameters and the obtained results are shown in Table 5.

Table 4
observations from the conducted experiments

Observations (tons/hr)		Pressure (bar) 1.5	1.7	2	2.2
Temperature (°C)	75–77	(12.7)	(10)	(14.9)	(16)
		(12.7)	(10.2)	(15)	(16)
		(12.8)	(10)	(14.8)	(16)
	78–79	(12.28)	(10.7)	(15.6)	(14)
		(12)	(10.5)	(15.32)	(15)
		(12.2)	(10.7)	(15.6)	(15)
	80–81	(12)	(11.2)	(14.9)	(13.7)
		(12)	(11)	(15)	(13.5)
		(12)	(11)	(14.8)	(13.4)

Table 5
ANOVA calculations on results of obtained results

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Pressure	3	122.400	40.7999	1048.54	0.000
Temperature	2	1.882	0.9411	24.19	0.000
Pressure*temperature	6	10.402	1.7336	44.55	0.000
Error	24	0.934	0.0389		
Total	35	135.617			

A confidence level of 95% was used for the calculations and the null hypothesis was that there is no significant difference. In this case, it is observed that the null P-value is less than the ‘α’ level (0.000 < 0.05) for the two parameters and the interaction between them. Therefore the null hypothesis that no significant difference was rejected and the two parameters and the interaction between them are significant. The results obtained from these calculations and future analysis conducted on this data can be used with confidence as a test was run to determine the fit of the model to the data and the most important results can be seen in Table 6.

Table 6
Summary of the model

S	R-sq.	R-sq. (adjusted)	R-sq(predicted)
0.197259	99.31%	99.00%	98.45%

The interpretation to the results as shown in Table 6, the value of S is used to test how the model responds to the data used. It is measured in the units of the response variable and represents how far the data values fall from the fitted values. The lower the value of S, the better the model describes the response. R-sq is the percentage of variation in the response calculated by the model. The higher the R-sq value, the better the model fits the data. R-sq adjusted is used when it is desired to compare models that have different numbers of predictors. R-sq predicted is used to determine how well the model would predict the response for new observations. The model responds well to the data and therefore it can be concluded with a confidence level of 95% that the temperature, pressure and the interaction between both of them has a significant effect on the productivity. With the results of the data collection and analysis phase in consideration, the implementation and results phase can be started.

Results

Optimal Operating Parameters

Design Expert is chosen as the software to conduct the analysis on these experiments in order to obtain the optimal parameters for improvement. Firstly, determine which factor effects should be examined, identify the responses that need to be measured, and how many runs is it needed to satisfy the objective. In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. This model is only an approximation but can be used because it is such an easy model to estimate and apply, even when little is known about the process. RSM can be used to maximize the production by optimization of operational factors. As shown in Fig. 8.

Response surface methodology process is summarized in the following sequence:

a) Identify Responses

After clarifying the objective, the next step is to figure out which responses to measure and how to measure them. The responses in this study were chosen to be productivity and pellet durability index (PDI) as seen in Table 7.

Table 7
Response information

Response	Name	Units	Observations	Analysis	Min.	Max.	Mean	Std. Dev.	Ratio	Transform	Model
R1	Productivity	Ton/hr	36.00	Polynomial	10	16	13.19	1.97	1.60	None	cubic
R2	PDI	%	36.00	Polynomial	0.854	0.897	0.8802	0.0103	1.05	None	2FI

b) Identify Factors and Levels

Factors are the inputs to the process. Factors in the experiment are controlled and set to levels prescribed by the design. In this, case the levels for temperature ranges from (75°C to 81°C) and for pressure ranges from (1.5 to 2.2) bar as seen in Table 8.

Table 8
Factors information

Factors	Name	Units	Type	Min.	Max.	Coded low	Coded high	Mean	Std. Dev.
A	Temperature	C	Numeric	75	81.00	-1—75.00	+ 1—81.00	78.39	1.98
B	Pressure	bar	Numeric	1.50	2.20	-1—1.50	+ 1—2.20	1.85	0.2731

The analysis can proceed once the response data has been entered. Each response must be analyzed individually, and analysis of variance is used to test the model as whole and individual terms in the model.

Other statistical tests are computed if they are applicable along with descriptive statistics to aid with verifying the correct model has been chosen and Inspect various diagnostic plots to statistically validate the model.

c) Analysis for productivity:

Analysis of variance showed that the P-value of the model is less than 0.0500 which indicate that the model terms are significant. Also the analysis showed that the P-value of the lack of Fit is less than 0.0500 which indicate that the lack of Fit is significant as shown in Table 9.

Table 9
ANOVA for Response 1: Productivity

Source	Sum of squares	df	Mean square	F-value	p-value	
Model	132.51	9	14.72	118.56	< 0.0001	Significant
A-temperature	0.3211	1	0.3211	2.59	0.1199	
B-pressure	75.75	1	75.75	609.99	< 0.0001	
AB	1.85	1	1.85	14.89	0.0007	
A^2	0.0781	1	0.0781	0.6292	0.4348	
B^2	6.33	1	6.33	51.00	< 0.0001	
A^2B	0.0844	1	0.0844	0.6795	0.4173	
AB^2	5.43	1	5.43	43.75	< 0.0001	
A^3	0.0559	1	0.0559	0.4501	0.5082	
B^3	44.80	1	44.80	360.74	< 0.0001	
Residual	3.23	26	0.1242			
Lack of fit	3.12	18	0.1733	12.70	0.0005	Significant
Pure error	0.1092	8	0.0136			
Cor total	135.74	35				

Table 10 shows that the confidence intervals around the estimated cubic model coefficients. While most analyses don't require examining these intervals, they can help sort out issues when the analysis doesn't make sense. The coefficients are adjustments around that average based on the factor settings. VIFs coefficients are greater than 1 but within acceptable range and it is less than 10 so there is no large indication for multi-collinearity, and the higher the VIF the more severe the correlation of factors. The larger the standard error of a regression coefficient, the less likely it is that this coefficient will be statistically significant.

