

Research Article

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Design and fabrication of a fish feed mixing cum pelleting machine for small-medium scale aquaculture industry

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Abstract: The study developed a compact, single unit of fish feed mixing and pelleting machine. In this work, a compact fish feed mixing and pelleting machine was designed, fabricated, and evaluated for its performance efficiency. The basic units of the machine are the processing unit, structural support, and the prime mover. The major component of the feed substrates used were maize, fish meal, soya bean cake, blood, and bone meal in their varied proportions blended with wet cassava starch to establish the machine performance and efficiency. The results showed that the varied proportions of starch inclusion in the blended substrate have influence on the investigated machine performance parameters. The performance outputs from the machine revealed the highest pelleting efficiency of 80.36%, pellet durability of 98.74%, throughput capacity of 4.16 kg/h, and the least labour requirement of 0.23 man-hour per kg at a starch inclusion of 0.125 kg, while the highest pellet bulk density of 0.302 g/cm³ was recorded at 0.20 and 0.125 kg starch addition. Machine economic analysis revealed that it can be of benefit for small- to medium-scale fish feed farmers.

Keywords: aquaculture, fish feed, cassava starch, pellet quality, economic analysis

1 Introduction

Fish farming, which is an integral of animal husbandry, has gained increasing popularity because of the high demand for fish, fish protein, and oil that have a wide array of applications in the cosmetic and pharmaceutical industries. The aquaculture industries have played significant roles in the emancipation of most developing economies and the actualisation of the Sustainable Development Goals 1–3: No poverty, zero hunger, and good health and well-being. It has provided employment, enhanced income, and supplemented the nutritional needs of the populace [1]. Fish farming due to technological advancement has been recognised as one of the fastest-growing sectors of food production chains in the world [2]. Over the years, the quest for fish consumption in Nigeria has resulted in an annual importation amounting to about 90 billion Naira which is equivalent to 3 million tonnes in national demand [3]. Factors responsible for these are mainly related to the overall high cost of fish production in terms of their feeds and the crude or less developed fish feed production technologies. Therefore, proper fish feed development and management practices will play a vital role in the growth and expansion of this important sector of the economy, especially at the small- to medium-scale level [4]. Feed formulation and processing have been regarded as the two most important challenges faced by aquaculture industries' feed processors [5]. This is due to the high technical know-how required for producing the exact feed mix, the high cost of raw materials which increases the overall feed cost, and the lack of technological tools which are not available to the small-scale farmers. Fish feed accounts for about 60% of fish production costs, therefore for the profitability of such a venture, the need to examine how these input costs can be reduced significantly becomes imperative [4]. Fish feed production processes involve milling of the substrates, mixing, pelleting, and drying. How these processes are handled has notable impacts on the overall production costs and output.

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Mixing as a unit operation in feed processing helps in the uniform distribution of the feed ingredients to ensure each piece of the pellet contains an equal proportion of the feed composition. Pelleting is a mechanical process used in the production of agglomerated feeds, by compacting and passing the feed mix through a die. It involves compacting and forcing individual or mixed ingredients through a die orifice or opening [6–8]. Pelleting of feed improves fish feeding, produces feeds of high durability, reduces wastage, and improves the ease of handling by fish farmers [8]. Fish feed development in sub-Saharan Africa has not influenced aquaculture development significantly as expected due to the low mechanisation of this important sector [4]. Many research efforts have been tailored towards the improvement of the traditional technology of feed processing. These research include the following: Ugoamadi [6] who developed a horizontal type cassava pelleting machine with pelleting efficiency (PE) of 80.30% at 250 rpm; Burmamu *et al.* [9] developed a horizontal type manually operated fish feed pelleting machine with PE of 88.30%; Ojediran *et al.* [4] developed a horizontal type fish feed pelleting cum batch dryer with PE of 72.35% at 18% moisture content; Olu-segun *et al.* [3] developed a vertical type fish feed pelleting machine with PE of 94.20% at 400 rpm; Okewole and Igbeka [8] evaluated a vertical pelleting press having a PE of 95.79% at 25% moisture content, feed rate of 499.99 kg/h, at speed of 250 rpm.

