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ORIGINAL PAPER

Development of a processing unit for the production of extruded poultry feed

Yasser Kamal Osman [a, ✉], Samir Hafez Mohamed [a], Abdelrafea Ahmed Elshafie [b], Ibrahem Mahmoud Ibrahem Abo-elsoud [a]

[a] Department of Agricultural Machinery and Power Engineering, Faculty of Agricultural Engineering, Al-Azhar University, Cairo, Egypt.

[b] Animal Production Department, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt.

[a] Post Graduate Student, Department of Agricultural Machinery and Power Engineering, Faculty of Agricultural Engineering, Al-Azhar University, Cairo, Egypt.

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ABSTRACT

This study addresses a major challenge in Egypt's poultry industry, where small- and medium-scale farmers struggle to meet market demands due to a lack of efficient feed processing machines. To overcome this issue, a single integrated machine was developed to combine milling, mixing, and pelleting into one horizontal unit. The machine features a feeding hopper with a 3 hp three-phase electric motor, which powers all three functions via pulleys and V-belts. The milling unit is equipped with rotary knives for grinding ingredients, the mixing chamber utilizes levers to ensure uniform blending, and the pelleting section incorporates an auger and die plate to shape the feed into pellets. This study evaluated the performance of the poultry feed pelleting machine using a 3×3×3 factorial design to examine the effects of liquid amounts (15, 17, and 20 L/100 kg), auger speeds (1.2, 1.8, and 2.4 m/sec), and die diameters (4, 6, and 8 mm) on pellet quality and machine efficiency. Results indicated that machine efficiency averaged 81.06% (ranging from 70% to 91%), with the optimal performance achieved using higher liquid levels, smaller die sizes, and lower auger speeds. Productivity varied between 67.44 to 97.99 kg/h, increasing with greater liquid amounts, while specific energy consumption decreased with more liquid but increased with higher auger speeds and larger dies. With a production cost of 20,000 Egyptian pounds and the advantage of local manufacturability, this system offers an economical solution for small- and medium-scale farms in developing countries, enhancing feed production efficiency and shelf life.

1. Introduction

The global population is expected to reach 9.2 billion by 2050, significantly increasing the demand for animal-based food (CAPMAS Egypt, 2024). This demographic shift is particularly evident in Egypt, where rapid population growth drives a higher demand for poultry meat, creating an urgent need for cost-effective feed production systems. As Seidavi et al. (2022) highlighted, feed constitutes the largest share of production costs in livestock farming, making the optimization of feed processing technologies not just beneficial but essential for the industry's sustainability. Although the poultry feed industry relies heavily on high-quality pelletized feed, current production methods face significant challenges related to efficiency and cost. Dosoky et al. (2021) documented the substantial advantages of pelleted feed, particularly its ability to enhance broiler performance by reducing wastage and improving nutrient absorption. Despite these benefits, the high cost of pelleting technology remains a major barrier, especially for small- and medium-scale poultry farmers, who struggle with both the expense and the limited availability of suitable feed processing equipment (Aljebory and Naji, 2021).

✉ Corresponding authors.
E-mail addresses: yasser.kamal@azhar.edu.eg (Yasser Kamal Osman)

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Technological innovation in feed processing has led to significant advancements in key areas such as ingredient mixing uniformity and pellet durability. Brennan et al. (2008) examined various mixing techniques, emphasizing how mechanical mixers ensure homogeneous ingredient distribution, an essential prerequisite for high-quality feed. Expanding on this foundation, Muramatsu et al. (2015) identified pellet durability as a critical factor in efficient feed handling and transportation, noting that more robust pellets reduce fines and maintain nutritional integrity throughout the supply chain. Further refining this understanding, Abdollahi et al. (2018) conducted a comprehensive study on how factors such as moisture content, ingredient composition, and processing parameters influence pellet quality, concluding that precise control over these variables is essential for producing premium feed products. Recent research has increasingly focused on developing economically viable pelleting technologies that maintain performance standards while reducing costs. In a promising study, Abo-Habaga et al. (2017) evaluated the performance and energy efficiency of a locally designed feed pelleting unit, revealing its potential to substantially reduce production costs without compromising processing efficiency. Complementing these findings, Fouad et al. (2015) assessed a feed processing system that not only achieved significantly improved pellet production rates but also proved economically feasible for implementation by smaller poultry operations.

Against this backdrop, the present research aims to develop and rigorously evaluate an integrated poultry feed extrusion processing unit capable of efficiently producing high-quality pelleted feed. This study will assess the unit's performance through a detailed analysis of key metrics, including production throughput, the physical characteristics of the resulting pellets, and energy consumption patterns during operation. Additionally, we will examine how processing variables, specifically liquid content, auger speed, and die diameter, influence the extruded feed products' quality and nutritional profile. By identifying optimal processing parameters, this research seeks to enhance the final feed's nutritional value, digestibility, and palatability. Furthermore, a comprehensive economic analysis will compare the cost-effectiveness and investment viability of the developed unit against conventional feed processing methods. Based on these findings, we will provide evidence-based recommendations for system refinement and explore potential applications in commercial-scale poultry feed manufacturing, with the potential to transform how small- and medium-scale operations approach feed production in resource-constrained environments.

2. Materials and methods

This study aims to develop and manufacture a thermal extrusion machine for producing nutritionally enhanced livestock feeds, specifically designed for Egyptian poultry farmers. The machine will be built using locally sourced materials and expertise to ensure accessibility and ease of use.