Table 10
Coefficients in terms of coded factors for productivity

Factor	Coefficient estimated	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	12.87	1	0.4698	11.91	13.83	
A-temperature	-0.3201	1	0.3442	− 1.02	0.3829	1.01
B-pressure	1.93	1	0.2953	1.32	2.53	1.04
AB	-0.4978	1	0.4466	− 1.41	0.4143	1.04
A^2	-0.3260	1	0.5881	− 1.53	0.8750	1.01
B^2	0.8505	1	0.5459	− 0.2644	1.97	1.00

d) Normal Probability for productivity

The normal probability plot as shown in Fig. 9 which indicates whether the residuals follow a normal distribution, thus follow the straight line. Some scatter should be expected even with normal data that indicates the response provides a better analysis. Externally Studentized residuals based on a deletion method are the default due to being more sensitive for finding problems with the analysis. Figure 10 represents a plot of the residuals versus the ascending predicted response values with tests of the assumption of constant variance. The plot consists of a random scatter (constant range of residuals across the graph). The residuals have about the same up and down spread across the plot, which indicate the analysis does not need any transformation.

e) Analysis for PDI:

ANOVA analysis for PDI showed that the value of F-value is 3.03 which imply that the model is significant. There is only a 4.35% chance that large F-value could occur due to noise as shown in Table 11. P-values are less than 0.0500 which indicate that the model terms are significant. In this case AB is a significant model term. Also P-values are greater than 0.100 which indicate that the model terms are not significant. If there are many insignificant model terms, the reduction of the model also in this response case will improves the model.

Table 11
ANOVA for response 2: PDI

Source	Sum of squares	df	Mean square	F-value	p-value	
Model	0.0008	3	0.0003	3.03	0.0435	Significant
A-temperature	0.0001	1	0.0001	1.31	0.2617	
B-pressure	0.0002	1	0.0002	1.71	0.1999	
AB	0.0006	1	0.0006	7.02	0.0124	
Residual	0.00029	32	0.0001			

Table 12 shows that the confidence intervals around the estimated model coefficients. While most analyses doesn't require examining these intervals, they can help sort out issues when the analysis doesn't make sense. VIFs for PDI coefficients are greater than 1 but within acceptable range and it is less than 10 so there is no large indication for multi-collinearity, and the higher the VIF the more severe the correlation of factors.

Table 12
Coefficients in terms of coded factors for PDI

Factor	Coefficient estimated	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	0.8798	1	0.0016	0.8765	0.8831	
A-temperature	0.0028	1	0.0024	-0.0022	0.0078	1.00
B-pressure	-0.0028	1	0.0021	-0.0070	0.0015	1.04
AB	0.0084	1	0.0032	0.0019	0.0149	1.04

Figure 11 shows that the residuals fall within the straight line of normal probability plot which indicate a normal distribution. Large deviations from a straight line suggest departures from normality, but in the figure there is almost no deviation from the straight line which is acceptable as the ANOVA test is insensitive to even very small deviations from normality.

Figure 12 represents a plot of the residuals versus the experimental run order of PDI observations. It checks for lurking variables that may have influenced the response during the experiment. The plot is showing random scatter. Trends indicate a time-related variable lurking in the background. Blocking and randomization provide insurance against trends ruining the analysis. In this case the PDI response does not suggest many variations.

Optimization

The optimization module searches for a combination of factor levels that simultaneously satisfy the criteria placed on each of the responses and factors. Numerical optimization uses the models to search the factor space for the best trade-offs to achieve multiple goals. Choose the desired goal for each factor and response from the menu. The possible goals are maximize, minimize, target, within range, none (for responses only) and set to an exact value (factors only.) A weight can be assigned to each goal to adjust the shape of its particular desirability function. The importance of each goal can be changed in relation to the other goals. Table 13 shows that the factors temperature and pressure goals are set as in range and their importance at 3, while responses productivity and PDI are set to maximize and their importance at 5.

Table 13
Optimization Constraints

Name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
A:temperature	Is in range	75	81	1	1	3
B:pressure	Is in range	1.5	2.2	1	1	3
Productivity	Maximize	10	16	1	1	5
PDI	Maximize	0.854	0.897	1	1	5

As shown in Table 14, after the analysis has run a list of possible solutions is generated. The criteria for choosing the best optimal solution is based on the desirability of 1.00 the closer the solution to 1.00 the better it is. Here the best solution was at temperature of (81∘C), pressure of

(2.074 Bar), productivity of (15.351 Ton/hr) and PDI of (88.6%).