To achieve proper mixing in feed production, intensive labour is needed especially when done manually. For a mechanised feed process, most of the time, the mixing and pelleting units are separated, which might be a burden on the budget of small-scale fish farmers, due to the high cost of production. From literature, it was observed that a fish feed processing machine incorporating both mixing and pelleting as a single unit has not been developed.

The labour requirement (LR), which explains the man-hour required per kg, has also not been established by previous research for the pelleting machine, as this suggests to the processors how much labour is required for a smooth running of the production process. Also, the effect of different weights of wet starch (WS) in the mixing stage on the performance efficiency of a pelleting unit has not been studied. Therefore, the aims of the work were to (a) design and fabricate a fish feed mixing cum pelleting machine, (b) investigate the effect of different weights of WS inclusion in the mix on the performance efficiency of the machine, and (c) study the economic analysis of the developed machine.

2 Materials and methods

2.1 Materials

Fish feed substrates used were bought from a local market in Omu-Aran (Latitude 8.1239°N, Longitude 5.0834°E), Kwara State, Nigeria. It was used in evaluating the performance of the developed fish feed mixing cum pelleting machine (Table 1).

2.2 Methodology

2.2.1 Machine design considerations

In designing the fish feed mixing cum pelleting machine, some important factors [10] were considered. These are the cost of machine production, ease of construction, assembling and dismantling, strength and durability, safety, construction materials availability, and mechanical properties.

2.2.2 Machine design analysis and computation

The design analysis was carried out to evaluate the design parameters needed in the selection of the various machine parts for its optimum performance during usage, and to avoid incessant failure during the required working life of the machine.

2.2.3 Determination of the mixing/hopper capacity

The average bulk density of the fish feed composition was taken into cognizance in determining the mixing/hopper

Table 1: Feed substrates used in the feed formulation per batch

Raw material	Quantity (kg)
Maize	9.00
Fish meal	1.00
Soya bean cake	6.00
Blood meal	0.50
Bone meal	0.50
F/premix	0.08
Lysine	0.02
Methine	0.02
Vitamin C	0.02
Salt	0.04
Dicalcium phosphate	0.20
Cassava starch	0.1, 0.125, 0.150, 0.175, and 0.200

capacity of the machine. The average bulk density of the fish feed composition used was determined to be 300 kg/m³.

2.2.4 Mixer capacity

The volume of the mixer = volume of rectangular unit
+ volume of half a cylinder, (1)

$$\text{Volume of the mixer} = lwh + \frac{\pi r^2 h}{2} = (0.2 \times 0.25 \times 0.265) + \left(\frac{\pi \times 0.1^2 \times 0.265}{2} \right) = 0.01741 \text{ m}^3,$$

$$\text{Bulk density} = \frac{\text{mass}}{\text{volume}},$$

$$\text{Mass} = 5.223 \text{ kg}.$$

The mixer capacity was 5.223 kg, but during the operation of the machine, only half of this capacity was used (2.5 kg). This is to give allowance for the proper mixing of the feed substrates used.

2.2.5 Pelleting hopper capacity

This was designed bearing in mind the mass of properly mixed feed coming from the mixing unit since the allowable mass per time is 2.50 kg.

The volume of the hopper was determined using equation (2).

Volume of hopper = volume of a cube
+ volume of a square pyramid, (2)

$$\text{Volume of hopper} = lwh + \frac{a^2 h}{3} = (0.13 \times 0.23 \times 0.23) + \left(\frac{0.23^2 \times 0.1}{3} \right) = 8.6403 \times 10^{-3} \text{ m}^3,$$

$$\text{Hopper capacity} = 2.59 \text{ kg}.$$

2.2.6 Mixer/pelleting shaft design

The shaft size for the mixer and pelletiser unit was calculated using the equation below [11,12].

$$\begin{aligned} \text{Weight of the fish feed substrates} &= mg = 2.5 \times 9.81 \\ &= 24.525 \text{ N} = 0.0245 \text{ kN}. \end{aligned}$$

The mass of the mixing shaft and pulley were determined using a weighing scale to be 2 and 0.5 kg, respectively.