2.1. Materials

2.1.1. Time and Place of the Study

This experimental study was conducted at a private poultry feed facility in Gamasa City, Damietta Governorate, Egypt, from September 2023 to March 2024. The research utilized a custom-designed thermal extrusion system capable of milling, mixing, and pelletizing feed ingredients.

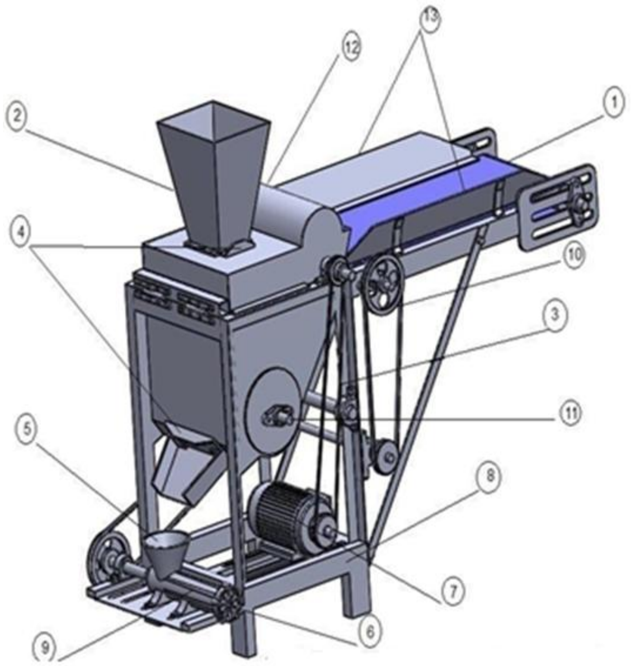
2.1.2. Raw Materials

The experimental poultry feed was formulated with corn (40.64%), wheat (24%), soybean meal (24%), fish meal (5%), oil (4.5%), and minerals and amino acids (1.86%), to provide 19.7% crude protein and 3206 kcal/kg of energy, following the guidelines of the National Research Council (NRC, 1994) guidelines.

2.1.3. Machine Components Description and Specifications

A feed processing machine was designed and constructed using locally sourced materials to reduce costs while meeting performance requirements. Initially modeled in SolidWorks, the final product incorporates a thermal extrusion system to enhance feed digestibility and nutritional value. The construction process involved precise cutting, welding, and finishing utilizing lathes, welding equipment, drilling machines, and bench tools (Fig. 1 and 2).

The machine's foundation is a welded L-shaped iron beam chassis (0.75m length × 0.38m width × 0.17m height) equipped with four 12cm universal wheels for mobility across various surfaces. The fully assembled machine measures 1.42m long, 1.05m wide, and 1.8m tall. The feeding and milling unit is a critical component that processes incoming feed material. It incorporates a 900mm × 350mm inlet feeding belt with dual edges that guide materials as they enter the mill, providing improved control and consistency while optimizing the milling unit's overall performance. The feeding unit features a dual-compartment hopper positioned above a moving belt. This design enables proper proportioning of coarse feed ingredients before they undergo softening in the milling unit and subsequent mixing with softer ingredients. Each hopper compartment has a sliding gate to regulate feed flow rate, while cross-sections at the belt's beginning prevent material spillage during the feeding process. The unit's core component is an interior cutter drum designed for precise feed milling. It works in conjunction with four high-performance milling blades (250mm × 60mm) mounted on a disc with a diameter of 320mm that operate at 1260 rpm, generating a linear velocity of 6.6 m/s. This configuration ensures efficient material processing and maintains proper flow through the apparatus. The raw material feed hoppers were constructed from 2 mm thick steel, shaped into trapezoidal plates, and welded together for strength. Each 500 mm high hopper featured an upper opening of 800x450 mm, a lower opening of 150x150 mm with two outlets, and a 60-degree tilt for efficient material flow. A smaller 250 mm high hopper on the mixing unit had openings of 300x250 mm (upper) and 80x80 mm (lower). Sliding gates enabled precise feed control, reducing waste. With a 40 kg capacity, these hoppers allowed for continuous operation, improving efficiency in both small-scale and commercial settings. The mixing unit, essential in feed manufacturing, ensures thorough blending of raw materials in a dedicated chamber. Equipped with four 260 mm x 40 mm mixing levers that are mounted on 180 mm diameter fixing discs within a mixing chamber with a diameter of 650 mm, rotating clockwise at 267 rpm (1.4 m/s), it insuring uniformity. The 30 kg capacity chamber includes a cover to prevent segregation, particularly of lightweight components. Connected to a steam unit via three steam pipes with a diameter of 50 mm, it ensures even steam distribution. The unit features an automatic gate mechanism for discharge after mixing. The process includes dry blending (45s), liquid addition (60-90s), and wet mixing (25s), optimizing feed consistency before thermal pelleting (Fig. 3).



(1) Feeding belt. (2) Feeding hooper. (3) Feeding belt. (4) Gates. (5) Feeding extruder. (6) Die. (7) Main electric motor. (8) Main frame. (9) Extruder screw. (10) Pulley. (11) Mixing shaft. (12) Cutting knives. (13) Edges.

Fig. 1. Visualization for the proposed machine.

Front view Side view

Fig. 2. A photo of the developed machine.