Table 14
list of acceptable solutions

Number	Temperature	Pressure	Productivity	PDI	Desirability	
1	**81.000**	**2.074**	**15.351**	**0.886**	**0.818**	**Selected**
2	81.000	2.077	15.343	0.886	0.818	
3	81.000	2.070	15.360	0.886	0.818	
4	81.000	2.067	15.367	0.886	0.817	
5	81.000	2.083	15.322	0.886	0.817	
6	81.000	2.062	15.372	0.886	0.817	
7	81.000	2.08	15.305	0.886	0.817	
8	75.000	1.5000	12.763	0.888	0.605	

Table 15
Obtained results after implementation the process optimization

Assessment criteria	Implementation of optimization parameters		Improvement (%)
	Before	After	
Machines downtime (Hr./Month)	44	10	77
Productivity (Ton/Hr.)	11.58	15.35	32.5
PDI (%)	87.37	88.6	1.23

Table 16
The cost saving from improve the productivity

Assessment criteria	Quantity saved	Equivalent cost	Total sale cost
Decrease machines downtime (Hr./Month)	34x15.35 = 214.9	521.9 x 6000	3,131,400
Increase the productivity (Ton/Month)	3.77x8x20 = 603.2	603.2 x 6000	3,619,200
Total saving (LE/ Month)			6,750,600

Conclusion

The proposed paper considered a research methodology with a case based analysis and optimize the operating parameters of pelleting machine to improve the productivity. In addition to decrease the machine downtime due to jamming which, support in achieving the objectives of the organization. The proposed work developed based on literature survey by using Minitab and Design expert software method. This work adopted in an Egyptian factory for producing Poultry Feed Mill. The obtained results indicate that by changing the pelleting machines' dies from 3mm to 4mm the total stoppages due to jamming decreases from (44 to 10) Hr. per month. The experimentation is conducted by using the Minitab and Design expert software to optimize the operating parameters of the pelleting machine. The obtained results from the statistical analysis showed that the best operation parameters are at a temperature of (81°C) and pressure of (2.074 Bar) which, increase the productivity from (11.58 to 15.35) Ton/ Hr. and PDI from (87.37 to 88.6) % as shown in Table 15. Also Fig. 13 showed the graphical representation of the total improvement before and after implementation of the optimization results. These significant results indicate that the total sales increased by 6,750,600 LE/Month as shown in Table 16.

Abbreviations

PDI Pellet durability index

NSP Non-starch polysaccharides

ANOVA Analysis of variance

Declarations

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Authors’ contributions

SA: data collection and analysis, writing the manuscript project administration, NS reviewing and editing the manuscript and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate. We obtained ethical approval from the WADI poultry feed factory.

Competing interests

The authors declare that they have no competing interests.

Author details

1Department of industrial system engineering, University of October for Modern Science and Arts, Cairo, Egypt.

2Dean of faculty of engineering, University of October for Modern Science and Arts, Cairo, Egypt.

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Figures

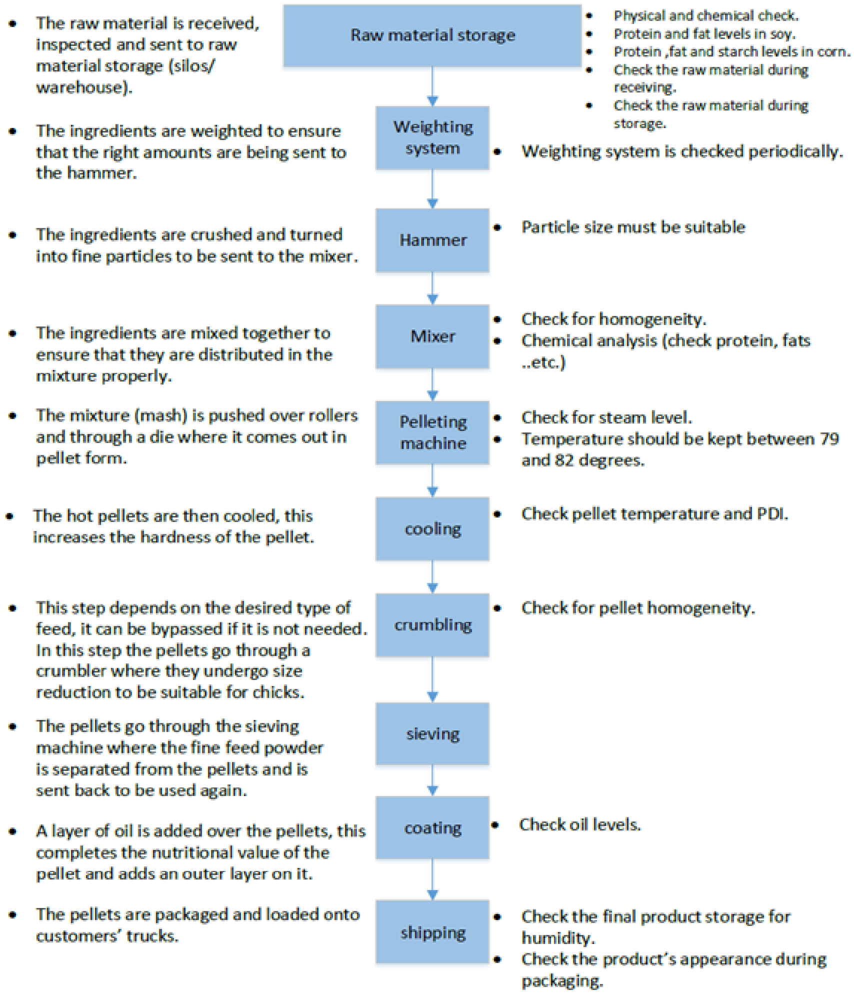

Figure 1

The different processes of feed manufacturing [4].