$$\text{Weight of the mixing shaft} = mg = 3 \times 9.81 = 29.43 \text{ N},$$

$$\text{Weight of the pulley} = mg = 0.5 \times 9.81 = 4.905 \text{ N},$$

$$\text{Torsional moment } (N_t) = \frac{9,550 \times W}{60}, \quad (3)$$

$$\begin{aligned} \text{Torsional moment } (N_t) &= \frac{9,550 \times (29.43 + 4.905)}{60} \\ &= 5464.99 \text{ Nm}. \end{aligned}$$

The bending moment was obtained using equation (4) as follows:

$$M_b = \frac{WL}{4}, \quad (4)$$

where W is the weight (kg), and L is the length of the shaft (m).

$$d^3 = \frac{16}{\pi S_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2}, \quad (5)$$

$$m_1 g_1 = 3 \times 9.81 = 29.43 \text{ N}, m_2 g_2 = 0.5 \times 9.81 = 4.905 \text{ N},$$

$$M_b = \frac{w \times L}{4} = \frac{(4.5 \times 9.81) \times 0.315}{4} = 3.476 \text{ Nm},$$

$$d^3 = \frac{16}{\pi \times 4} \times \sqrt{(1.5 \times 3.476)^2 + (1 \times 5464.99)^2},$$

$$d^3 = 695.73399, d = 8.86 \text{ mm} = 0.886 \text{ cm} \approx 1 \text{ cm}.$$

Since the closest shaft size is 2 cm, this was chosen for the mixer.

2.2.6.1 Pelleting shaft design

Length of pelleting shaft = 40 cm,

Volume of the pelletising unit is V_{pu} ,

and

Length of the pelleting unit = 21.50 cm.

$$M_t = \frac{9550 \times (0.99 + 4.905 + 34.335)}{60} = 6403.28 \text{ N},$$

$$\text{Bending moment } (M_b) = \frac{wL}{4} = \frac{(3.6 \times 9.81) \times 0.4}{4} = 0.36,$$

$$d^3 = \frac{16}{\pi \times 40} \sqrt{(1.5 \times 3.5316)^2 + (1 \times 6403.275)^2},$$

$$d = 9.34 \text{ mm} \approx 10 \text{ mm}.$$

A shaft of 20 mm was used for the pelleting unit since it was the closest.

2.2.7 Determination of pelleting barrel thickness

The barrel thickness was calculated using the formula stated by Ndirika and Onwualu [13].

$$\sigma_h = \frac{P \times d}{2t}, \quad (6)$$

where σ_h is the circumferential or hoop stress of the material used (MPa), P is the intensity of internal pressure (N/mm²), t is the thickness of the barrel (m), and d is the internal diameter of the barrel (mm). The σ_h for ductile material (mild steel) was 42 MPa, the intensity of pressure was 0.99 N/mm², and the diameter of the pelleting unit was 100 mm.

$$t = \frac{P \times d}{2\sigma_h} = \frac{0.99 \times 100}{2 \times 42} = 1.18 \text{ mm.} \quad (7)$$

But 2 mm thick steel pipe was used.

2.2.8 Pressure on the pelleting barrel

The limiting pressure (P_b) that the pelleting barrel can withstand was calculated using equation (8) as given by [13].

$$P_b = \frac{t\delta_a}{D_i}, \quad (8)$$

$$\delta_a = 0.27\delta_o, \quad (9)$$

where δ_a is the allowable stress, δ_o (N/mm²) is the yield stress of the pelleting barrel material (170 N/mm²) for mild steel material, and D_i is the internal diameter of barrel (mm).

$$\delta_a = 0.27 \times 170 = 45.9 \text{ N/mm}^2, \\ P_b = \frac{2 \times 45.9}{100} = 0.92 \text{ N/mm}^2.$$

2.2.9 Pelleting screw shaft design

The pelleting screw shaft was acted upon by the weight of the feed substrates and the pulley. A screw shaft with decreasing pitch was used. The pitch at the entrance of the feed gate was maximum to increase the feed capacity at the inlet and decreased towards the exit unit to increase the pressure on the exit point.

