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Effect of Holes Diameter and Speed of Die on the Performance of Machine and Feed Pellet Quality

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Abstract. The aim of this study to evaluate the effects of die holes diameter and speed of die on the performance of machine and feed pellet quality. Machine productivity ($Kg.h^{-1}$), consumed power (kW), pellet durability (%) and pellet bulk density ($g.cm^{-3}$) was studied. The study factors consisted of three diameter of die holes (3, 4, and 5 mm), and three speeds die (280, 300, and 320 rpm). Results showed with increasing of die holes diameter from 3 to 4 and to 5 mm give a significant increase in machine productivity, while consumed power, pellet durability and pellet bulk density a significant decreased. By increasing the die speed, from 280 to 300 then to 320 rpm, the machine productivity increased significantly, while consumed power, pellet durability, and pellet bulk density decreased significantly. The highest machine productivity 86.90 $Kg.h^{-1}$, less consumed power 2.34 Kw recorded with die holes diameter of 5 mm and speeds of 320 rpm, while die holes diameter 3 mm and speed of die 280 rpm recorded the highest pellet durability 91.96% and pellet bulk density 0.6383 $g.cm^{-3}$. It was concluded that the die holes diameter and die speed have a significant effect in the performance of machine and the pellet produced.

Keywords. Consumed power, Machine productivity, Pellet durability, Pellet bulk density.

1. Introduction

It has been established that 60 to 70 % of the costs associated with producing broilers come from feeding. Therefore, the productivity and profitability of broilers can be significantly impacted by feed manufacturing procedures [1]. Pelletizing is the most used heat treatment in the chicken feed manufacturing sector. Pelleting is done with the intention of condensing tiny feed particles into larger particles in order to boost growth performance and economic profit through an increase in feed consumption [2].

By the physical feed form of pellet, broiler performance is improved, because during feed intake the feed waste and energy minimizes [3]. Because pelleted feed is easier for birds to consume than mash feed, there may be a higher amount of feed consumed [4], and finally it has been observed that numerous variables affect the physical quality of pelleted, such as formulation, particle size, conditioning, general features of the mill die, and cooling or drying of pellet [5].
A change in the die features, steam treatment, or the use of additives could enhance the binding quality of the feedstock of the pellet. The durability of the final pellet should climb to 95% if the majority of the fines were treatment in the pellet [6].
According to researches, more research is required to determine the factors that influence the pellet formation process in a favorable or negative way and to develop fresh approaches for enhancing the pellet's physical characteristics [7]. Wilson [8] States that the factors of die speed, die holes diameter, and fineness of grind are thought to have a major effect on the quality of pellets. Baker [9] Demonstrated the importance of considering die speed, one of the operating parameters that is correlated with die holes diameter, die speed influences the relationship between temperature and humidity, which is correlated with pellet quality.
According to Peng et al. [10] Production efficiency in the feed industry is an important metric for evaluating the effectiveness of pellet machines, and production efficiency is significantly impacted by the stability of the pellet forming process. Evans et al. [11] Demonstrated that increasing the feed pellet machine die rotational speed enhanced output while lowering the buildup of steam-conditioned feed in front of the rollers and die of the machine. Energy and fuel are consumed by agricultural machinery throughout production, and as the need for food production rises, so does the amount of energy used in agriculture [12]. Depending on the industry and production practices, the energy consumption in agricultural production varies [13]. Concluded that as the speed of the die increased, the energy requirements decreased [14]. Fahrenholz [15] Showed that there are several characteristics of the balers die that can affect the energy consumption of the machine, including the die holes diameter.
Abbas [16] Said that what is meant by the quality of the feed pellet is its durability. He defined durability as the physical cohesion of the feed manufactured in the form of pellets with the least fine particles or broken parts of those pellet during processing or transportation. Measuring the pellet durability should be the first step to correct the production process conditions to improve the quality [17]. According to Radwan et al. [18], machine variables like die speed and diameter of die holes have a significant impact on the durability of pellet, making it one of the most important markers of feed pellet quality. Pelletizing is the process of condensing feed materials by pressing them through small holes while applying pressure, according to Abbas and Ali [19]. Bulk density is one of the physical quality attributes that are used in produced pellet quality evaluations, according to [20]. Die speed and diameter die holes of machine are just two of the several variables that impact the bulk density of pellet [18]. The aims of this research to study the effect of die holes diameter and speed of die on the machine performance and quality of pellet.