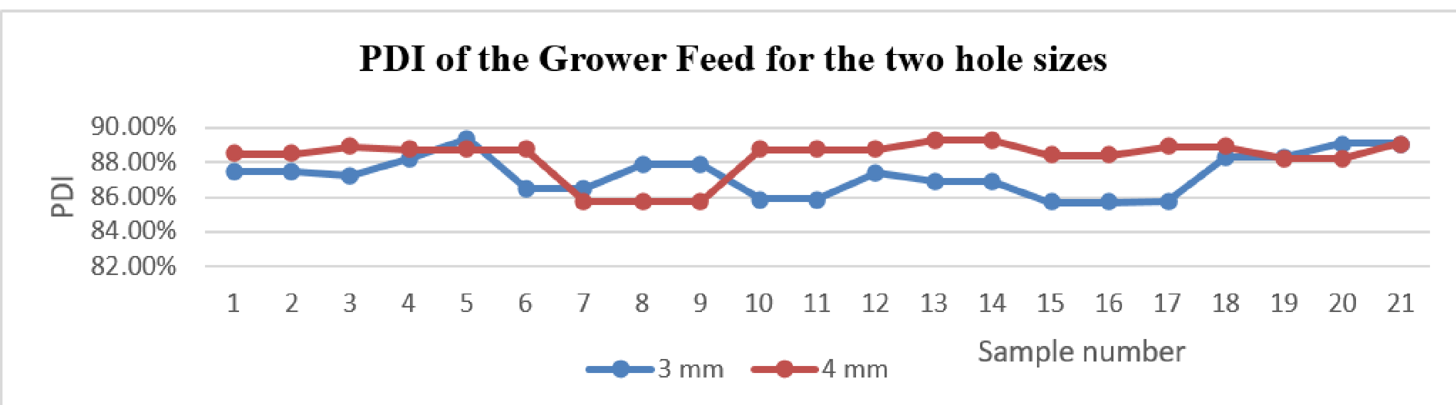

Figure 2

The PDI of the grower feed of the two die holes size

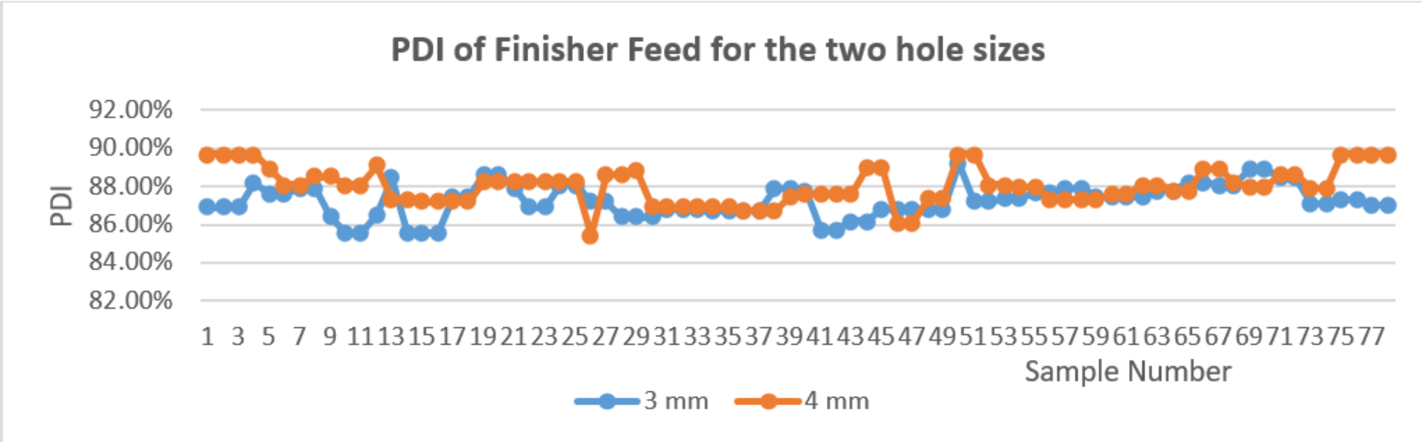

Figure 3

PDI of Finisher Feed for the two hole sizes

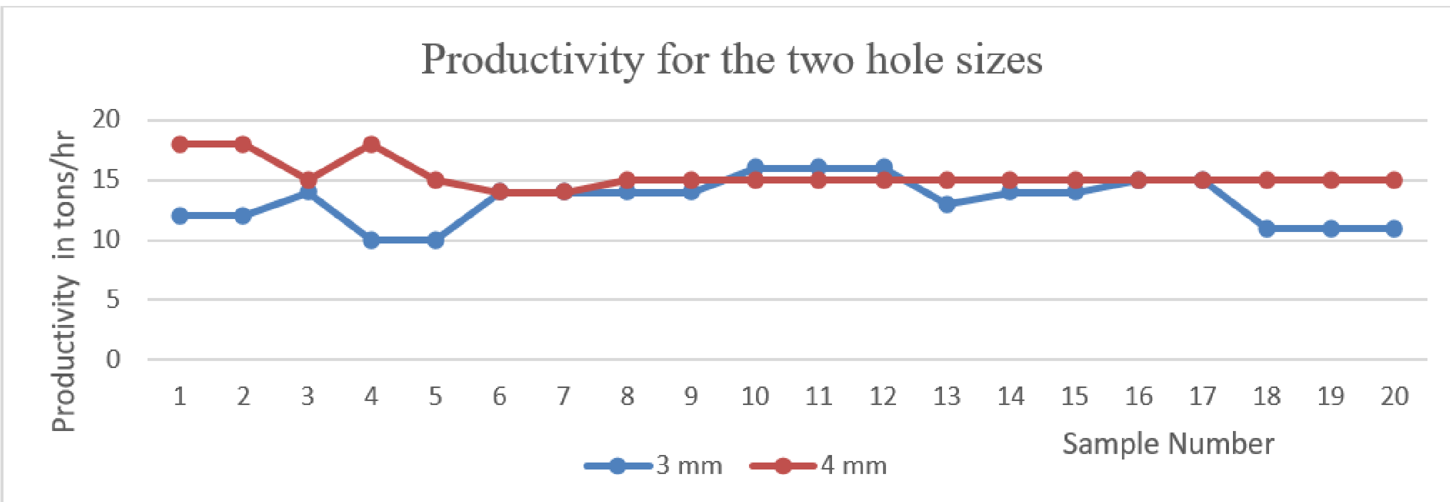