2.2.10 Volume of material transfer per revolution

This was determined by calculating the material volume within a unit groove for a complete circle. The effective diameter (D_E) of the circle was calculated using equation (10) given by Ndirika and Onwualu [13].

$$D_E = D - 2 \left[\frac{H}{3} \right], \quad (10)$$

$$D_E = 0.09 - 2 \left[\frac{0.03}{3} \right] = 0.07 \text{ m.}$$

For material transferred by the screw shaft, it required one revolution of the screw shaft.

$$V = \pi D_E A, \quad (11)$$

$$A = \frac{(L + M)H}{2}, \quad (12)$$

$$A = \frac{(0.04 + 0.03)0.03}{2} = 0.0011 \text{ m}^2,$$

$$V = \pi \times 0.07 \times 0.0011 = 0.00023 \text{ m}^3,$$

where V is the material transfer per revolution in m³, A is the cross-sectional area (m²), H is the height of the groove (m), L is the upper width of the groove (m), M is the lower width of the groove (m), and D is the maximum external diameter of the screw (m).

2.2.11 Power requirement

The power required (P) to operate the mixing and pelleting unit was determined using the formula given by Ndirika and Onwualu [13].

$$P = QL_s \rho g F, \quad (13)$$

where Q is the volumetric capacity, L_s is the length of the pelleting shaft (m), g is the acceleration due to gravity (m/s²), and F is the material factor.

$$P = 2.58 \times 0.4 \times 300 \times 9.81 \times 0.4 = 1,216 \text{ W,}$$

$$P_m = \frac{P}{\eta}, \quad (14)$$

where P_m is the motor horsepower, and η is the motor efficiency.

$$P_m = \frac{1.216}{0.8} = 1.52 \text{ kW or 2 hp.}$$

2.3 Machine description

The fish feed mixing cum pelleting machine was operated by a single-phase electric motor. The power was transmitted through the belt coupled on the sheave of the electric motor, which is small and the bigger sheave on the shafts as shown in Figures 1–3. The machine consists of the pelleting auger, auger housing, frame, mixing unit, mixing shaft, 5 hp electric motor, and belt and pulley system. The drive from the motor is transmitted to the driving mechanism which connects both the mixer and pelleting auger. The feed substrates were introduced into the mixing unit where they were thoroughly mixed and