Fig. 3. Mixing unit and steam conditioner

The additional heating system adjacent to the extrusion chamber raises the temperature for thermal extrusion using electric-powered heating elements. These 2 mm diameter metal pipes transfer hot vapor from a 10 L stainless steel steam conditioner (30-110°C thermal control). Strategically positioned around the chamber, they ensure uniform heating with precise temperature control. Feed undergoes steam conditioning at 60°C for 20-30 seconds, with monitoring at the conditioner outlet. A 1500 W heating element provides further heating as feed moves through the barrel. The process includes steam conditioning at 80-82°C for 120 seconds, expansion for 5 seconds at 110°C, and final pellet pressing.

The thermal pelletizing process takes place within the extrusion chamber, a durable cylindrical structure made from heat-resistant materials to withstand extreme conditions. A specially designed extrusion screw facilitates the movement, compression, and uniform mixing of raw materials. Pellets are formed by mechanical force as the material is pushed through a die opening. After extrusion, the feed passes through a die and cutter assembly, which shapes and cuts the pellets according to specific size and form requirements. Multiple dies and cutters can be used to produce pellets of varying dimensions.

The pelletizing unit consists of a screw conveyor and a die plate. The 320 mm long, 100 mm diameter screw conveyor, with a 40 mm pitch, operates at 263.18 rpm (1.3 m/s) to efficiently transfer extruded material. The detachable die, made from an 8 mm thick mild steel plate, withstands high pressure and features perforations for pellet formation. The die plate, 100 mm in outer diameter and 10 mm thick, supports three interchangeable dies: 4 mm (57 holes), 6 mm (48 holes), and 8 mm (33 holes). These variations allow customization of pellet size to meet specific feed requirements. A poultry feed pelletizing machine, Model 125, was used in this study. The machine was purchased from Shandong Jie Siming Precision Machinery Equipment Co., Ltd., and features a productivity range of 80–100 kg/h. Its compact design includes dimensions of 370 × 130 × 200 mm, and it weighs 8 kg. Jannasch and Samson (2003) highlighted the importance of modern equipment for pilot projects. After extrusion and shaping, the feed products pass through a cooling system that rapidly lowers their temperature to ambient levels, preserving nutritional integrity and quality. The system features a 1.2-meter-long, 0.25 cm wide belt with horizontal beams spaced 10 cm apart, operating at 0.23 m/s. A fan (Model FP17251 EX-S1-S, AC220/240V, 50/60 Hz, 0.32 A, 38 W) mounted on top of the pulley enhances cooling efficiency (Fig. 4).

The machine features a sophisticated control panel that allows operators to monitor and adjust various parameters during extrusion. It includes switches for operating all components and an indicator lamp for tracking voltage and other critical variables, ensuring precise control and process optimization. The system is powered by a 3-horsepower (2.2 kW) electric motor operating at 220/380V, drawing 8.7A, with a speed of 1400 rpm. An inverter regulates its function. Power transmission is achieved via a series of pulleys and five V-belts. The motor's 70 mm pulley drives an 80 mm pulley on the milling blades shaft, which then transfers power to a 200 mm pulley on the mixing levers shaft. From there, power moves to a 190 mm pulley on the feeding belt shaft and finally to a 190 mm pulley on the pelletizing unit shaft. This setup ensuring synchronized operation for seamless feed processing (Fig. 5).

Fig. 4. Horizontal pellet cooler.

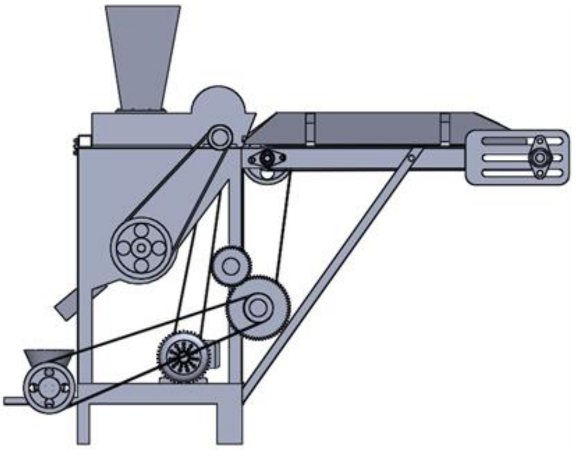


Fig. 5. The power transmission system.

2.2. Methods

2.2.1. Principle of Operation

The process began with precise weighing and loading of raw materials into the divided hopper atop the feeding belt, which transported them through various processing stages. First, ingredients are passed through trapezoidal hoppers into the milling unit for size reduction and added in descending order of quantity. The mixture was then conveyed to the mixing unit for uniform blending, monitored through a viewing window. After mixing, heat and pressure were applied in the thermal unit to initiate extrusion, transforming raw materials into a cohesive mass. The material then entered the shaping unit for pellet formation before being transferred to the cooling unit for solidification.

An electric motor powered the system, ensuring smooth operation across all stages. Practical studies were conducted to optimize key operational parameters, enhancing pellet quality and machine efficiency. These experiments provided insights into the relationship between operating conditions and pellet characteristics, refining the thermal extrusion process for improved poultry feed production.

2.2.2. Experimental Design

The experimental methodology followed a fully randomized design to ensure unbiased and reliable results. Moisture content analysis was conducted using the oven-drying technique at 105°C for 48 hours, adhering to ASAE Standard S269.4 (2003). Shaft rotational speed was measured with a handheld speedometer for precise readings, while sample mass was determined using an electrical digital balance for accuracy. Additionally, process duration was monitored with a standard stopwatch calibrated to 0.01-second accuracy. This rigorous approach emphasized precision and scientific rigor in evaluating experimental parameters and performance.

2.2.3. Studied Factors

The study considered both fixed and variable factors affecting the pelletizing machine's performance.