2. Materials and Methods

2.1. Conduct of Experiment

The study was carried out from December 9, 2021, to January 19, 2022, in the fields of the Department of Animal Production, College of Agricultural Engineering Sciences at the University of Baghdad.

2.2. Diets

That the experiment employed feed pellet prepared from a specific diet in accordance with the fundamental nutritional needs of broiler chickens [21]. Its constituent parts were bought from the neighbourhood market; they included several feed items in the amounts in Table 1.

Table 1. Diet Composition and Amounts Analysis.

Materials	Percentage (%)
Maize	40.64
Wheat	24
Soybean meal-hulls 48%	24
Protein concentrate	5
Oil	4.5
Di calcium phosphate	0.4
Free lime	1.1
Methionine	0.13
Lysine	0.13
Salt	0.1

(1) The soybean meal from Argentina origin was used, the crude protein content is 48 %, and the energy content is 2440 Kcal.kg^{-1}. (2) Protein concentrate from a Dutch company called Brocon is used; it has a crude protein content of 40 %, 2107 Calories.kg^{-1} Protein represented energy, 5 % Crude fat, 2.20 % Crude fiber, 5 % Calcium, 2.65 % Phosphorous, 3.85% Lysine, 3.70 % Methionine, 4.12 % Methionine + Cysteine, 0.42 % tryptophan, and 1.70% Threonine, 0.42 % tryptophan, and 1.70% Threonine.

2.3. Mixing of Feed

Feed materials were mixed using a vertical feed mixer, which is made in Skiold Denmark, electric motor (3 Phase), 5.5 kW, equipped with two feeding openings, one of which is connected to the mill and the other to add oil and other supplements. The mixing process takes 12 minutes according to [22].

2.4. Manufacturing of Feed Pellet

Grains have been ground and then mixed in a mechanical mixer to form pellet. The device was a modern pellet machine Chinese-made. The machine's specifications are as follows: the model 125 has an output of 80–100 Kg.h^{-1}, 220 volts of voltage, 4 kW engine capacity, and dimensions of 10 * 27 * 78 cm (length * width * height). It also weighs 70 kg, figure (1).

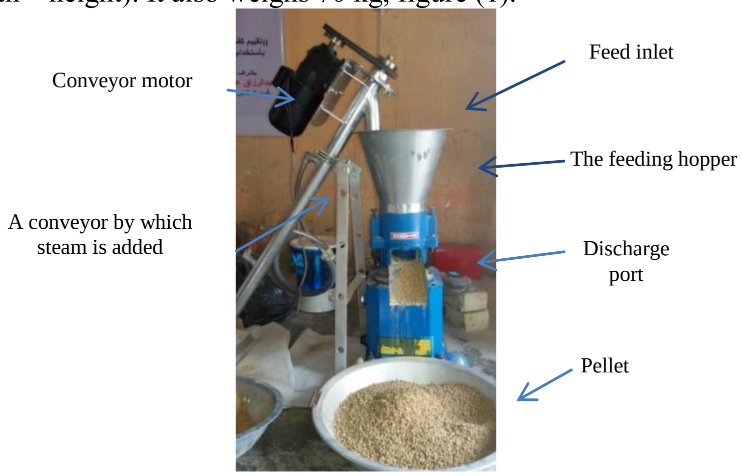

Figure 1. The pellet machine used in the experiment.

For about 20 to 30 seconds, the feed was steam-conditioned at 60 degrees Celsius. At the conditioner's outlet, the temperature of the air conditioner was recorded. The experiment was conducted with an air temperature of between 0 and 5 degrees Celsius. The pellet were collected as soon as after unloaded from the machine and spread out on the ground for 10 minutes to cool using a fan-powered air stream, until the temperature of the pellet approached that of the surrounding air, as per reference [23]. To measure the temperature a digital infrared laser thermometer was used, randomly selected subsamples were tested. Testing the pellet after cooling was a followed procedure of the Standard [24].