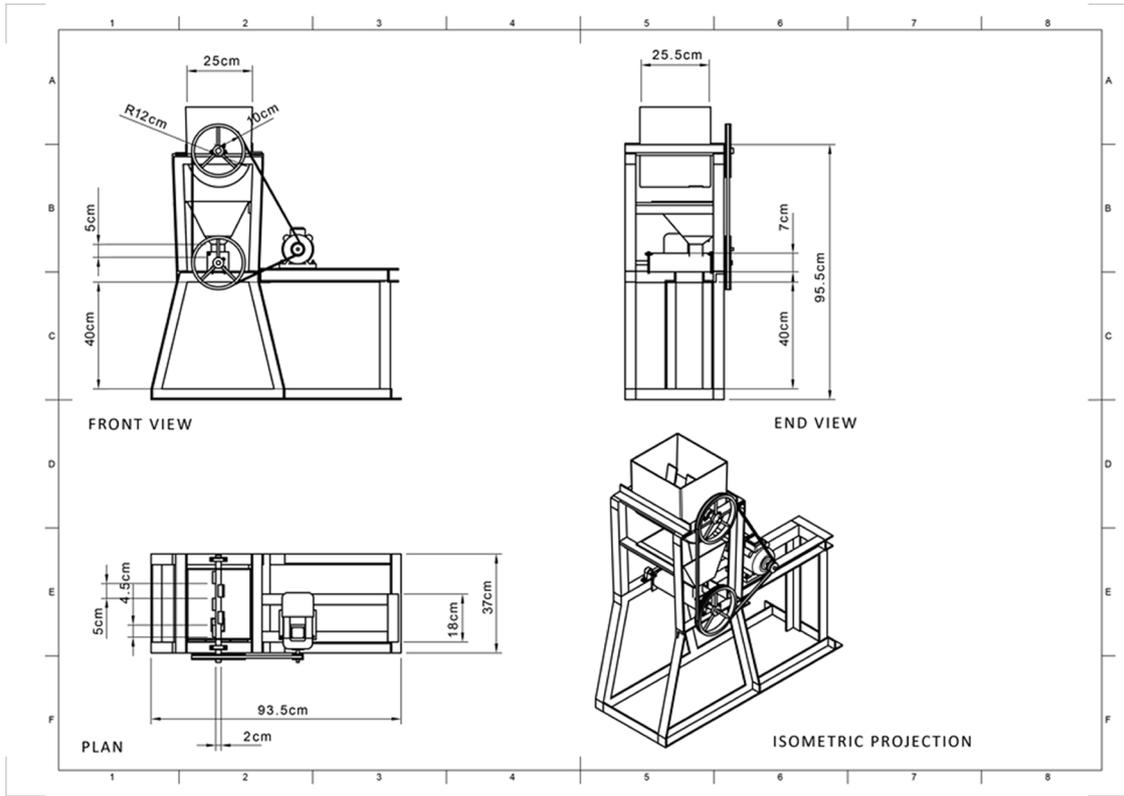


Figure 1: Orthographic view of the designed mixing cum pelleting machine.

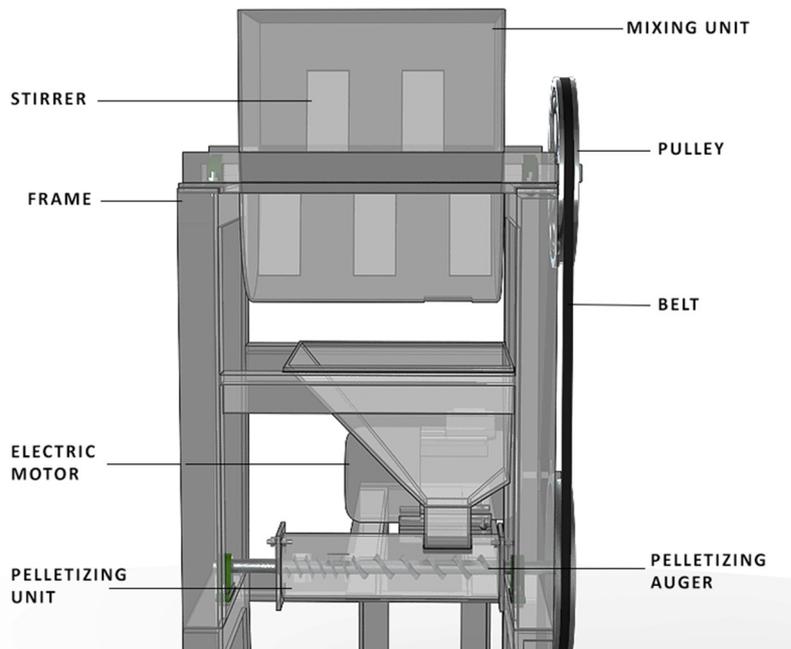


Figure 2: Schematic view of the developed mixing cum pelleting machine.

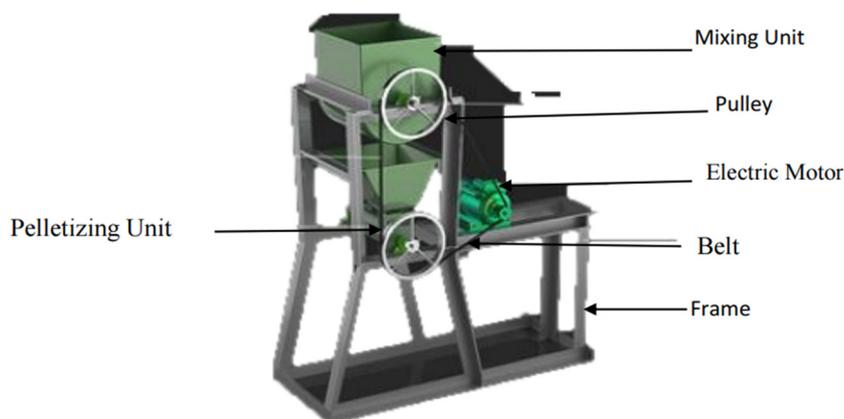


Figure 3: The developed mixing cum pelleting machine.