2.2.3.1. Relatively Fixed Factors

1) Power: A 2.2 kW (3 hp) electric motor.
2) Temperature: The optimal temperature for poultry feed production was set at 70°C, enhancing pellet quality and digestibility (Abdollahi *et al.*, 2013).

2.2.3.2. Tested Variable Factors

Three key factors were analyzed:

1) Liquid hydration level (L): Feed hydration levels of 15 (L_1), 17 (L_2), and 20 liters (L_3) of water per 100 kg of raw material were tested to evaluate their effect on pellet quality.
2) Auger speed (A): The study examined auger speeds of 1.2 m/s (A_1), 1.8 m/s (A_2), and 2.4 m/s (A_3), corresponding to rotational speeds of 60 rpm, 90 rpm, and 120 rpm, respectively. These variations were tested to evaluate their impact on processing efficiency and product quality.
3) Die hole diameter (D): Die hole diameters of 4 mm (D_1), 6 mm (D_2), and 8 mm (D_3) were tested to evaluate their impact on pellet characteristics.

2.2.4. Measurements

The experiments were replicated three times to ensure accuracy and reliability. Key parameters were thoroughly analyzed to identify the most effective settings for the pelletizing machine. These procedures followed ASAE (2003) guidelines, which emphasize evaluating the pellet after the cooling process.

2.2.5. Mixing Efficiency (%)

Mixing efficiency quantifies the uniformity of the blended material relative to the total input mass. It is calculated using Equation (1), which measures how effectively the mixing process homogenizes the ingredients.

$$\text{Mixing Efficiency (\%)} = \frac{\text{Mass of homogeneously mixed material}}{\text{Total mass input}} \times 100 \quad \dots [1]$$

2.2.6. Machine Efficiency (%)

The operational efficiency of the machine (ε) is calculated using the formula:

$$\varepsilon = \frac{M_o}{M_i} \times 100 \quad \dots [2]$$

where: M_O = Mass of the pellets obtained after processing.
M_i = Mass of the feed material introduced into the machine.

2.2.7. Machine Productivity **(MP, kg/h)**

Machine productivity is determined by measuring the quantity of pellets collected per hour. Before sample collection, the machine was operated for 10 minutes to stabilize conditions. The productivity is calculated using the formula:

$$M_P = \frac{M_o}{t} \quad \dots [3]$$

where: M_P = Machine productivity (kg/h)
Mo = Mass of total output pelletized material (kg)
t = Duration of the test (h)

2.2.8. Pelletizing Efficiency (η_e, %)

Pelletizing efficiency measures the proportion of actual feed pellets collected at the primary outlet compared to the total feed input within a specific timeframe. After each experiment, the remaining feed mixture in the pelleting chamber was manually extracted and weighed. Efficiency was calculated using the formula:

$$\eta_e = \frac{M_o}{M_i} \times 100 \quad \dots [4]$$

where: η_e = Pelletizing efficiency (%)
Mo = Mass of total output pelletized material (kg)
Mi = Mass of total raw material input (kg)

2.2.9. Total Power Consumption **(P C, kW)**

The total power consumption of the machine was estimated to be using the power factor of the inductive cycle drive motor, as Li et al. (2015) reported**.** Since direct measurements were not taken, the calculation relied on the following formula:

$$P_c = \frac{\sqrt{3} \times I \times V \times P_f}{1000} \quad \dots [5]$$

where: P C = Total power consumption (kW)
I = Line current (A)
V = Line voltage (V)
P_f = Power factor (0.817)

2.2.10. Specific Energy Requirements **(SER, kW/Mg.h)**

The specific energy requirements were calculated by measuring pellet production under stable conditions to determine the mass flow rate. Using the observed total power consumption (PC) and machine productivity (M_P), the SER was computed using the formula:

$$SE_R = \frac{P_c}{M_P} \quad \ldots [6]$$

where: SE_R is in $kW \cdot Mg^{-1} \cdot h^{-1}$, PC is in kW, and MP is in $Mg \cdot h^{-1}$.

2.2.11. Statistical Analysis

A 3×3×3 factorial design was used to evaluate the effects of water addition (15, 17, 20 L/100 kg), auger speed (1.2, 1.8, 2.4 m/s), and die hole diameter (4, 6, 8 mm). The experiment followed a completely randomized design (CRD) with three replications. Data analysis used the LSD test ($\alpha = 0.05$) in SAS (2009).

3. Results and discussions

3.1. Machine Performance

3.1.1. Effect of Hydrating Liquid Amount (L/100 kg) on Mean Mixing Efficiency After 3 Minutes

Increasing the hydrating liquid from 15 to 20 L/100 kg improved mixing efficiency, averaging 78%, 82%, and 85% for 15, 17, and 20 L/100 kg, respectively (Fig. 6). The standard deviation (S.D.) was 8, and the coefficient of variation (C.V.) was 9.76%, indicating moderate variability. Higher moisture content enhanced blending and homogenization by acting as a binding agent, ensuring uniform material distribution. The linear equation ($L = 1.3684\ M_{eff} + 57.947$, $R^2 = 0.9616$) demonstrated a strong correlation (96.16% of variability explained), confirming the role of hydrating liquid in optimizing pelletization efficiency.