Figure 4

the productivity for the two hole sizes

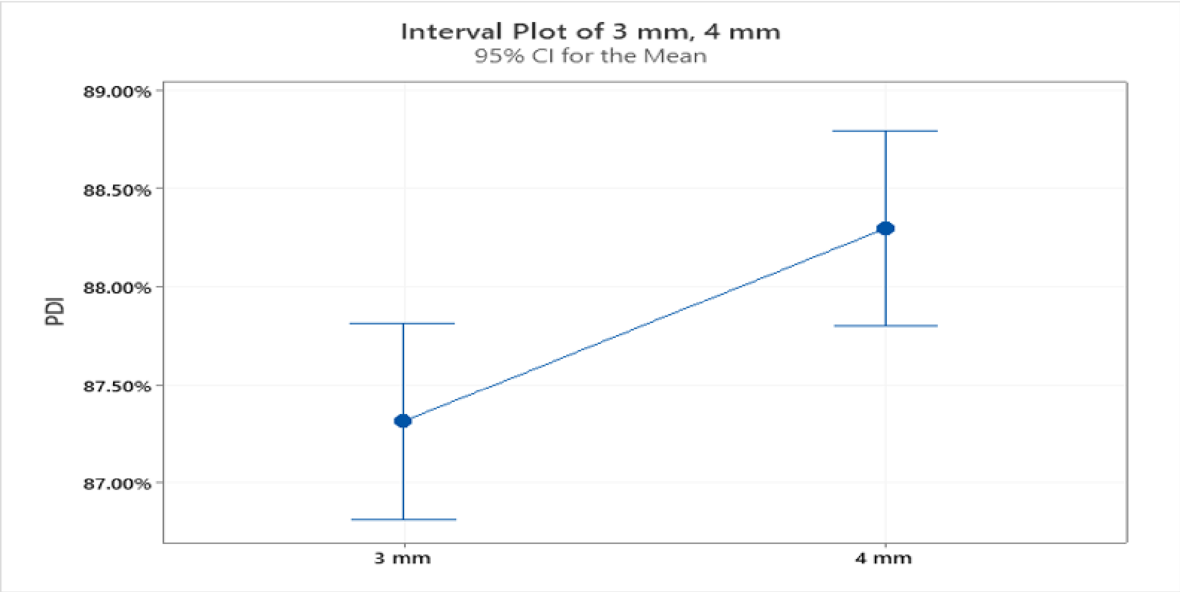

Figure 5

Interval plot for the PDI at the two die holes sizes for the grower feed

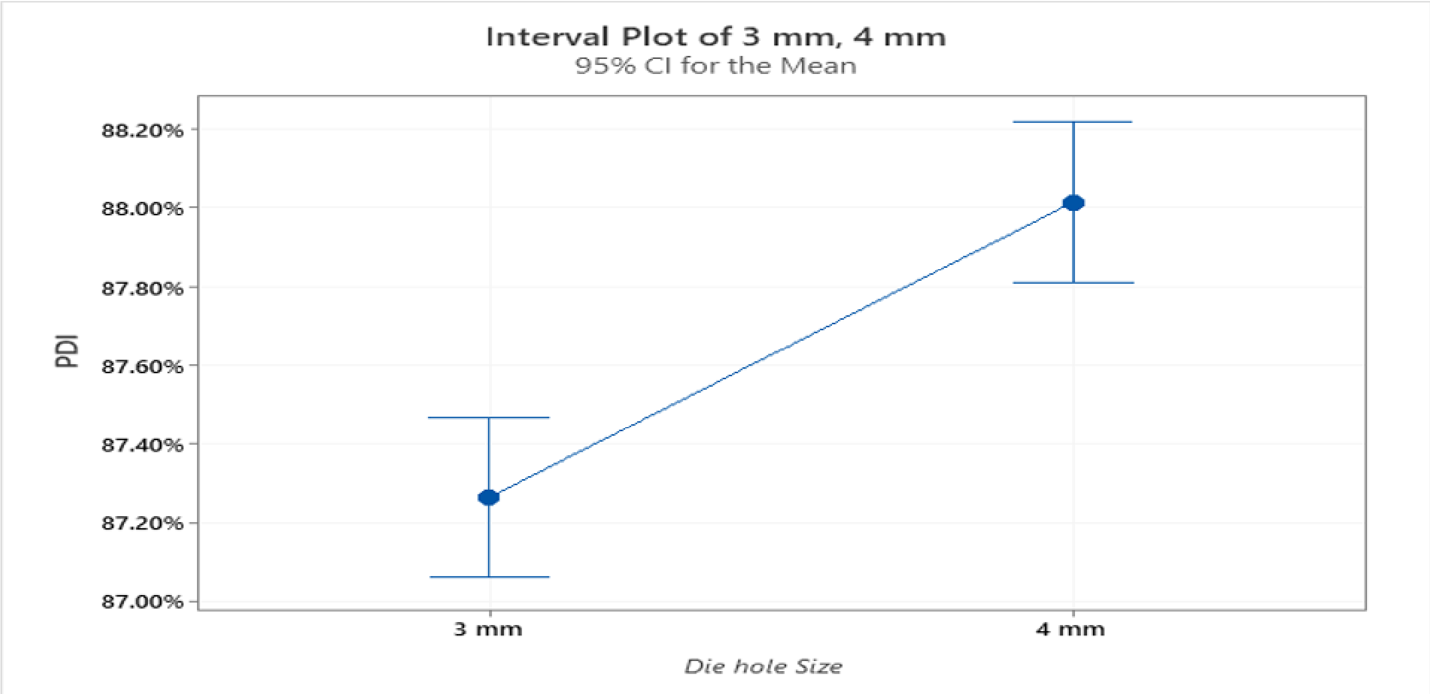

Figure 6

