Research Article

# Design of a Varying Die-plate Fish Feed Pelletizer and Performance Evaluation Using a Non-conventional Feed Sources

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**Abstract**
An electrically-operated fish feed pelletizer was designed, fabricated and tested. The machine was incorporated with an easily detachable die plates capable of extruding different sized feed. Performance evaluation of the machine was carried out using a non-conventional feed resources of fermented citrus and plantain peels each formulated with fish feed constituents such as fish oil and groundnut cake prepared at a moisture content of 20% wet basis. The performance indices considered in the evaluation of the pelletizer were pelleting efficiency, percentage recovery and percentage of unpelleted feed. Results obtained when 250 g of formulated feed was introduced into the pelletizer showed an higher pelleting efficiency (91.50%), percentage recovery (73.20%) and a lower percentage of unpelleted feed (26.81%) when die plate having screen size of 5 mm holes was used. Evaluation using die plate having 3 mm holes showed that the average values for pelleting efficiency, percentage recovery, and percentage unpelleted feed were 82.09, 65.67 and 35.73% respectively. Statistical analysis of the performance indices with respect to the 3 mm and 5 mm die sizes showed that performance indices had significant difference on formulated feed having fermented citrus peel while not statistically significant for feed formulated with fermented plantain peel at $p < 0.05$.

**Keywords**: Agro-waste, Aquaculture, Extrusion, Feed, Pelleting

## 1 Introduction

Pelleting of agro-waste is considered a best way through which wastes from agricultural produce could be effectively converted thereby minimizing losses. Pellets are manufactured by grinding, conditioning and forcing the ground sample through dies having diameter range of 2 to 10 mm or even larger [1]. Extrusion is the process of forcing a material through a specifically design opening [2]. In literatures, it is established that ways by which pellets processing could be improved relies solely on some factors such as the die specification, ingredient characteristics, temperature control/regulating process, binding agents, moisture relationship and pellet management and safety. Advantage of pelleted feeds is that they are easier to handle and palatability is sustained when compared to the dusty (unprocessed) feeds.

The characteristic of pelleting in fine form influences the feed quality in feed processing

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operations [3] thereby resulting to a high production efficiency [4] even though feed processing operations could be affected either positively or negatively [5]. Factors such as the working temperature of the environment and the machine, exerted force per unit area and the die diameter plays an active role in pellet formation.

About 35% of cost spent in aquaculture is on fish feeds [6]. In order to lower the cost of feed purchase, formulation of available materials for plant and animal sources have been developed as a better replacement for commercial feeds. Utilization of agricultural wastes such as poultry offal [7], fermented shrimp head waste meal [8], maggot meal [9] and water hyacinth meal [10] have been emphasized in the formulation of the least cost fish feed towards ensuring profitable fish business.

The maintenance of fish requires 25–35% crude protein, however, the particle size of the fish feeds must also be changed because of the growth of the fishes [11]. Mechanism through which it could be achieved is by mixing nutrients together and feeding them into a feed pelletizer [12].

Researches carried out by [13] suggested that agro-wastes are feasible for feed formulation for livestock, poultry and aquatic animals. Agro-wastes utilization offers a tremendous advantage based on the fact that raw materials needed for feed conversion and production are readily available and found at low-cost. Despite fundamental knowledge proffered by researchers, there has been dearth of appropriate technology required to convert these wastes into animal feeds. Cylindrical pellets from combined agro-wastes could be easily formed from pelleting machine as produce such as maize, groundnuts and millets have been yielded palatable pellets for animal feed [14]. A pellet mill was designed and the performance evaluation carried out showed a feed production capacity of 57 kg/h [15]. The machine operated on roll-type extrusion. Some of the major components of the machine were die plate, hopper and screw. The machine was able to produce 4 mm and 1 mm long pellet. A manually-operated fish feed pelleting machine was developed by [16]. The major components of the machine were hopper, bearing and the pelleting chamber. The researchers reported that the machine when tested with 3 kg mixture of fish feed recovered 2.65 kg which gave an efficiency of 88.3%. The design, construction and testing of a poultry feed pellet machine was carried out by [17]. The major components of the machine were hopper, barrel pelletizing die, suitable bearing and conveyor belt. The researchers reported that the machine could produce 5 kg/h of feed. Also, a higher throughput capacity of 19.7 kg/h with maximum pelletizing efficiency of 87.6% for an evaluated fish feed pelleting machine was reported by [18]. The researchers observed that moisture content constituted a greater portion of variability in efficiency than speed and further reported that a unit increase in moisture content resulted in an increase of about 20% in pelletizing efficiency whereas a corresponding unit increase in speed only increased the pelletizing efficiency by 3%. A pellet quality was evaluated in terms of the durability of the pellets against the moisture content of the mash (18, 20 and 22% w.b.), die size (4, 6 and 8 mm) and the screw speed (90, 100 and 120 rpm) [1]. The authors reported a maximum durability of 84.437% at 20% (w.b.) moisture content using 4 mm die and low durability of 61.26% with using 8 mm die at 18% (w.b.) moisture content. The best durable pellet was obtained using 4 mm die at 20% (w.b.) moisture content and least durable using 8 mm die at 18% (w.b.) moisture content. The researchers concluded that die size affects pellet quality with the use of the pelletizer at different pre-conditions.