3.1.2. Factors Affecting Mean Machine Efficiency (%)

The analysis of Fig. 7 illustrates various factors influence machine efficiency during pelletization. Increasing the hydrating liquid volume correlates with higher efficiency, with 15 L/100 kg yielding approximately 78% efficiency while 20 L/100 kg achieves around 85%, suggesting that greater liquid content reduces processing time. Auger speed exhibits an inverse relationship with efficiency, as higher speeds lead to decreased performance. Specifically, an auger speed of 1.2 m/s results in about 82% efficiency, whereas 2.4 m/s reduces efficiency to 73%, likely due to increased wear, shorter material residence time, or compromised pellet quality. Die diameter also significantly impacts efficiency, with smaller 4 mm dies achieving approximately 85% efficiency compared to 80% for 8 mm dies, indicating that finer control and improved compaction enhance performance. Overall, machine efficiency across all experimental conditions averages 80.37% with a standard deviation of 5.43% and a coefficient of variation of 6.76%, indicating moderate performance variability.

The regression analysis examining machine efficiency identified three significant predictors: hydrating liquid volume (positive effect), auger speeds (negative effect), and die diameters (negative effect). The derived regression equation is ε, (%) = 68.5 + 1.72L - 6.79A - 0.852D, with all predictors showing statistical significance ($p < 0.05$). The model's validity is confirmed by ANOVA ($p < 0.05$), and its explanatory power is substantial, accounting for 84.6% of the variance in machine efficiency (R-squared = 84.6%).

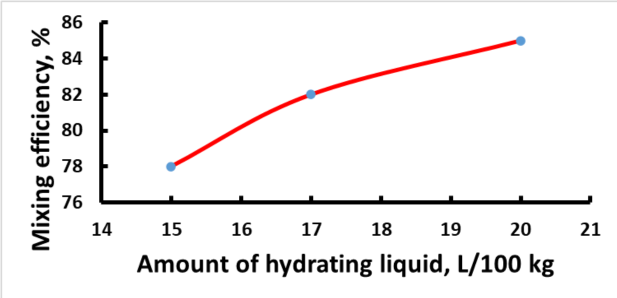


Fig. 6. Effect of hydrating liquid volume on mean mixing efficiency after 3 minutes.

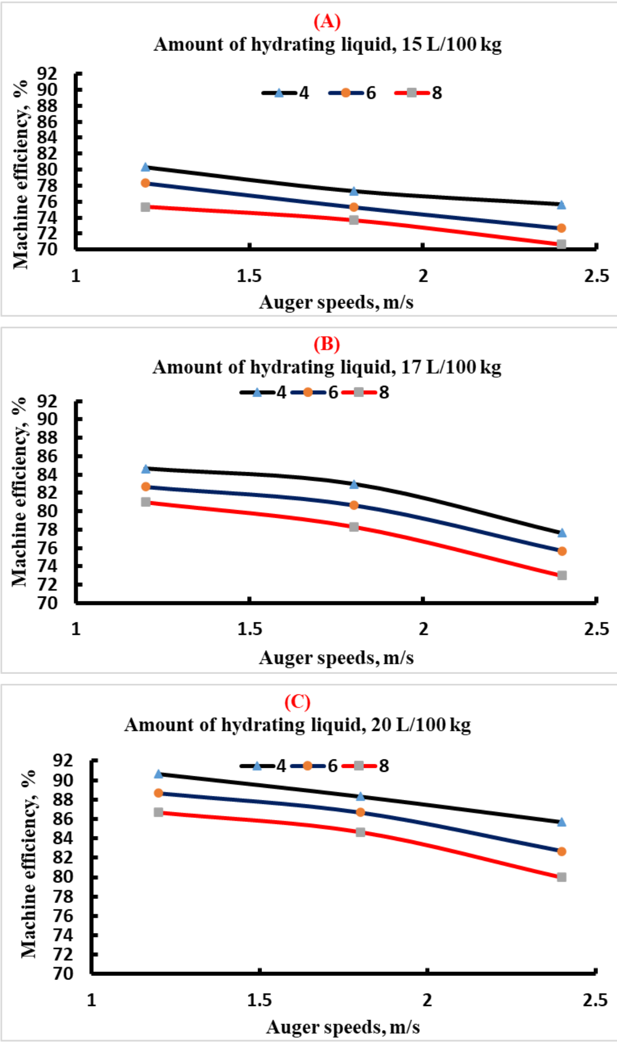


Fig. 7. Factors affecting mean machine efficiency (%) at different hydrating liquid volumes: (A) 15 L/100 kg), (B) 17 L/100 kg), and (C) 20 L/100 kg)].

3.1.3. Factors Affecting Mean Machine Productivity, kg/h

The experiment presented in Fig. 8 investigated factors influencing machine productivity (kg/hr), namely hydrating liquid volume (L/100 kg), auger speeds (m/s), and die diameters (mm). A strong positive correlation was observed between hydrating liquid volume and productivity. Increasing the liquid volume from 15 to 20 L/100 kg raised average productivity from 76.97 to 84.95 kg/hr. This improvement is partly attributed to the lubricating effect of the added liquid, which reduces friction and enhances material flow, and partly to the increase in the overall weight of the materials being processed due to water addition. Auger speed also had a significant impact on productivity. For instance, at 15 L/100 kg with an 8 mm die, increasing the auger speed from 1.2 to 2.4 m/s boosted productivity from 77.4 to 81.33 kg/hr by accelerating the material feed rate. Die diameter had a less pronounced but still noticeable effect; larger die openings generally led to higher productivity, especially at greater liquid volumes and auger speeds. For example, at 20 L/100 kg and a 2.4 m/s auger speed, increasing the die diameter from 4 to 8 mm raised productivity from 93.59 to 97.7 kg/h by accommodating a larger volume of material and reducing flow resistance. Each combination of conditions was tested in triplicate to ensure result reliability.