Interval plot for the PDI at the two die hole sizes for the finisher feed

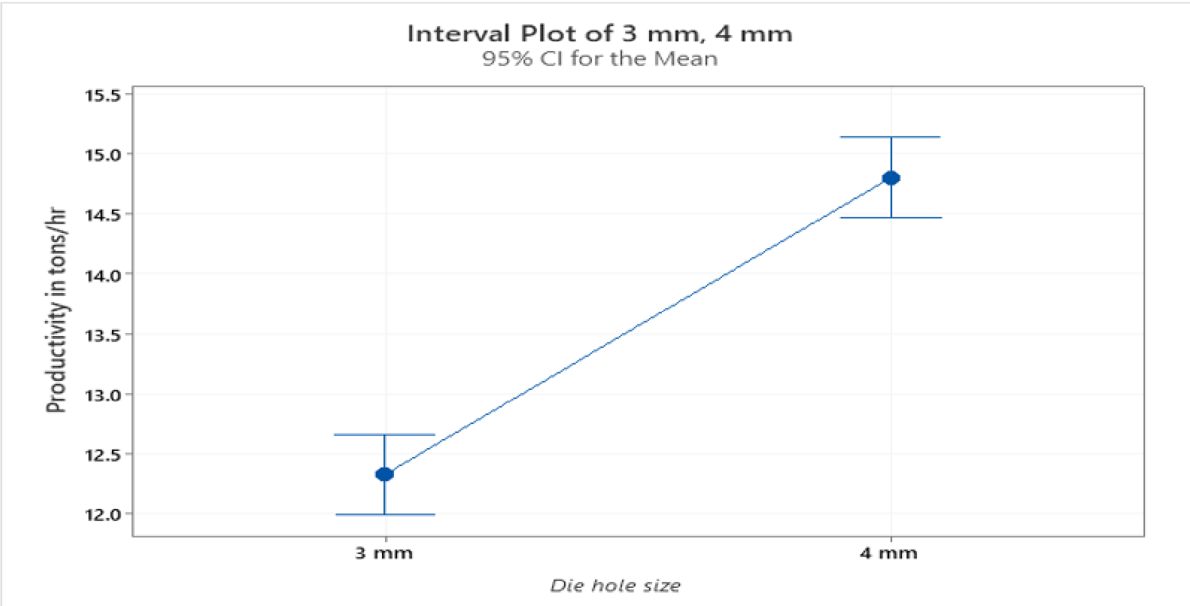

Figure 7

Productivity for the two die hole sizes

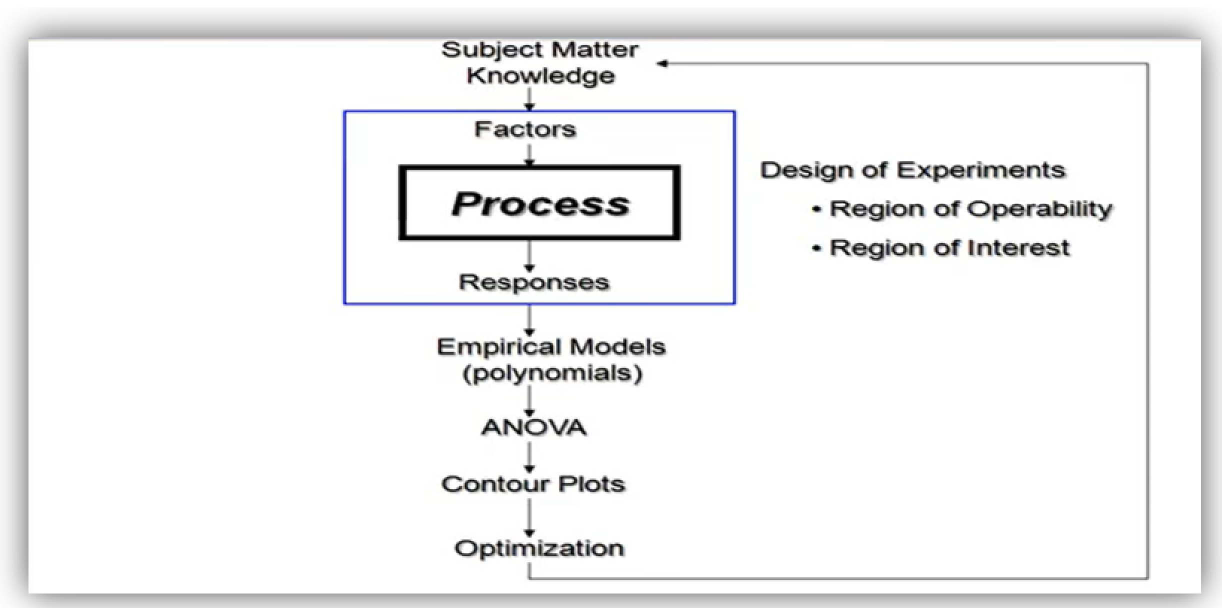

Figure 8

