DESIGN ANALYSIS OF AN AQUACULTURAL FEED PELLET MACHINE FOR RURAL DWELLERS

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ABSTRACT

Nigerian aquacultural sector faces a critical technological constraint, inability of locally manufactured feed pellet machines to produce pellets larger than 9mm in diameter, a size insufficient for optimal feeding of bloodstock hybrid fish species. This study addresses this hole through the modified, constructed and performance evaluated custom-built feed pellet machine capable of producing 10mm to 12mm diameter for rural dwellers. It utilizes a flat-die pelleting principle powered by a 5.5 HP petrol engine, chosen for operational reliability in regions with unstable electricity, such as Borno State. The production employed locally sourced mild steel for the frame and stainless steel for the critical wear components (die and auger). It's confirmed that the machine accomplished a production rate of 81.43 kg/h with an efficiency of 89.06%. The pellets produced exhibited satisfactory water stability for over 10 minutes, meeting the requirements for floated feeding through the appropriate ingredients. This work positively demonstrates a viable, cost-effective (₦154,500) for the rural dwellers, and locally maintainable solution that enhances the specialized feed production capacity within the Nigerian aquacultural value chain.

Keywords: Pellet Machine, Aquaculture Sector, Feed Size, Fish Growth, Rural Dwellers

1 INTRODUCTION

Aquaculture is a rapidly growing sector worldwide, driven by the demand for sustainable protein sources. While fish, dairy animals, constitutes approximately greater percentage of protein intake [1, 2] but domestic production in Nigeria meets only 30-40% of the demand [3] necessitating significant imports. Though according to [2] edible crickets are a rich source of macronutrients, proteins (up to 70%), and due to an increasing world population, rising affluence, urbanization, and changing eating habits are all contributing factors diversifying the protein production as the building block of life as a healthy diet [4]. The use of biomass for fish feed production according to [5] has been identified as energy intensive due to high cost. However, palletisation reduces the bulk density of the biomass, thereby reducing the cost. Therefore, a critical component of modern aquaculture is the production of high-quality feed pellets (6) which offers greater advantages such as reduced waste, improved nutrient delivery, and ease of handling. Conversely, a significant technological gap exists in the local machinery market. Most commercially available feed pellet machines found in the rural areas are designed to produce the pellets with a maximum diameter of 9mm. This size is insufficient for larger hybrid fish species (brood stock), which require pellets exceeding 9mm for optimal growth and feed efficiency. Consequently, farmers are forced to rely on expensive imported feeds or machinery, increasing production costs. Furthermore, power instability in Nigeria poses a challenge for electric-powered machinery for production for the existing designs that often rely on electric motors, which are less practical in rural areas like Borno State. This study therefore addresses these challenges by designing and modified evaluated feed pellet machine capable of producing 10mm to 12mm pellets using a 5.5 HP petrol engine with locally sourced materials.

2 MATERIALS AND METHOD

2.1 Materials

Materials selection as for the rural dwellers is critical to ensure that the feed pellet machine responsible for both grinding and pelleting operations meets its performance requirements. Since the machine components will experience various levels of stress, strain, torque, and wear throughout operation, it's essential to use materials with appropriate engineering properties such as hardness, tensile strength, fatigue resistance, and toughness as suggested by [6, 7]. The main component parts of the machine and its factors with the objective of selection is as tabulated in Table 1.

Table 1. Material selection

S/N	Machine components	Materials	Factor	Objective for Selection
1	Hopper	Mild Steel	Rigidity	Cheap, Available, Reliable and Durable
2	Frame	Mild Steel	Strength	Strong, Cheap, Available
3	Pulley	Mild Steel	Strong and Tough	Strong and not easily defected
4	Shaft	Stainless rod	Hard and Tough	Corrosion resistance, Strong, Availability and not easily deflected
5	Auger	Stainless Steel	Strong and ability to withstand impact stress	Corrosion resistance and Strength
6	Die and Rollers	Stainless Steel	Hard and Tough	Very strong and Corrosion Resistance

2.2 Design Analysis of the Five Major Components

The machine is designed based on the flat-die pelleting principle. The assembly comprises five key subsystems: the hopper, screw conveyor (auger), die, power transmission system, and the supporting frame. The machine was designed based on the choice of the engineering materials chosen below in Table 2 and was evaluated to meet the production capacity of 80–100 kg/h.

