EXPERIMENTAL RESEARCH ON A FEED PELLETIZING EQUIPMENT DESIGNED FOR SMALL AND MEDIUM-SIZED FISH FARMS
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CERCETARI EXPERIMENTALE ALE UNUI ECHIPAMENT DE PRODUCERE A FURAJELOR PELETIZATE DESTINATĂ FERMELOR PISCICOLE DE DIMENSIUNI MICI SI MEDII

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ABSTRACT

Due to the recent rise in the price of energy and grains, purchasing high-quality pelletized food has caused significant challenges for small and medium-sized fishing farms. The present article aims to assist breeders and farmers with limited financial resources in producing high quality feed by providing in detail the design and performance of a wet pelletizing equipment. The proposed pelletizing technology demonstrated high efficiency in use, reduced operating expenses, and a high productivity. Four different feed mixes were processed using the pelleting equipment, functioning with a 5 mm die. The experimental results indicated a maximum processing rate of 100 kg/h at an average pelletizing efficiency of 91.5%. The total pelletizing capacity of 0.8 - 1 tons per day is sufficient to provide feed for a medium-sized fishing farm, reducing dependence on the feed market and allowing for a simple nutritional mix customization.

REZUMAT

Datorită creșterii recente a prețului energiei și al cerealelor, achiziționarea de furaje peletizate de înaltă calitate a devenit mai costisitoare, provocând probleme semnificative fermelor piscicole de dimensiuni mici și mijlocii. Prezentul articol își propune să asiste crescătorii de puiet de peste si fermierii cu resurse financiare limitate în producerea de hrană de calitate prin prezentarea în detaliu a designului și performanței unui nou echipament de peletizare umedă. Tehnologia de peletizare propusă a demonstrat o eficiență ridicată in utilizare, cheltuieli de operare reduse și productivitate ridicată. Patru amestecuri de furaje diferite au fost prelucrate cu echipamentul de peletizare, echipat cu o matriță cu gaura de 5 mm. Rezultatele experimentului au indicat un randament maxim de procesare de 100 kg/h la o eficiență medie de peletizare de 91,5%. Capacitatea totală de peletizare de 0,8 - 1 tonă pe zi este suficientă pentru a furniza hrană pentru o fermă de pescuit de dimensiuni medii, reducând dependența de piața furajelor și permițând o personalizare mai ușoară a amestecului nutrițional.

INTRODUCTION

Pelletizing is the most common approach for preparing feed granules, a relatively new process in fish farming that increases the nutrients utilization and helps increasing the efficiency of operational management *(Olusegun et al., 2017; Mircea et al., 2020)*. This simple processing technique increases the feed's bulk density while lowering storage and transportation expenses. Pellet size requirements is determined by the age and types of the fish species grown, and may have different specific characteristics such as the time of floating, the amount of protein, vitamins and fat content. Since the pellets are compressed during the agglomeration process, palletizing offers a superior quality than powdered feed, case when the feeder faces severe nutritional loss attributable to leaching. Some technologies, in addition to the extrusion stage, have incorporated some processes of temperature rise or steam treatment, which helps the starch to gelatinize more rapidly. Mechanical processes such as pressure and grinding are used to create gelatin, in order to improve feeder properties *(Malgwi et al., 2020)*.

Moisture, temperature, and time are the main parameters that work together to provide binding properties to the pellets and, when later dried, increases pellet durability and their stability in water *(Gageanu et al., 2022; Hussein et al., 2021; Cardei et al., 2021; Gageanu et al., 2021)*.

A pelletizer is a simple equipment that compresses and transforms various powdered feed ingredients into a semi-solid material. A brief and accurate description of the elements that affect the high-level operation of a pelletizer is substantiated by Harper (1987) into 5 main features. He argues that the following variables have the most impact on the characteristics of the pelletized product:

1) The equipment working conditions, such as temperature, pressure, die diameter, and transfer rate.

2) The rheological characteristics of the powder, including its moisture content and its physical condition.

3) The components nature and their chemical composition, namely the quantity and kind of starches, proteins, and lipids that are present in the mix.

4) Leakage stream, which is influenced by the pressure gradient and is related to the pressure flow.

5) The flow takes place within any openings in the barrel wall or surfaces as well as in the space between the rollers passes and the barrel. Leakage flow limits the performance of the system.