Fish rearing for commercial purposes have in these days brought lack of interest among fish growers as a result of high purchase cost for commercial feeds and no readily-available substitute for fish feed. Furthermore, the devised means by fish growers to address different sized feeds to fishes are met by lack of technological-related measures as farmers devised primitive way of manual breaking of feeds using hands while some resorted to using local processing method of size reduction such as knife cutting, meat grinder, and breakage on mortars [19]. All these methods are not only primitive but also laborious and could cause health stress on fish growers. Therefore the objective of this study was to design and evaluate a varying die-plate fish feed pelletizer. The specific objectives were to use a non-conventional feed resource to evaluate the fish feed pelletizer with respect to the following performance indices: pelleting efficiency, percentage recovery, percentage of unpelleted feed of the pelletizer.

## 2 Material and Methods

### 2.1 *Machine description*

The major components of the electrically-operated pelletizer were the hopper, which was welded on a cylindrical-shaped pelleting barrel, the pelleting barrel which housed the auger, a detachable die-plate through which the pelletized feed comes out from. The principle of operation of the machine is majorly by compression. The semi-plasticized feed was fed through the hopper. The auger gelantize feed as it transports the feed to the compression end of the pelleting machine. A clearance is created between the auger and the die plate. The clearance provides impact of force required to compress the material through the die thereby leading to formation of shaped pellets.

### 2.2 *Design consideration and procedure*

Appropriate materials were selected during the fabrication process. The materials were selected based on machinability, workability and cost effectiveness and availability. The hopper was constructed with a 3 mm stainless steel as a result of non-corrosiveness of the material.

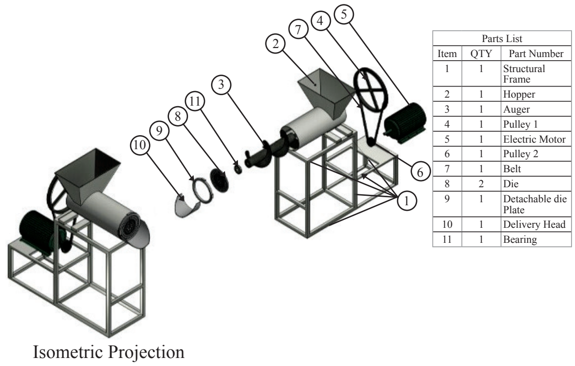
It has dimension of 108 mm × 180 mm × 180 mm. The pelleting barrel was a 20 mm stainless steel sheet folded to make a cylindrical steel pipe of ∅ 92 mm × 400 mm. The frame has dimension of 680 mm × 520 mm × 280 mm made of galvanized steel which was cut using hacksaw and welded together. The die is made of stainless steel having dimension of ∅ 85 mm to which fifteen 5 mm and twenty-five 3 mm holes were bored.

Figure 1 shows the isometric and exploded views of varying die-plate fish feed pelletizer. Figures 2 and 3 shows the orthographic projection and pictorial views of the varying die-plate fish feed pelletizer respectively.