2.5. Statistical Analysis

In this study a complete randomized design (CRD) has been used to evaluate the effects of three die holes diameter (3, 4, and 5 mm) and three die speeds (280, 300, and 320 rpm) in the pellet machine with three replications, resulting in a total of 27 experimental units. The statistical analysis was conducted by SAS program [25] to perform the least significant difference test (LSD) at 0.05 of probability level.

2.6. Parameters Measured

2.6.1. Machine productivity ($kg.h^{-1}$)

An electric digital scale it can be charged reads from 1g – 40 kg, was used, and a timer to confirm the measurement. In order to collect the pellet for each experimental unit for weight cognition, a set time was followed (3 minute). Used to measure productivity the following equation mentioned by Ali et al. [26]:

$$P = W/T$$

Where:
P is Productivity ($kg.h^{-1}$), W is Weight of Sample (kg), T is pelleting Time (h).

2.6.2. Consumed Power (kW)

An AC digital multi-function meter was used to measure the power used by the machine engine during each experimental unit. Figure (2) shows the digital screen that displays the voltage, current, and power consumed. The readings were obtained by taking a mobile phone photo of the meter screen after the machine was turned on and the production rate stabilized.

Figure 2. AC digital multi-function meter.

2.6.3. Pellet Durability (%)

To determine the feed pellets' durability a double action feed pellet durability measuring device was used. First, a 100 g sample of pellets was weighed using a digital scale, then the pellets were placed in the device's cylinder and tightened closed. The device then rotated at the designated speed for ten minutes; at the end, the sample was released and weighed once more to calculate the durability according to [27] using the following equation:

Pellet Durability (%) = [Remained weight after testing (g) / Initial sample weight (g)] ×100

2.6.4. Pellet Bulk Density (g.cm $^{-3}$)

Was determined Feed pellet bulk density. A known volume (V) cylinder is weighed while empty and cleans (w_1). The cylinder is set up horizontally and feed pellets are poured into it from a set height until the desired amount of pellets is inside. A piece of smooth wood is used to level the pellets' surface with the cylinder's surface. Pellets are added to the cylinder and it is weighed (w_2), Using the technique described [28] by the following equation:

$$M = W2 - W_1$$

$$Bd = M / V$$

Where:
Bd is Bulk density (g.cm $^{-3}$), M is Pellets weight (g), V is Cylinder Volume (cm^3).

3. Results and Discussion

3.1. Machine Productivity (kg.h^{-1})

Effect of diameter of die holes and die speed on the pellet machine productivity (kg.h^{-1}) was shown in Table 2, with increase in diameter of die holes from 3 to 4 and 5 mm, it caused a significant increase on machine productivity from 79.08 to 82.16 and to 84.72 kg.h^{-1}. The reason is because the decrease in the amount of pellet coming out of the die holes per unit time with the smaller diameter of the holes. This result is consistent with [29,30], who showed that the productivity of the pellet machine decreases as the diameter of the produced material decreases. It is also obvious from Table 2 that the die speed a significant effect in the machine productivity, with increase in the speed of die from 280 to 300 and 320 rpm, caused a significant increase in the machine productivity from 79.89 to 81.64 and to 84.43 kg.h^{-1}, the reason for this is due to the increase in the amount of pellets coming out of the die holes per unit time with the increase in the speed of the die, thus increasing the machine productivity. This result supports the findings of [11,18], which showed that a rise in machine productivity was correlated with an increase in die speed.

Table 2. Effect the diameter of die holes and die speed on Machine productivity (kg.h^{-1}).

Die holes diameter (mm)	Die speed (rpm) 280	300	320	Mean effect of die holes diameter (mm)
3	76.67 f	78.85 e	81.73 cd	79.08 c
4	80.05 de	81.78 cd	84.65 b	82.16 b
5	82.96 bc	84.29 b	86.90 a	84.72 a
Mean effect of die speed	79.89 c	81.64 b	84.43 a	
LSD at 0.05				
1.99 :interaction 0.83 die speed: 0.83die holes diameter:				

* LSD: Least significant difference at probability level of 5%.
* The different letters within the same column indicate that there are significant differences between the treatments at probability level of 5%.