Extruded or pelleted aquaculture diets use high-durability granules in order to resist handling and transportation, and they have to show superior water stability, to reduce nutrient loss and disintegration when immersed in water *(Obahi et al., 2020)*. In order to stabilize feeds in water and extend the duration that feed floats, farm-made fish feed has to contain high-quality binding agents *(Muo et al., 2016; Nenciu et al., 2022)*. If the water stability of the pellets is reached, there will be less waste than in the conventional techniques, which is very beneficial to aquaculture systems. Binders can be used to increase the water stability of pellets, these compounds can be either natural, modified, or synthetic substances with variable degrees of effectiveness *(Regupathi et al., 2019)*. The dry matter loss rate was shown to significantly decrease over time in studies examining the impact of various binders, including agar, gelatin, carrageenan, and carboxymethyl cellulose. Starch is an essential component of fish feed, minimum concentrations needed for floating pellets ranging between 18 - 22%, while 9-11% starch content is required for sinking pellets. Starch serves as a binder and an agent that helps expansion during feeder production. The gelatinization of starch is necessary for the production of fish feed because it improves stability in water, digestibility, and expansion. Starch gelatinizes at a different rate depending on temperature, processing time, moisture content, and particle size. Fine grinding of mix components improves the physical characteristics of the finished feed as well as digestibility *(Nwaokocha et al., 2018; Nenciu et al., 2020)*.

Feeds that have been granulated or pelletized are therefore complex foods which are usually enriched with several other important nutrients and stimulants. These products are made using specialized equipment and technology and have to be available as stable and easily digestible compounds. To be completely valuable, pellets released into the water must rapidly rehydrate and keep their form for 3.5 to 4 hours *(Obahi et al., 2020)*.

While the granulation is made to preserve homogeneity and retain the nutrients and biostimulators in better conditions, the size of the pellets is determined by the age and the species of the fish grown. This approach facilitates the handling and transportation operations and increases shelf life by three to four times. A 20–30% volume decrease is achieved by granulation, along with the elimination of pathogens, the removal of air from the spaces between the particles, and the development of a protective coating on the surface of the granules *(Muo et al., 2016)*.

MATERIALS AND METHODS

The proposed technology was designed for pelletizing various raw nutritional materials in order to produce qualitative alternative pelletized fodder, at affordable prices and high qualities. The primary goal of the developed technology was to maintain a simple design, to present a simple operation, to be easy to use and to consume minimum human and energy resources.

Description of equipment and its working principle

The pelletizer is composed of a feed inlet component (hopper) and the pelletizing chamber, which is a shaft equipped with rollers that transports and press the mixture in the extrusion section. A driving electric motor is used to revolve the worm-like attachments on the shaft. When the ground feed ingredients are added to the hopper, the hopper conveyor moves the feed to the barrel, where it is managed by the rollers until it reaches the heating chamber, where some moisture is lost as a result of increased friction at the barrel.

The feed is sent to the die opening, where it undergoes an extrusion process. The rollers were designed to easily intake feed into the extruder equipment. The rollers and the feed materials undergoing extrusion are enclosed in the cylindrical barrel. The rollers are mounted on a central shaft that rotates the two rollers and takes the material and forces it to pass through the die, thereby also mixing the feeds before extruding them out through a multi-channel die with a specific size. The electric motor is operated to provide the proper rollers speed selected by user. The extruder frame stand gives adequate supports to the drive, bearing, extruder head, barrels, and rollers assembly.

Figure 1 illustrates the design and layout of the equipment used to produce pelletized feed, while figures 2-7 display the equipment detailed subassemblies, so that it can be easily reproduced by farmers.