The regression analysis examined the impact of three factors, namely, hydrating liquid volume (L), auger speeds (A), and die diameters (D), on machine productivity. The resulting model is expressed as MP (kg/h) = 24.3 + 2.22L + 6.11A + 1.25D, where all three predictors have positive coefficients, indicating their contribution to increased productivity. Among them, auger speed has the strongest positive effect (6.11). Statistical analysis confirmed the significance of all predictors, with p-values less than 0.05. Additionally, ANOVA results validated the model's fit ($p< 0.05$), and the model explains 74.3% of the variance in productivity (R^2 = 74.3%).

3.1.4. Factors Affecting Mean Pelletizing Efficiency (%)

The experiment examined the effects of hydrating liquid volume, auger speed, and die diameter on pelletizing efficiency. Results in Fig. 9 showed that hydrating liquid had a moderate positive effect, with efficiency increasing from 91.00–94.13% at 15 L/100 kg to 95.27–96.27% at 20 L/100 kg. Auger speed had a minor impact, with efficiency increasing slightly at higher speeds, particularly with smaller die diameters and higher liquid volumes. Die diameter had a more noticeable influence, with larger diameters generally improving efficiency, especially at higher auger speeds and liquid volumes.

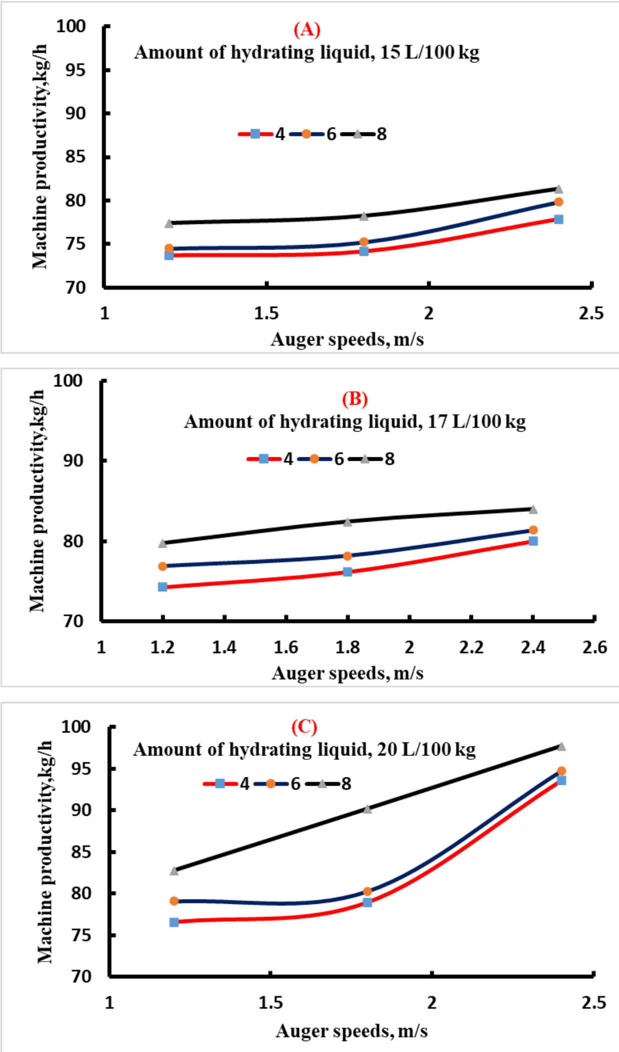


Fig. 8. Factors affecting the mean machine productivity, kg/h at different amounts of hydrating liquid [(A, 15 L/100 kg), (B, 17 L/100 kg), and (C, 20 L/100 kg)].

However, this finding may seem contradictory to earlier results from the productivity analysis, which suggested that a larger die diameter could sometimes reduce the efficiency of pellet formation. This discrepancy can be explained by the fact that efficiency (the proportion of material successfully converted into pellets) and productivity (the total amount of material produced) measure different aspects of the process. While larger die diameters can increase productivity by allowing more material to flow through, they may also negatively impact the efficiency if conditions such as low hydration or low auger speed do not allow for adequate compaction and pellet formation.

In contrast, larger die diameters may improve efficiency and productivity under optimized conditions (e.g., higher hydration volumes and auger speeds). The experiment showed low variability (standard deviation = 1.68, CV = 1.78%), indicating consistent results. These findings suggest that hydrating liquid enhances binding and lubrication, auger speed affects material compaction, and die diameter influences material flow and pellet formation. The interaction among these factors is crucial for optimizing both pelletizing efficiency and productivity.

The regression analysis examining the relationship between pelletizing efficiency and key factors hydrating liquid volume, auger speed, and die diameter produced the equation η_e (%) = 85.9 + 0.215L + 1.57A + 0.330D. The positive coefficients indicate that increasing any of these factors enhances pelletizing efficiency. Statistical significance is confirmed, with all predictors having p-values below 0.05. ANOVA results further validate the model's reliability, showing a high F-value and a significant p-value (<0.05), confirming a strong fit between the model and the data.