### 2.3 *Design calculations*

#### *2.3.1 Pelleting pressure*

The pressure in pelleting process is dependent on diameters of the inner and outer walls. The existing relationship between pelleting pressure and force was mathematically related by [20] as shown in Equation (1):




| Item | QTY | Part Number |
|---|---|---|
| 1 | 1 | Structural Frame |
| 2 | 1 | Hopper |
| 3 | 1 | Auger |
| 4 | 1 | Pulley 1 |
| 5 | 1 | Electric Motor |
| 6 | 1 | Pulley 2 |
| 7 | 1 | Belt |
| 8 | 2 | Die |
| 9 | 1 | Detachable die Plate |
| 10 | 1 | Delivery Head |
| 11 | 1 | Bearing |

**Figure 1**: Exploded view of the varying die-plate fish feed pelletizer.

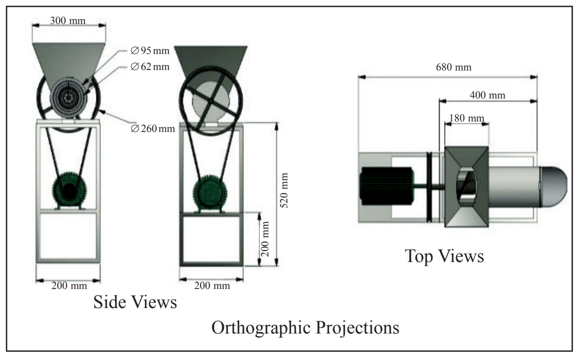



**Figure 2**: Orthographic projections of the varying die-plate fish feed pelletizer.

**Figure 3**: Pictorial view of a varying die-plate fish feed pelletizer.

$$P = \frac{F}{A_W} \quad (1)$$

Where $P$ is the extrusion pressure in (N/m$^2$), $F$ is the resultant force acting on shaft ($N$), $A_W$ is the area of worm-shaft (m$^2$). According to [21], forces in a shaft can be divided into two namely vertical forces and horizontal forces as expressed in Equation (2):

$$N = P_V \sin\theta + P_H \cos\theta \quad (2)$$

Where $\theta$ is the friction angle between shaft and bearing (10°), values obtained for bending moments were, $P_V$ (30 N) and $P_H$ (35 N), where $P_V$ is the vertical force and $P_H$ is the horizontal force to drive the pellet through the die; $N$ is the resultant force (39.26 N). Therefore, from Equation (1), $P$ is the extrusion pressure in (0.005904 MN/m$^2$), F is the resultant force acting on shaft (39.26 N), $A_W$ is the area of worm-shaft ($6.6503 \times 10^{-3}$ m$^2$)

*2.3.2 Extruding force*

The extruding force is given by [17] as stated in Equation (3):

$$F = P\,(A_C - A_0) \quad (3)$$

Where $F$ is the extruding force, $P$ is the extrusion pressure (0.005904 MN/m$^2$), $A_0$ is the output area of the die ($0.5A_C$) and $A_C$ is expressed in Equation (4) as:

$$A_c = \left(\frac{\pi}{4}\right)\left(d_b^{\,2} - d_s^{\,2}\right) \quad (4)$$

Where $A_C$ is the effective area of barrel (6283.34 mm$^2$), $d_b$ is the diameter of barrel (92 mm), $d_S$ is the diameter of shaft (21.56 mm).

Using the relations in Equations (3) and (4), the extruding force for the pellets is 18.5484 N.

*2.3.3 Thickness of pelleting barrel*

The thickness of pelleting barrel is calculated based on specific factors such as area, density of material and mass as expressed in Equation (5):

$$t = \frac{m}{A_c \rho} \quad (5)$$

Where $t$ is the thickness of material (mm), $m$ is the mass of (stainless steel) material (1 kg), $A_C$ is the area of pelleting barrel (0.00628334 m$^2$), $\rho$ = density of (stainless steel) material (8000 kg/m$^3$).

The thickness of the barrel used for the construction is 19.894 mm.