Table 2. Cost Analysis

S/N	Item	Rate (₦)	Quantity	Amount (₦)
1.	Angle 5mm x 2	-	1.5	30,000
2.	Sheet metal	-	-	20,000
3.	Centre bearing	3,000	2	6,000
4.	U-Channel	-	-	15,000
5.	Flat bar	-	-	6,500
6.	Shaft	-	-	6,000
7.	Pulley	-	2	8,000
8.	V belt	800	1	800
9.	Electrodes (cutting/filling)	-	-	5,000
10.	Paint	-	-	3,000
11.	5.5HP Petrol engine	-	1	35,000
12.	Labour cost	-	-	20,000
	Sum Total			154,500

2.2.1 Hopper Volume

The hopper was sized to hold approximately 20 kg of feed ingredients (maize, soybeans, fish meal) with a bulk density of ~650 kg/m³. The volume was determined by the equation: Volume (conical shape):

$$V = 13\pi r^2 hV = \backslash\text{frac}\{1\}\{3\}\backslash\text{pi } r^2 hV = \frac{1}{3}\pi r^2 h \quad (1)$$

2.2.2 Compression Mechanics

To ensure pellet durability, the design targets a compression ratio of approximately 8:1, which is necessary for larger pellets. The force required for pelleting (F) is derived from the compression pressure (P) and the total cross-sectional area of the die holes, governed by the formulas:

2.2.3 Die Hole Area

The Die hole area was estimated using equation 2.

$$A = \pi r^2 \quad (2)$$

- Force required:

The forced required was estimated using equation 3.

$$F = P \times A_{total} \quad (3)$$

Where: F: Total force (N), P: Compression pressure, Total cross-sectional area of the die holes.

2.2.4 Power Transmission

The 5.5 HP engine drives the system via a pulley arrangement designed to reduce the engine speed to a functional range of 50–100 rpm for the rollers. The torque (T) delivered was calculated using equation 4.

$$T = F \times r_r \quad (4)$$

Where: r_r: Roller radius.

- Power:

The power required was estimated using equation 5.

$$P = \frac{T \times \omega}{\eta} \quad (5)$$

2.2.5 Frame

Design Analysis: Supports total weight, withstanding dynamic loads.

$$F = mg \quad (6)$$

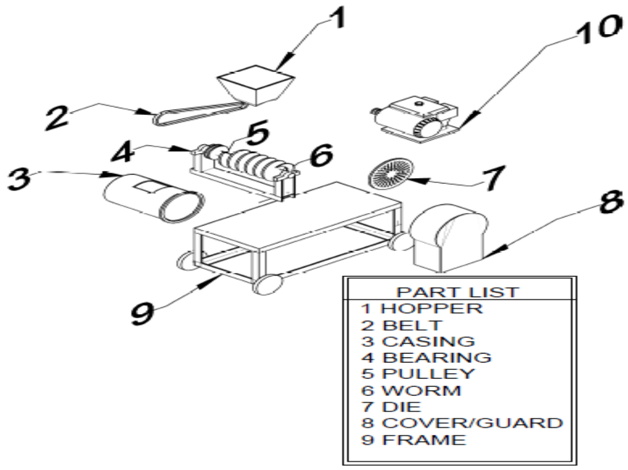

Figure 1. Exploded View

Figure 2. The Petrol-Powered Feed Pellet Machine

2.2.6 Principle of operation

The machine operates by converting mechanical energy from the 5.5 HP petrol engine into the compression and extrusion processes required for pellet formation. Firstly, feed ingredients (e.g., maize, soybeans, and fish meal) are ground, mixed, and loaded into the hopper. The conical design ensures a smooth flow into the screw conveyor. The screw conveyor, driven by the petrol engine via the power transmission system, rotates to transport the feed material into the pelleting chamber. In the pelleting chamber, the feed material is forced through the die's 10mm or 12mm holes by the rotating auger, which apply pressure to compress the material into cylindrical pellets. The compression ratio ensures pellet durability and uniformity. The extruded pellets exit the die and are collected for cooling and storage.

3 RESULTS AND DISCUSSIONS

3.1 Performance Evaluation Results

The machine was evaluated based on three primary tests: Production Rate and throughput efficiency Test A, Physical Pellet Quality (PPQ) Test B, and Water Stability Test C, and finally, the user comfort was also determined qualitatively by the operators.

3.1.1 Production Rate and Output Efficiency Test A

The capacity of the machine was tested by feeding a weighed sample of feed mixture into the hopper and recording the time taken for extrusion. The Output efficiency was found to be greater than that of [5] and [6] as calculated and determine the percentage of the raw materials that were successfully converted into pellets as indicated in Table 3.

Table 3. Production Rate and Efficiency Data

Input weight (W_i)	3.20 kg
Time taken (t)	2.10 min
Output Weight (W_o)	2.85 kg
Production Rate	81.43 kg/h
Machine Efficiency	89.06%

The production rate of the machine (81.43kg/h), fallen within the target design range of 80–100 kg/h. The efficiency was calculated as 89.06% higher than that of. [5, 6]. The loss of approximately 11% (0.35kg) was attributed to the initial residue that remains in the auger housing and die holes during short test runs, which is a normal characteristic of screw-extruder designs. Literature suggests that for small scale batch operations, recovery rates between 85% and 95% are acceptable, as the initial residue is significant relative to the small input mass (3.20kg). In continuous industrial operation, this efficiency would likely increase as the dead volume becomes negligible overtime.