Table 2: Performance of the developed mixing cum pelleting machine as affected by the weight of starch used

Weight of WS (g)	Treatment replicates	PE (%)	TC (kg/h)	LR man-hour required/kg	PD (%)	PBD (g/cm ³)
100	T1	71.00	3.87	0.26	98.45	0.27
	T2	71.05	3.87	0.26	98.44	0.27
	T3	71.03	3.88	0.262	98.46	0.27
	Mean value \pm SD	71.03 \pm 0.03 ^a	3.87 \pm 0.002 ^a	0.26 \pm 0.004 ^a	98.40 \pm 0.008 ^a	0.27 \pm 0.001 ^a
125	T1	80.32	4.18	0.24	98.73	0.28
	T2	80.35	4.12	0.22	98.74	0.28
	T3	80.40	4.18	0.24	98.73	0.28
	Mean value \pm SD	80.36 \pm 0.04 ^b	4.16 \pm 0.03 ^a	0.23 \pm 0.01 ^a	98.74 \pm 0.003 ^{ab}	0.28 \pm 0.001 ^a
150	T1	61.54	3.13	0.32	98.38	0.28
	T2	61.34	3.12	0.32	98.38	0.28
	T3	61.56	3.12	0.32	98.38	0.28
	Mean value \pm SD	61.48 \pm 0.120 ^c	3.12 \pm 0.010 ^b	0.32 \pm 0.002 ^b	98.38 \pm 0.004 ^a	0.28 \pm 0.004 ^a
175	T1	75.85	3.79	0.26	98.55	0.30
	T2	75.83	3.75	0.262	98.58	0.30
	T3	75.80	3.78	0.265	98.56	0.30
	Mean value \pm SD	75.83 \pm 0.03 ^d	3.78 \pm 0.02 ^{ac}	0.26 \pm 0.001 ^a	98.562 \pm 0.016 ^{ac}	0.30 \pm 0.001 ^{ab}
200	T1	71.14	3.32	0.30	97.10	0.30
	T2	71.11	3.31	0.30	97.11	0.30
	T3	71.56	3.32	0.31	97.11	0.30
	Mean value \pm SD	71.27 \pm 0.25 ^a	3.32 \pm 0.01 ^d	0.31 \pm 0.008 ^b	97.11 \pm 0.006 ^d	0.30 \pm 0.001 ^{ab}

*SD denotes standard deviation, letters a–d represent the mean significant relationship among treatments, and different letters along the same column signify significant differences ($p < 0.05$).

discharged to the pelleting unit for pellet production. The diameter of the holes in the pressure plate determines the diameter of the pellets.

2.4 Samples preparation

The fish feed substrates used were first dried with an electric oven (Mettler UF 75 models 30-750) to a moisture

content of 10% (dry weight basis) and then milled to a uniform size of 11 μ m using a laboratory hammer mill (Armfield FT2-A Hammer mill, 230 V, 50 Hz). The cassava starch was used as a binder, and it was prepared by dissolving the starch granules in boiled water and stirred vigorously to form a paste, which was subsequently weighed into the fish feed substrates in the mixing component of the developed machine for the different batches. The weight of the starch added for each batch was varied as shown in Table 2.

2.5 Performance evaluation

The developed mixing cum pelleting machine was evaluated using equations (15)–(19) as given by Okewole and Igbeka [8] and Okonkwo et al. [10].

2.6 PE

$$PE = \frac{W_p}{W_m} \times 100, \quad (15)$$

where W_p is the weight of the actual pelletised feed (kg), and W_m is the weight of the total feed input (kg).

2.7 Throughput capacity (TC)

$$TC = \frac{W_p}{T}, \quad (16)$$

where W_p is the weight of pellets (kg), and T is the time taken (h).

2.8 LR

$$LR = \frac{1}{TC}, \quad (17)$$

where LR is the man-hour required per kg.

2.9 Pellet durability (PD)

This was evaluated with a vibratory sieve shaking machine (Mechanical Jinling Shaker AC 220 V, 150 W, 50 Hz), 100 g fish feed pellets for each batch were introduced into the sieve shaking machine and vibrated for 30 min at 50 Hz and 150 W. The pellet remaining after shaking was then used to calculate the PD as in the equation below.

$$PD = \frac{W_a}{W_b} \times 100, \quad (18)$$

where W_a is the pellet mass after shaker treatment (kg), and W_b is the pellet mass before shaker treatment (kg).