*2.3.4 Shaft design*

Shaft required for the pelleting operation is selected based on rigidity and torsional strength. The shaft is connected in between two bearings however during operation, various action such as bending, twisting and torsion occurs. The twisting and bending action is calculated using a formula given by [22] in Equations (6)–(8):

$$M_{eq} = \frac{1}{2}\left(M + \sqrt{M^2 + T^2}\right) \quad (6)$$

Where $M_{eq}$ is the equivalent bending moment (20.649 Nm), $M$ is the maximum bending moment (15.704 Nm), $T$ is the torque transmitted by the shaft (20.2092 Nm) stated in Equation (7) :

$$T = W_p \times \gamma_P \quad (7)$$

Where

$$W_p\,(\mathrm{N}) = (M_1 + M_2) \times 9.81 \quad (8)$$

$W_p$ is the total weight of shaft and formulated feed (50.523 N), $M_1$ is the mass of Shaft (5 kg), $M_2$ is the mass of feed (0.15 kg), $\gamma_P$ is the perpendicular distance of shaft to the bearing (0.40 m). From Equation (7), design assumptions, design stress for steel shaft is 10.5 N/mm$^2$ under a factor of safety of 4 as reported by [23]. The formula is expressed in Equation (9):

$$D = \sqrt[3]{\frac{16 M_{eq}}{\pi\tau}} \quad (9)$$

Where $D$ is the shaft diameter (21.544 mm), $\tau$ is the design stress (10.5 N/mm$^2$), $M_{eq}$ is the equivalent moment (20.649 Nm)

*2.3.5 Power requirement*

It is necessary to determine the power required for selection of motor size. The screw speed is reduce through a means of gear reduction system when pellet is about to be produced thereby making the output to be desirable howbeit application of laws of physics and rearranging elements of equations to establish necessary power and energy relationships are carried out [24]. Power required is mathematically related by [6] as expressed in Equation (10) as:

$$P_W = \frac{P(\pi DN)}{60} \quad (10)$$

Where $P_W$ is the power required (1056.047 W), $P$ is the pressure (design force) (274 N), $D$ is the Diameter (0.092 m), $N$ is the number of revolution per minute (800 rpm)

*2.3.6 Length of belt*

Selection of belts depends on power rating and the speed of rotation of the electric motor [21]. The formula for calculating belt design is given by [3] and this is shown in Equation (11):

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \quad (11)$$

Where $C$ is the centre distance between the adjacent pulleys (0.5 m), $D_1$ is the diameter of driving pulley (0.05 m), $D_2$ is the diameter of driven pulley (0.13 m).

*2.3.7 Performance evaluation*

The substrate used for the fermentation process were milled plantain and citrus peels (Figures 4 and 5 respectively) retained on U.S. standard sieve size number 50 (0.30 mm opening). The fermentation process was carried out in a sterilized environment three factors were considered: incubating temperature (40°C), inoculum concentration (15 mL) and the fungi (Aspergillus niger) and the proximate analysis of the fermented peels was determined using AOAC method [25]. The fermented plantain and citrus peels was oven dried at 40°C. A higher temperature than these could denature the enzymes of the cell which may in turn affect the fungi harmfully [26]. The fermented peels was formulated with some local feed sources such as milled groundnut cake and oil. The diet preparation was done by methods of [27] who substituted fermented cassava peels for soymeal and fish meal in fish feed formulation. However, some modifications were made based on grammes to be pelleted. The feed ration and the material components used in the fabrication process is presented in Tables 1 and 2 respectively. The samples of the feed were prepared at a moisture content of 20% wet basis and replicated three times for the 5 mm and 3 mm die sizes. Using electronic digital weighing balance (Adam Nimbus ± 0.01), 250 g of the formulated feed were fed into the pelleting machine. The total feed input was calculated to be 15 kg/h using Equation (12) as given by [18]. The machine speed of operation was 200 rpm and operating at a temperature of 95°C. The total number of experimental runs carried out on the machine was eighteen (18). The performance indices used in the evaluation of the fish feed pelleting machine were percentage recovery, percentage unpelleted, and pelleting efficiency. The formula for percentage recovery, percentage unpelleted and pelleting efficiency is given by [18] as

**Figure 4**: Milled plantain peel retained on U.S. standard sieve size number 50 (0.30 mm opening).

**Figure 5**: Milled citrus peel retained on U.S. standard sieve size number 50 (0.30 mm opening).

stated in Equations (12)–(15). Using Microsoft Excel (2013) version, a t-test was conducted to check for significance of the different sizes of dies as related to percentage recovery of feed, percentage unpelleted feed and the pelleting efficiency.