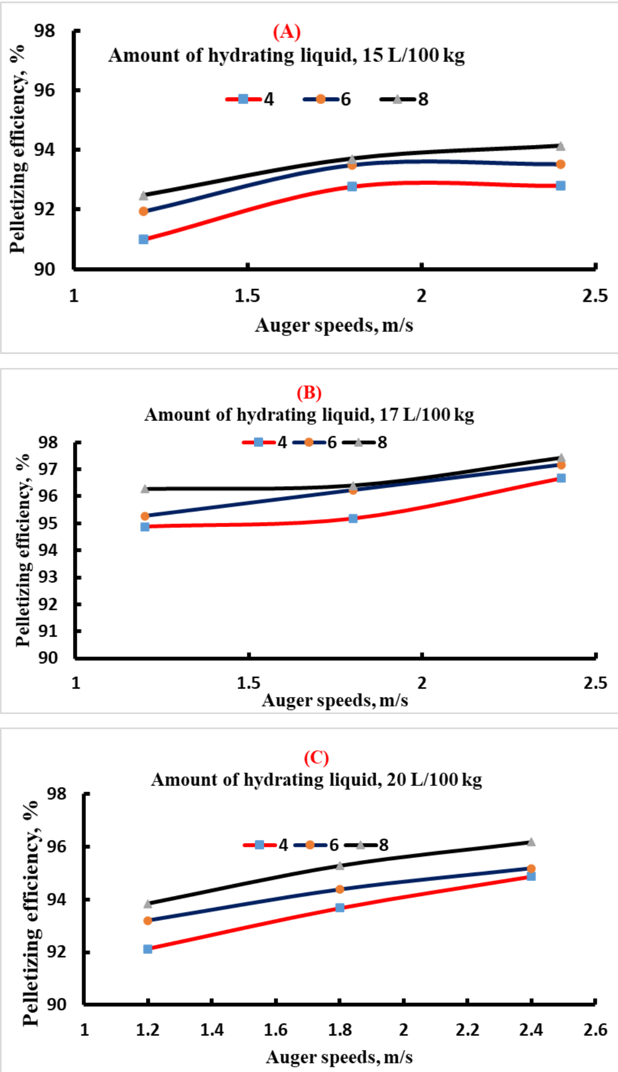


Fig. 9. Factors affecting mean pelletizing efficiency, % at different amounts of hydrating liquid [A, 15 L/100 kg), (B, 17 L/100 kg), and (C, 20 L/100 kg)].

3.1.5. Factors Affecting Mean Specific Energy Requirements (kW/Mg.h)

The analysis of specific energy requirements (kW/Mg.h) reveals that hydrating liquid, auger speed, and die diameter significantly influence energy consumption (Fig. 10). Increasing the hydrating liquid from 15 to 20 L/100 kg generally reduces specific energy requirements, as seen in a decrease from 23.81 to 20.54 kW/Mg.h at an auger speed of 1.2 m/s and a die diameter of 4 mm. This reduction in energy is primarily attributed to the lubricating effect of the added hydrating liquid, which reduces friction and enhances material flow, leading to lower energy consumption. This aligns with previous findings on productivity, where an increase in hydrating liquid was shown to improve material flow and reduce energy demands.

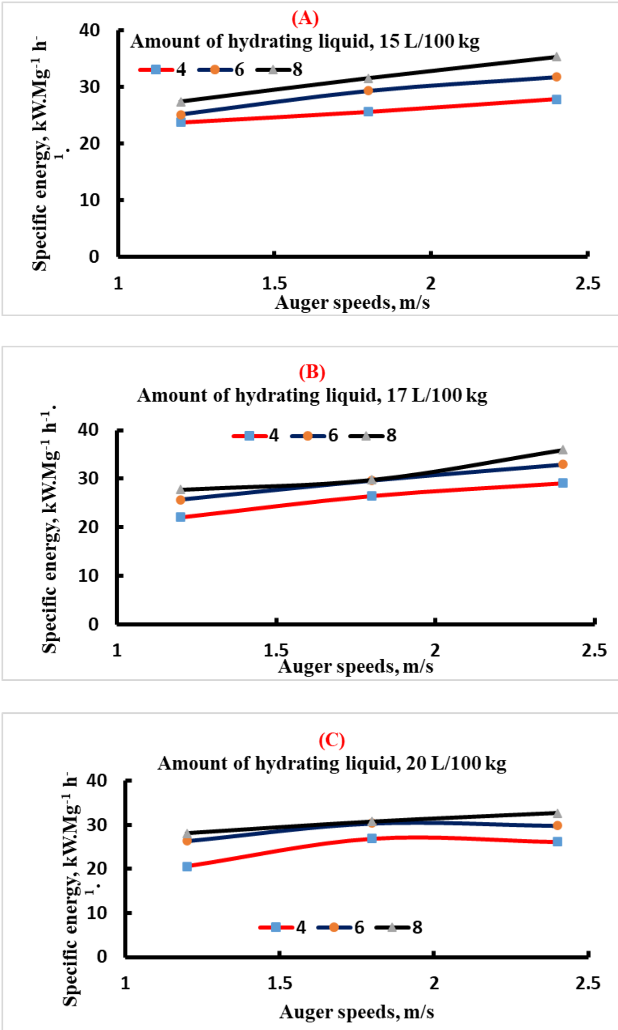


Fig. 10. Factors affecting the mean specific energy requirements, kW.Mg-1 h-1 at different amounts of hydrating liquid [A, 15 L/100 kg), (B, 17 L/100 kg), and (C, 20 L/100 kg)].

Conversely, higher auger speeds tend to increase energy demands, with specific energy rising from 25.19 to 31.82 kW/Mg.h at 15 L/100 kg and a die diameter of 6 mm as speed increases from 1.2 to 2.4 m/s. The increase in energy consumption at higher speeds is due to the higher shear forces and friction within the system, requiring more energy to process the material. This is consistent with previous observations that higher speeds improve material flow but demand more energy.