RSM process sequence

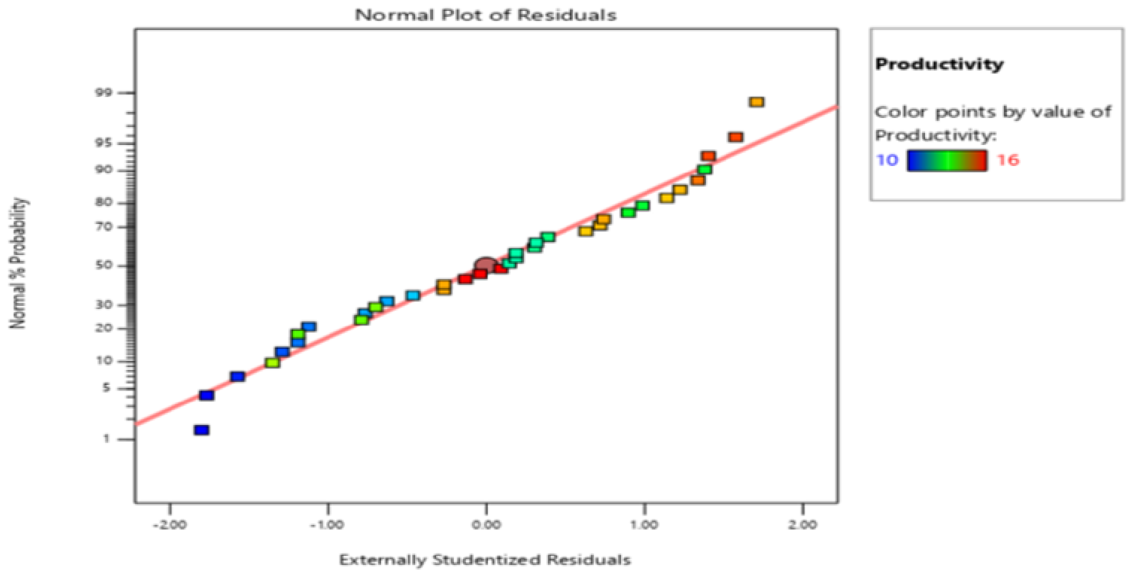

Figure 9

Normal probability plot for productivity

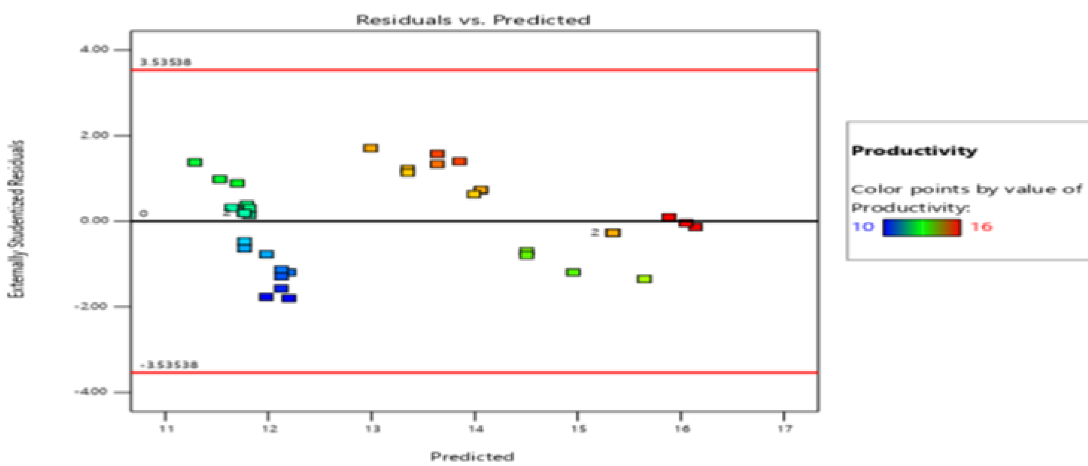

Figure 10

Residuals vs. Predicted plot for productivity

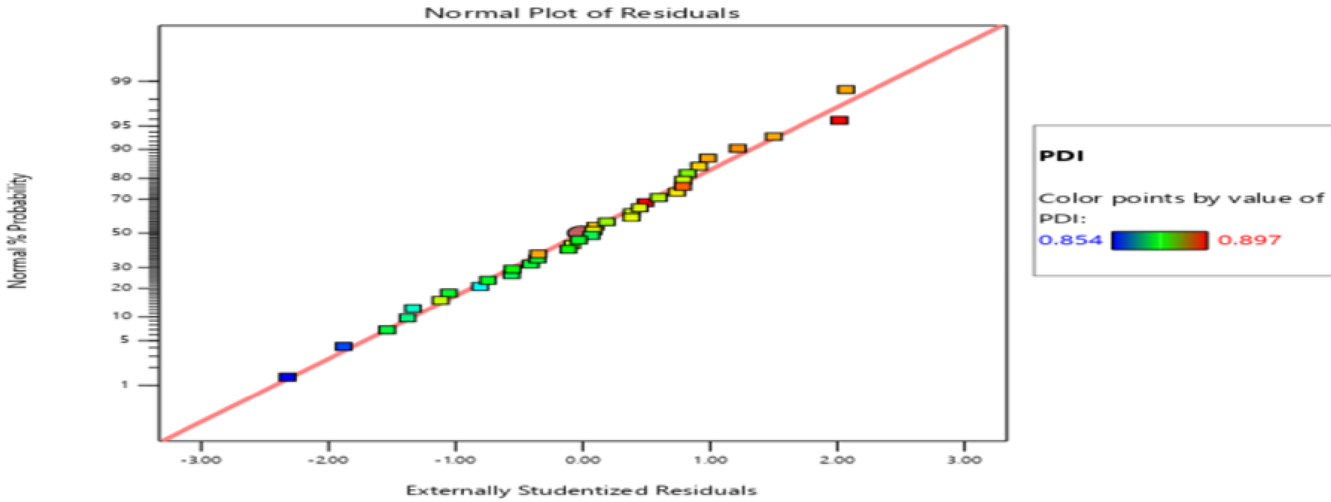