(i) Total Feed Input ($T_F$):

$$Q \times K \tag{12}$$

(ii) Percentage Recovery ($P_R$):

$$\frac{W_p}{W_o} \times 100\% \tag{13}$$

(iii) Percentage Unpelleted ($P_U$):

$$\frac{W_P - W_A}{W_o} \times 100\% \tag{14}$$

(iv) Pelleting Efficiency ($\eta_P$):

$$\frac{W_A}{T_F} \times 100\% \tag{15}$$

Where $W_p$ is the weight of pelleted feed (g), $W_A$ is the actual weight pelleted (g), $W_O$ is the original weight of feed (g), $T_F$ is the total feed input (kg/h), $K$ is the friction coefficient between material and barrel.

**Table 1**: Feed ration

| S/N | Formulated Feed (A) | Formulated Feed (B) | Weight (g) | Weight by Percentage (%) |
|---|---|---|---|---|
| 1 | Plantain Peel | Citrus Peel | 126.99 | 85 |
| 2 | Groundnut Cake | Groundnut Cake | 3.36 | 2 |
| 3 | Bone meal | Bone meal | 4.5 | 3 |
| 4 | Fish Oil | Fish Oil | 4.5 | 3 |
| 5 | Maize | Maize | 9.9 | 7 |
| 6 | Salt | Salt | 0.75 | 0.5 |
| | **Total** | | **150** | **100** |

**Table 2**: Materials legend

| Materials | Specifications | Quantity |
|---|---|---|
| Stainless Steel | 5 mm | 1 sheet |
| Angle Iron | 10 mm | 2 Standard Length |
| Bolts and Nuts | - | 9 Pairs |
| Mild Steel | 10 mm | ¼ Sheet |
| Electric Motor | 220–240 V Single Phase | 1 |

## 3 Results and Discussion

### 3.1 *Effect of speed and moisture content on pelleting efficiency*

Tables 1 and 2 shows the results obtained from the performance evaluation of the fish feed pelleting machine. From the results, it was observed that there was the formulated feeds had different output results when the feeds were fed into the machine. The machine recorded higher pelleting efficiency when 5 mm die size was used. The highest values for pelleting efficiency, percentage recovery were 91.50 and 73.20% respectively as compared to 82.09 and 65.67% when 3 mm die was used. The pelleting efficiency in this case is higher than what [6] obtained in the performance evaluation of a Dual-mode laboratory-sized pelleting machine where efficiency of 91.4% (when operated manually) and 92.6% (when electrically-operated) was obtained and also [18] obtained highest efficiency of 87.56% with a feed prepared at 15% moisture content. The result indicates higher die sizes tends to high pelleting efficiency. Factors responsible for this could be attributed to method of feed preparation, nature of feed materials (moisture content, physical state, and chemical composition), operating conditions of the machine (speed, temperature, pressure, die size).

### 3.2 *Effect of speed and moisture content on percentage recovery and percentage unpelleted*

From Tables 3 and 4, the highest percentage recovery was 73.20 and 65.67% on 5 mm and 3 mm dies respectively. The value of the percentage recovery is close to [18]. The researchers obtained about 80% percentage recovery for a pelletizer working at 400 rev/min with feed prepared at 15% wet basis. Moreover, it could also be observed that the percentage weight of unpelleted feed using 3 mm (35.73%) die size was higher than that of 5 mm (26.81%) size. This shows that the effectiveness of the auger as it was able to convey materials conveniently over a suitable cross- sectional area. Furthermore, the 5 mm pellets were susceptible to breakage than those of 3 mm. This could be as a result of quicker pelletizing which affected proper gelatinization of the binder with the feed material. This is in line with the observation of [1] where pellets produced with die plate of 4 mm broke easily as they fall off from the die plate. This revealed that the binding forces in small sized pellets reinforces the bond between the particles of granulated materials. Table 5 shows the t-test result of the feed interactions with respect to die size.

From Table 5, it was observed that the interactions between the obtained values from the performance evaluation of 3 mm and 5 mm die sizes with respect to performance indices of pelleting efficiency, percentage recovery and percentage unpelleted had significant difference on formulated feed having fermented citrus content at $p < 0.05$ while not statistically significant for feed formulated with fermented plantain peel. This could be as a result of bulk density of the soft feed, texture, chemical composition (fat, fiber, carbohydrate, protein and moisture) and prevailing ambient conditions of temperature and relative humidity. Figures 6 and 7 shows the produced pellets from the 3 mm and 5 mm die plates.