Similarly, larger die diameters result in higher energy consumption, increasing from 25.66 to 31.62 kW/Mg.h at 15 L/100 kg and an auger speed of 1.8 m/s as the die diameter grows from 4 to 8 mm. This is because larger dies allow for a larger volume of material to pass through, leading to increased resistance and thus higher energy use. This finding aligns with earlier results indicating that larger die diameters improve productivity but may increase energy consumption in certain conditions.

The coefficient of variation (C.V.) of 12.71% indicates some variability across conditions. These variations stem from processing factors such as material flow, friction, shearing forces, and compression. Understanding these interactions enables manufacturers to optimize processing conditions, minimizing energy use while maintaining efficiency and product quality.

The regression analysis examining the relationship between specific energy requirements and key factors hydrating liquid amount, auger speed, and die diameter produced the equation SER ($kW.Mg^{-1}h^{-1}$) = 13.6 - 0.158L + 5.07A + 1.42D. The negative coefficient for hydrating liquid indicates that higher liquid amounts reduce specific energy requirements, while the positive coefficients for auger speed and die diameter suggest that increasing these factors raises energy consumption. Statistical significance is confirmed, with all predictors having p-values below 0.05. ANOVA results further validate the model's reliability, showing a high F-value and a significant p-value (<0.05). The model explains 89.6% of the variance in specific energy requirements ($R^2 = 89.6\%$), with an adjusted R^2 of 89.2%, indicating an excellent fit to the data.

4. Conclusions and recommendations

This study developed an affordable, electrically powered feed pellet machine using locally sourced materials to support poultry breeders in Egypt. The machine utilized thermal extrusion technology to enhance feed quality, digestibility, and nutritional value.

Experiments assessed the effects of hydrating liquid levels, auger speeds, and die diameters on feed properties and machine performance. Results indicated that increasing hydration improved pellet bulk density and reduced energy consumption, while higher auger speeds increased pellet density but also raised energy requirements. The machine achieved an efficiency of 80.37% and a productivity rate of 97.99 kg/h.

Recommendations

To further optimize performance and efficiency, future research should focus on:

1) Refining process parameters to enhance efficiency and productivity.
2) Exploring alternative raw materials to enhance pellet quality and sustainability.
3) Scaling up production to facilitate broader industry adoption.
4) Integrating automation to improve consistency and reduce manual labor.
5) Collaborating with industry stakeholders to enhance machine development and commercialization.

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تطوير وحدة لإنتاج أعلاف الدواجن المبثوقة

ياسر كمال عثمان [١]، سمير حافظ محمد [١]، عبد الرفيع أحمد الشافعي [٢]، إبراهيم محمود أبو السعود [٣]

[١] قسم هندسة القوى والآلات الزراعية، كلية الهندسة الزراعية، جامعة الأزهر، القاهرة، الجيزة، مصر.
[٢] قسم الإنتاج الحيواني، كلية الزراعة، جامعة الأزهر، القاهرة، مصر.
[٣] طالب دراسات عليا، قسم هندسة القوى والآلات الزراعية، كلية الهندسة الزراعية، جامعة الأزهر، القاهرة، الجيزة، مصر.

الملخص العربي

تعالج هذه الدراسة مشكلة كبيرة في صناعة الدواجن، حيث يعاني صغار المربين من صعوبة تلبية طلبات السوق بسبب نقص آلات تصنيع الأعلاف الفعالة. لحل هذه المشكلة، تم تطوير آلة واحدة تجمع عمليات الطحن والخلط والتحبيب في وحدة أفقية متكاملة. تزود الآلة بقادوس تغذية وتعمل بمحرك كهربائي بقدرة ٣ حصان، يشغل أجزاء الالة بواسطة طارات وسيور. تحتوي وحدة الطحن على سكاكين دوارة لطحن المكونات، بينما تستخدم في غرفة الخلط أذرع لمزج المواد بشكل متساوٍ، ويشتمل قسم التحبيب على بريمة وقالب لتشكيل العلف إلى حبيبات. ولقد اختبرت هذه الدراسة أداء الآلة باستخدام تصميم تجريبي ثلاثي العوامل (٣×٣×٣) لدراسة تأثير كميات السائل (١٥، ١٧، ٢٠ لتر/١٠٠ كجم)، وسرعات البريمة (١,٢، ١,٨، ٢,٤ م/ثانية)، وأقطار القالب (٤، ٦، ٨ ملم) على جودة الحبيبات وكفاءة الآلة.

أظهرت النتائج أن متوسط كفاءة الآلة ٨١,٠٦٪ (تتراوح بين ٧٠-٩١٪)، مع تحقيق أفضل أداء باستخدام المزيد من السائل، والقوالب الأصغر، وسرعات البريمة الأبطأ. بينما تراوحت الإنتاجية بين ٦٧,٤٤-٩٧,٩٩ كجم/ساعة، وتحسنت مع زيادة كميات السائل. وقد انخفضت متطلبات الطاقة النوعية مع زيادة السائل لكنها ارتفعت مع زيادة سرعة البريمة وحجم القالب. وكانت تكلفة تصنيع هذه الألة وتشغيلها ٢٠,٠٠٠ جنيه مصري بمواد محلية مع إمكانية التصنيع محلياً على نطاق واسع، توفر هذه الآلة حلاً اقتصادياً للمزارع الصغيرة والمتوسطة في الدول النامية لتحسين كفاءة إنتاج الأعلاف وإطالة فترة صلاحيتها.