Figure 11

normal probability plot for PDI

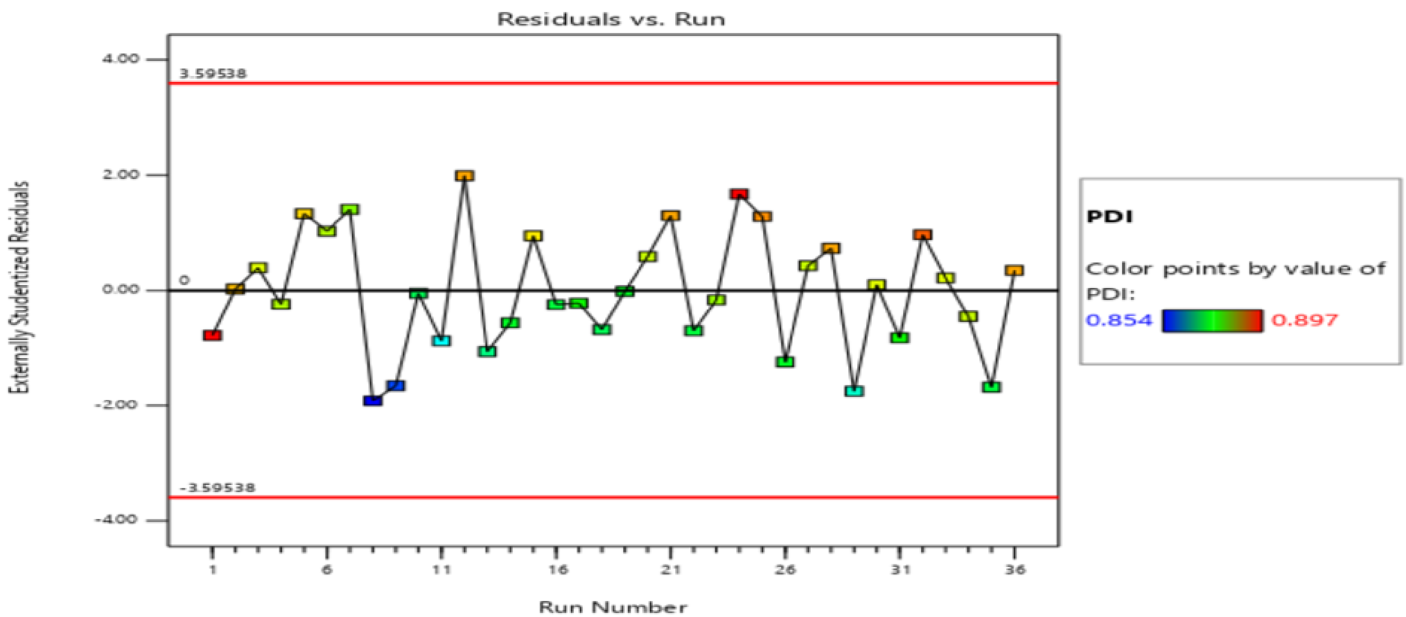

Figure 12

Residuals vs. Run plot for PDI

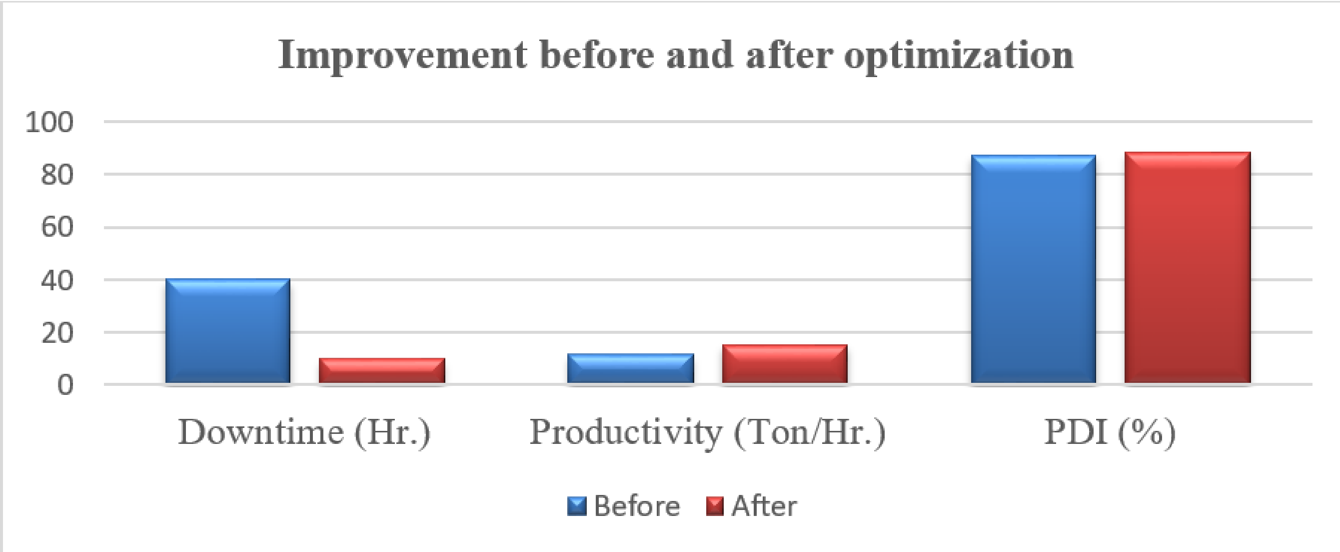

Figure 13

Improvement before and after optimization