2.10 Pellet bulk density (PBD)

$$PBD = \frac{W_d}{V_d}, \quad (19)$$

where W_d is the pelleting mass (g), and V_d is the pellet sample volume (cm³)

2.11 Economic analysis

The economic analysis of the developed fish feed mixing cum pelleting machine was determined using cost and return analysis which includes break-even point (BEP), payable period (PBP), and benefit-cost ratio (BCR). Equations (20)–(22) as given by Okonkwo [10] defined the economic viability of the machine as follows:

$$BEP = \frac{TFC}{\frac{MPF - TVC}{H} \times MPC}, \quad (20)$$

where TFC = total fixed cost (N/h), MPF = mixing/pelleting fee (N/kg), TVC = total variable cost (N/h), H = annual working hours, and MPC = mixing/pelleting capacity (kg/h).

$$PBP = \frac{IC \times H}{ANI}, \quad (21)$$

where IC = initial cost (N), and ANI = annual net income (N).

$$BCR = \frac{TB}{MPC \times DC}, \quad (22)$$

where TB = total benefit (N), and MPC = mixing/pelleting cost (N/kg).

2.12 Statistical analysis

The experimental design was a one factorial design. Each measurement was replicated three times and the data obtained were evaluated for its mean values and standard deviation using SPSS version 23. Analysis of variance (ANOVA) was used to check the significant differences ($p < 0.05$), and Duncan's multiple range test was further used to compare mean values.

3 Results and discussion

3.1 TC

The mean TC of the developed mixing cum pelleting machine under different quantities of starch used ranged from 3.12 to 4.16 kg/h as shown in Table 2 at 373 rpm. The highest TC of 4.16 kg/h was recorded with the inclusion of 125 g of wet

cassava starch, while the lowest TC of 3.12 kg/h was recorded with the inclusion of 150 g wet cassava starch. The various starch weight inclusions used showed different fluctuating TC. These observed phenomena might be due to the fact that the more the quantity of starch used, the sticker it will be to the mixing and pelletising barrel. The maximum TC recorded at 373 rpm was lower as compared to the TC (350–500 kg/h) reported by Okewole and Igbeka [8] for a vertical type pelleting machine at 200 and 250 rpm at different feed rates. Ugoamadi [6] reported a maximum TC of 80.40 kg/h for 250 rpm in a horizontal type cassava pelleting machine. These large differences observed are due to the volume of the pelleting barrel, feed rate, and the speed of operation.

3.2 PE

The PE describes the ability of the pelleting machine to produce whole pellets from the feed introduced through the hopper of the pelleting machine. From Table 2, it was observed that the mean PE of the developed mixing cum pelleting machine under different quantities of starch used ranged from 61.48 to 80.36% at 373 rpm. The highest PE of 80.36% was recorded with the inclusion of 125 g of wet cassava starch, while the lowest PE of 61.48% was recorded with the inclusion of 150 g of wet cassava starch. The various starch weight inclusions used showed different fluctuating PE. The result showed that inclusion of 125 g WS performed better with the developed mixing cum pelleting machine. The efficiency recorded was lower than that reported by Okewole and Igbeka [8] with maximum PE of 95% for a vertical fish feed pelletiser at 25% moisture content wet basis, 500 kg/h feed rate, and 250 rpm shaft speed, but within the same range with what was reported by Ugoamadi [6] with a maximum PE of 80.31% for 250 rpm in horizontal type cassava pelleting machine. A linear

relationship was established between PE and moisture content as studied by Ojomo *et al.* [14].

3.3 LR

The LR describes the man-hour required per kg of the pelleting material. From Table 2, it can be seen that the different starch weights used in the operation required one man labour to be able to manage the whole operations during production.