The interaction effect of die holes diameter and die speed had a significant effect on the machine productivity is clear that from Table 2. The highest pellet machine productivity was 86.90 kg.h^{-1} with a diameter of die holes was 5 mm and die speed 320 rpm, whereas the least pellet machine productivity was 76.67 kg.h^{-1} with a diameter of die holes was 3 mm and die speed of 280 rpm.

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3.2. Consumed Power (kW)

Effect the diameter of die holes and die speed on the consumed power (kW) was shown in Table 3, with increase in the diameter of die holes from 3 to 4 and to 5 mm, it caused a significant decrease in the consumed power from 3.99 to 3.55 and to 2.90 kW. The reason for this is due to the effect of the consumed power on the increase in the die holes diameter as a result of the decrease in the load applied to the engine, which reduces the force required to form the granules. These results are consistent with the results obtained by [31,32].

Also obvious from Table 3 that die speed as a significant effect in the consumed power, with increase in the die speed from 280 to 300 then 320 rpm, it caused a significant decrease in the consumed power from 4.13 to 3.31 and to 3.01 kW, the reason for this is due to the die affects how long feed stays in the machine during formation, which leads to lower feed accumulation in front of the die and rollers and higher output. This explains why, when die speed increases, more pellets are released from the die holes in a given amount of time, reducing the strain on the engine. This result is consistent with what [11], explained and what [18], who found that the basic energy requirements for forming pellets depend on productivity and are affected by some different operating factors such as the rotation die speed which leads to a decrease in energy requirements with increasing die speed.

Table 3. Effect the diameter of die holes and die speed on consumed power (kW).

Die holes diameter (mm)	**Die speed (rpm)**			**Mean effect of die holes diameter (mm)**
	280	**300**	**320**	
3	4.45 a	3.91 b	3.63 bc	3.99 a
4	4.31 a	3.28 cd	3.06 de	3.55 b
5	3.62 bc	2.75 e	2.34 f	2.90 c
Mean effect of die speed	4.13 a	3.31 b	3. 01 c	
LSD at 0.05				
0.39 :interaction 0.07 die speed: 0.07die holes diameter:				

The interaction between the diameter of die holes and the die speed had a significant effect on the consumed power is noted that from Table 3. The lowest consumed power was recorded 2.34 kW with the die holes diameter of 5 mm and die speed 320 rpm, whereas the highest consumed power reached 4.45 with the diameter of die holes 3 mm the die speed 280 rpm.

3.3. Pellet Durability (%)

Effect the diameter of die holes and the die speed on the pellet durability (%) were shown in Table 4, the increase the diameter of die holes from 3 to 4 and to 5 mm, it caused a significant decrease in the pellet durability from 90.16 to 88.88 and to 87.51 %. The due is attributed to the length of time the pellet is under pressure inside the machine is reduced due to the increase in the pellet die holes diameter. As a result, the pellet exit is accelerated, weakening the cohesion between its components and decreasing the pellet's endurance. These results are consistent with the results of the study by [33] who mentioned these decrease are due to the fact that the small pellet diameter has greater bonding forces than the large pellet diameter. This can be explained by the fact that the machine generates a lot of heat due to the narrow diameter of the pores, which causes a higher degree of starch gelatinization in the pellet. Therefore, it is not surprising that the large die holes diameter leads to decreased durability. This relationship can be part of the explanation for the improvement in the quality of the smaller pellet diameter and is consistent with the results of [34,35].

Also that the increase in the die speed from 280 to 300 and to 320 rpm, it caused a significant decrease in the pellet durability from 90.39 to 88.70 and to 87.46% in Table 4 indicates. The due is attributed to the change in the duration of the pellet during forming and its exposure to pressure and heat with the change in the die speed of the machine, in addition to the fact that speed is one of the main factors that affect the process of forming and the quality of the feed pellet. This results are consistent with the results obtained by [9], as well as the results of [36], who also explained the expected occurrence of a weakness in the physical quality of the feed pellet with the increase in the production rate due to the reduction in the retention time of the feed material inside the channels of the pressure and forming die molds, which negatively affects the rate of pressure and gelatinization of starch.