3.1.2 Pellet Quality Analysis Test B

Random samples of pellets were selected to analyse physical properties such as diameter, length, texture, and hardness indicated in Table 4.

Table 4. Physical Properties of the Pellets

Sample No.	Diameter (mm)	Length (mm)	Texture	Hardness Observation
1.	10	20	Smooth	Moderate
2.	10	18	Smooth	Moderate
3.	10	22	Smooth	Moderate
4.	10	20	Smooth	Moderate
5.	10	16	Smooth	Moderate
Average	10	19.2	Smooth	Moderate

The machine consistently produced pellets with a 10mm diameter, fulfilling the primary objective of the study. The surface texture was observed to be smooth, indicating effective friction and polishing within the stainless-steel die as shown in Figure 3. The length of the pellets varied between 16mm and 22mm. This variation is attributed to the absence of an automated cutter mechanism, pellets broke off via gravity or natural friction as they exited the die. The hardness was described as "moderate", the pellets held their shape but broke under twisting finger pressure. This indicates sufficient binding for handling, though an increase in binder quantity or compression could further increase hardness.

Figure 3. Extracted feed pellets product

3.1.3 Water Stability Test C

Water stability is a critical parameter for aquaculture feed to prevent water pollution and ensure nutrient uptake. The pellets remained solid and intact for over 10 minutes, only beginning to crumble at the 20-minute mark unlike that of that of 6 and 7 that was watery with excessive fatigue producing lesser than or equal to 9mm feed not sufficient for brood stocks growth. Since brood stocks are aggressive feeders that typically consume rations within 5–10 minutes, this stability profile is considered satisfactory and effective.

Table 2. Water Stability Observations

Time Elapsed	Observation	Status
2 mins	Still solid	Pass
5 mins	Still solid	Pass
10 mins	Slightly swollen	Pass
20 mins	Started crumbling	Limit Reached

3.1.4 User Comfort and Operational Assessment

Operators reported that the machine was comfortable to use. The noise and vibration levels generated by the 5.5 HP petrol engine and the rotating assembly were within acceptable limits, allowing for safe operation without excessive fatigue. The belt drive system effectively dampened engine vibrations before they reached the frame.

3.1.5 Quantitative Performance

Quantitatively**, t**he performance of the machine was evaluated based on pellet quality, physical property and stability compared to that of [6] evaluated for the hardness, tensile strength, fatigue resistance, and toughness using locally mixed feed of maize with following results and products with an efficiency less than 89.06 and production rate of 81.43kg/h successfully and the design capacity meeting the lower bound of the targeted 80–100 kg/h range. The efficiency loss is primarily attributed to material residue in the auger housing. Finally, the machine consistently produced pellets of 10mm diameter, confirming the success of the die modification. Due to the absence of a cutter, the length of the pellets was extruded as continuous strands, breaking at an average length of 19.2 mm, ranging 16mm–22mm. The water Stability of the pellets remained solid and intact in water for over 10 minutes, only beginning to crumble at 20 minutes. This level of durability is satisfactory for aquatic brood stock that feed rapidly. The operators describe the pellets as 'hard' but capable of breaking under twisting pressure. This indicated adequate binding resulting from the 8:1 compression target.

3.2 Advantages of the machine

The machine offers distinct advantages over pre-existing models. Pellet Size Specialization: It uniquely provides 10mm pellets for brood stock, a capability absents in common Nigerian pelletizers. Power Reliability: The 5.5 HP petrol engine provides crucial operational independence, ensuring production continuity regardless of the national power grid status. Local Economy and Maintenance: The machine's construction with locally sourced and available materials ensures low fabrication costs and simplified, affordable maintenance, contrasting sharply with high-cost imported equipment.

4 CONCLUSIONS

The project successfully designed and constructed a powered feed pellet machine capable of consistently producing 10mm diameter, durable pellets. Based on the results obtained, the following conclusions are drawn: The machine was successfully constructed using locally available materials. The modification of the die plate allowed for the consistent production of 10mm diameter pellets, which was the primary limitation of pre-existing machines. Performance Viability: The machine achieved a production rate of 81.43kg/h with an efficiency of 89.06%, making it suitable for small and medium-scale commercial use. Quality Assurance: The pellets produced exhibited a smooth texture and maintained water stability for up to 20 minutes, meeting the feeding requirements for aquatic brood stock. Operational Suitability: The use of a petrol engine proved effective for local conditions, and the machine was deemed comfortable and safe to operate by users.

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