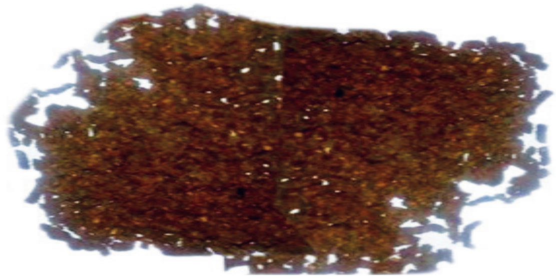


**Figure 6**: Formed pellets from the 3 mm die plate.

**Figure 7**: Formed pellets from the 5 mm die plate.

**Table 3**: Results obtained from the performance evaluation using 5 mm die

| Feed Type | Mass of Feed (g) | Percentage Recovery (%) | Percentage Unpelleted (%) | Pelleting Efficiency (%) |
|---|---|---|---|---|
| Formulated Feed (A) | 250 | 74.40 | 25.60 | 93.00 |
| | 250 | 72.00 | 28.00 | 90.00 |
| | 250 | 73.20 | 26.80 | 91.50 |
| | | **73.20 (1.20)** | **26.80 (1.20)** | **91.50 (1.50)** |
| Formulated Feed (B) | 250 | 73.10 | 26.90 | 91.38 |
| | 250 | 74.28 | 25.72 | 92.85 |
| | 250 | 72.19 | 27.81 | 90.24 |
| | | **73.19 (1.05)** | **26.81 (1.05)** | **91.49 (1.31)** |

Feed A: Feed formulated with Fermented Citrus Peel; Feed B: Feed formulated with Fermented Plantain Peel
*Values in parentheses are the Standard Deviation

**Table 4**: Results obtained from the performance evaluation using 3 mm die

| Feed Type | Mass of Feed (g) | Percentage Recovery (%) | Percentage Unpelleted (%) | Pelleting Efficiency (%) |
|---|---|---|---|---|
| Formulated Feed (B) | 250 | 68.00 | 32.00 | 85.00 |
| | 250 | 64.80 | 35.20 | 81.00 |
| | 250 | 60.00 | 40.00 | 75.00 |
| | | **64.27 (4.03)** | **35.73 (4.03)** | **80.33 (5.03)** |
| Formulated Feed (B) | 250 | 67.72 | 32.28 | 84.65 |
| | 250 | 66.10 | 33.90 | 82.63 |
| | 250 | 63.20 | 36.80 | 79.00 |
| | | **65.67 (2.29)** | **34.33(2.29)** | **82.09(2.86)** |

Feed A: Feed formulated with Fermented Citrus Peel; Feed B: Feed formulated with Fermented Plantain Peel
*Values in parentheses are the Standard Deviation

**Table 5**: T-test evaluation of interaction of die sizes with respect to the performance indicators

| Performance Indices | Feed A.A | | | Feed B.B | | |
|---|---|---|---|---|---|---|
| | t-stat | t-critical | Sig. | t-stat | t-critical | Sig. |
| Pelleting Efficiency (%) | 3.683 | 4.303 | 0.066 | 5.170 | 3.183 | 0.014 |
| Percentage Recovery (%) | 3.683 | 4.303 | 0.066 | 5.170 | 3.183 | 0.014 |
| Percentage Unpelleted (%) | 3.683 | 4.303 | 0.066 | 5.170 | 3.183 | 0.014 |

Feed A.A = 3 mm and 5 mm; Feed B.B = 3 mm and 5 mm

## 4 Conclusions

An electrically-operated fish feed pelleting machine was developed from locally-sourced materials such as steel, iron, and bolts and nuts. The machine test was carried out using non-conventional feed resource of fermented plantain and citrus peels with each formulated with fish constituents such as groundnut cake, and oil. The concept of its fabrication allows easily detachable dies for production of different sizes of fish feed. The machine was tested and efficient for the production of fish feed pellets recording a pelleting efficiency of 91.50 and 82.09% on 5 mm and 3 mm die size. Moreover, the machine had percentage unpelleted feed of 26.80 and 34.33% on 5 mm and 3 mm die sizes respectively. The machine has processing capacity of 15 kg/h. Since not only farmers are found in fish business but some interested household practice it on subsistence scale, this machine would help in production of different sizes of feed for the fishes as this will alleviate problem of sole reliance on industrial fish feed production machines.

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