Table 4. Effect the diameter of die holes and die speed on pellet durability (%).

Die holes diameter (mm)	Die speed (rpm)			Mean effect of die holes diameter (mm)
	280	300	320	
3	91.96 a	89.94 bc	88.57 cd	90.16 a
4	90.51 b	88.51 d	87.63 d	88.88 b
5	88.71 cd	87.64 d	86.20 e	87.51 c
Mean effect of die speed	90.39 a	88.70 b	87.46 c	

LSD at 0.05
1.41 :interaction 0.43 die speed: 0.43die holes diameter:

Interaction between the diameter of die holes and die speed on the pellet durability it was obvious that there was a significant effect in Table 4. The highest pellet durability was recorded at 91.96 % with the die holes diameter of 3 mm and die speed 280 rpm, whereas the lowest pellet durability of reached 86.20 % with the diameter of die holes of 5 mm and die speed 320 rpm.

3.4. Pellet Bulk Density (g.cm $^{-3}$)

Effect the diameter of die holes and die speed on the pellet bulk density (g.cm^{-3}) were shown in Table 5, with increasing the diameter of die holes from 3 to 4 and to 5 mm it caused a significant decrease in the pellet bulk density from 0.6346 to 0.6314 and to 0.6288 g.cm^{-3}, This is because, during the forming process, the pellet surface area is reduced due to the effects of heat and moisture. This lowers the cohesion force between the particles that emerge from the die holes diameter as pellet, which lowers the pellet bulk density. This result is in agreement with that found by [37,38].

Also Table 5 shows the increasing of die speed from 280 to 300 and to 320 rpm it caused a significant decrease in the pellet bulk density from 0.6352 to 0.6317 and to 0.6279 g.cm^{-3}. The due for this to a decrease in the pressure applied to the components of the feed, accompanied by an increase in the die speed, which leads to a decrease in its bulk density. These results are consistent with what was mentioned by [18].

Table 5. Effect the diameter of die holes and die speed on pellet bulk density (g.cm^{-3}).

Die holes diameter (mm)	Die speed (rpm)			Mean effect of die holes diameter (mm)
	280	300	320	
3	0.6383 a	0.6343 abc	0.6312 bcd	0.6346 a
4	0.6356 ab	0.6316 bcd	0.6271 de	0.6314 b
5	0.6378 bcd	0.6292 cde	0.6255 e	0.6288 c
Mean effect of die speed	0.6352 a	0.6317 b	0.6279 c	

LSD at 0.05
0.0054 :interaction 0.0022 die speed: 0.0022die holes diameter:

Also the interaction between effect the diameter of die holes and die speed had a significant effect on pellet bulk density in Table 5 shows. The highest pellet bulk density was recorded at 0.6383 g.cm^{-3} with die holes diameter of 3 mm and die speed of 280 rpm, whereas the lowest pellet bulk density reached 0.6255 g.cm^{-3} with the diameter of die holes of 5 mm and die speed of 320 rpm.

Conclusions

The results of the study showed that increasing the diameter of die holes from 3 to 4 and to 5 mm it caused a significant increase in machine productivity, while consumed power, pellet durability and pellet bulk density a significant decreased. With increasing the die speeds from 280 to 300 then to 320 rpm led to a significant increase in the machine productivity, while consumed power, pellet durability and pellet bulk density a significant decreased. Pellet die holes diameter of 5 mm and speeds of 320 rpm recorded the highest machine productivity 86.90 kg.h^{-1}, less consumed power 2.34 kW. While die holes diameter of 3 mm and die speed of 280 rpm recorded the highest pellet durability 91.96 % and pellet bulk density 0.6383 g.cm^{-3}. It was concluded that the die holes diameter and die speed of the pellet machine have a significant effect on the performance of machine and the pellets produced.

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