3.4 PD

PD describes the ability of pellets to withstand destructive loads, and frictional and abrasive forces during handling and transport. From Table 2, it was observed that the mean PD of the developed mixing cum pelleting machine under the different quantities of starch used ranged from 97.11 to 98.74%. The highest PD of 98.74% was recorded with the inclusion of 125 g of wet cassava starch, while the lowest PD of 97.11% was recorded with the inclusion of 200 g of wet cassava starch. The various starch weight inclusions used showed different fluctuating PD. The maximum PD estimated (98.74%) was slightly higher than the maximum PD (96.30%) reported by Okewole and Igbeka [8] for a vertical-type pelleting machine.

3.5 PBD

The PBD depicts the degree of compaction of the pellets per unit volume. From Table 2, it was observed that the mean PBD of the developed mixing cum pelleting machine under

Table 3: Materials for fabrication of components and projected cost

Materials	Components used	Amount in Naira (\$)
2 mm mild steel (1 no.)	Mixing unit and pelleting hopper	38.10
1.5 inch thick angle iron (2 nos.)	For framework and mixer cover	47.62
Iron pulley (15 and 30 cm)	For both the mixer and pelleting unit	16.67
Mild steel shaft (2 and 2.5 cm)	For mixing shaft and pelleting auger	17.86
Bearing (204 and 205)	For holding the mixing and pelting auger during operation	23.81
Cutter rod (1 length)	For the construction of the auger	7.14
5 mm thick flat bar (100 cm length)	For the mixing paddle	11.90
A-belt	For connecting the pulleys	2.38
Bolt and nuts (10)	For firmness during operation	1.20
5 hp electric motor	For the prime mover	71.43
Total		238.11

different quantities of starch used ranged from 0.268 to 0.302 g/cm³ as shown in Table 2. The highest PBD of 0.302 g/cm³ was recorded with the inclusion of 200 g wet cassava starch, while the lowest PBD of 0.268 g/cm³ was recorded with the inclusion of 100 g wet cassava starch. The various starch weight inclusions used showed that as the weight of the starch increased, the bulk density increased. The result was in agreement with the result reported by Fallahi et al. [15] and Okewole and Igbeka [8] where the PBD increased with moisture content.

3.6 Economic analysis of the developed fish feed mixing cum pelleting machine

The cost analysis in Table 3 gives the estimate for the development of the prototype of the mixing cum pelleting machine. The materials used for the fabrication of the machine were estimated to be \$238.110. The economic analysis parameters which include PBP, BEP, and BCR were used to evaluate the viability of the investment. A BCR greater than 1 signifies that the machine is theoretically beneficial. BCR of 2.81 was obtained for the developed mixing cum pelletising machine, indicating that the machine is highly beneficial. This value was slightly higher than the BCR reported by Okonkwo et al. [10]. BEP shows the level at which the machine has to be used to generate profit. BEP of 224 kg was estimated for the machine. This signifies that to break even with the developed machine, it would have to produce about 224 kg of pellet. The estimated BEP was lower compared to the BEP of 1,744 kg reported by Okonkwo et al. [10]. PBP is the time required to recover the capital invested. PBP of 53.80 h. (0.28 months) was estimated for the machine. This analysis, therefore, shows that the developed machine can be suitably adopted for small- to medium-scale fish feed producers and it is economically viable.

4 Conclusion

A mixing cum pelleting machine was designed and developed to reduce the drudgery associated with manual mixing and pelleting of fish feed among small-scale fish farmers who directly utilise the fish feed. The mixing cum pelletiser was evaluated using different weights of WS (0.100, 0.125, 0.150, 0.175, and 0.200 kg). The following key observations were inferred from the investigation:

1. Mixing and pelleting using 0.125 kg WS inclusion showed the highest PE (80.36%), TC (4.16 kg/h), PD (98.74%), and

least LR (0.23 man-hour required per kg), whereas, the inclusion of WS of 0.15 kg had the least PE (61.48%) and TC (3.12 kg/h).

2. The PBD increased (from 0.268 to 0.302 g/cm³) with the increased inclusion of WS.
3. The economic analysis and evaluation of the results showed that the developed mixing cum pelleting machine is highly beneficial, economical, and can be used by small- to medium-scale fish farmers and feed producers.

In conclusion, we found that the developed pelleting machine can produce pellets with high PE, and is economically viable if adopted by small- to medium-scale farmers.

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Data availability statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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