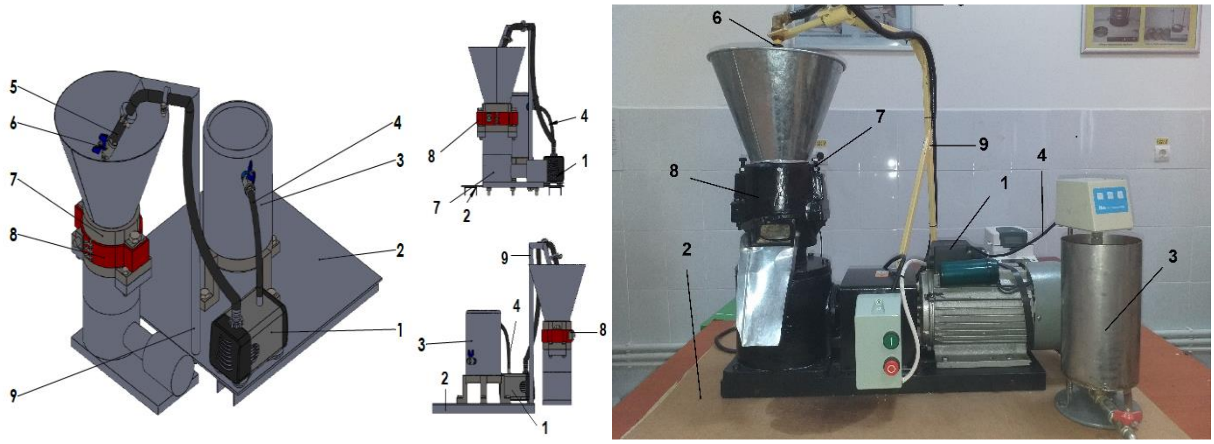
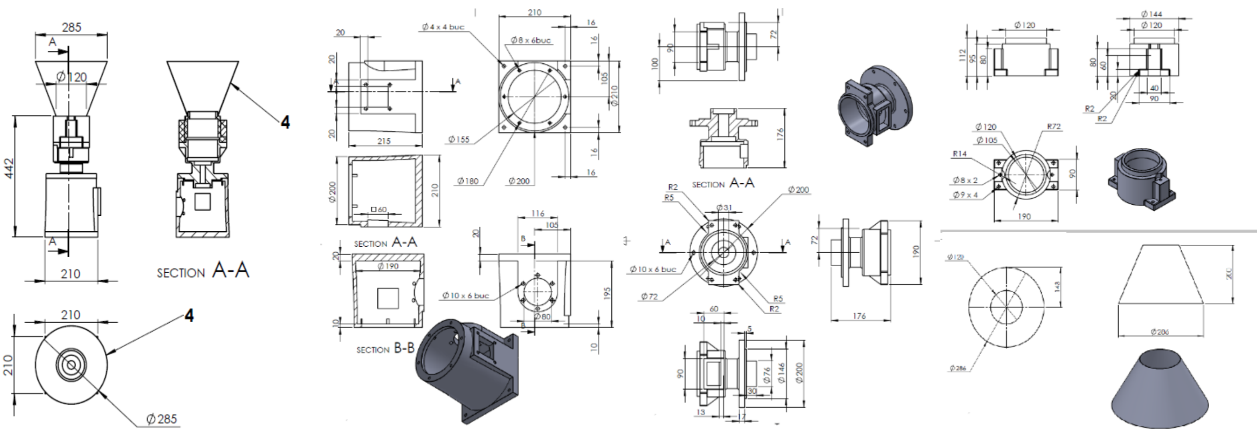


Fig. 1 - Design and layout of the equipment used to produce pelletized feed
1 – steam generator; 2 – working stand; 3 – tank for storing blending solutions; 4 – mobile hose; 5 – pipe; 6 – adjusting nozzle; 7 – feeding hopper; 8 – electric heating belt; 9 – arm used to adjust the spraying position

The system works on the principle of wet pelletizing, the binding steam being produced by the steam generator (1), located on the working stand (2), which intakes the evaporation solution from the tank (3), through the mobile hose (4). The steam produced is transported through the pipe (5) and is discharged through the adjusting nozzle (6) into the feeding hopper (7). An electric heating belt (8) is used to improve the coagulation process, while the spraying distance is fixed by the adjusting arm (9).

For easy replication and construction of the pelletizing equipment by farmers, the constructive detailing of each subassembly is presented below. The following elements are defined as follows: pelletizing extruder subassembly (Figure 2), Working stand subassembly (Figure 3), Coupling subassembly (Figure 4), Drive shaft subassembly (Figure 5), Pressing roller subassembly (Figure 6), Pellet compaction subassembly (Figure 7). The description does not detail the equipment driving motor (2.8 kW electric drive), because it was not produced in the current project, being purchased.



(A1) *(A2)* *(A3)* *(A4)*

Fig. 2 - Detailing of the pelletizing extruder subassembly
A1 – Overview of the subassembly; A2 – Technical details on the extruder subassembly base; A3 – Technical details on the extruder subassembly intermediate body, A4 – Technical details on the extruder subassembly upper body and the feeding hopper

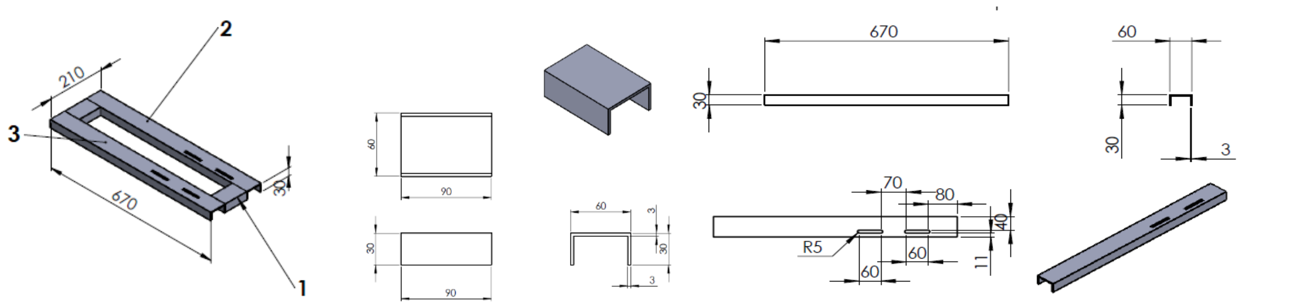
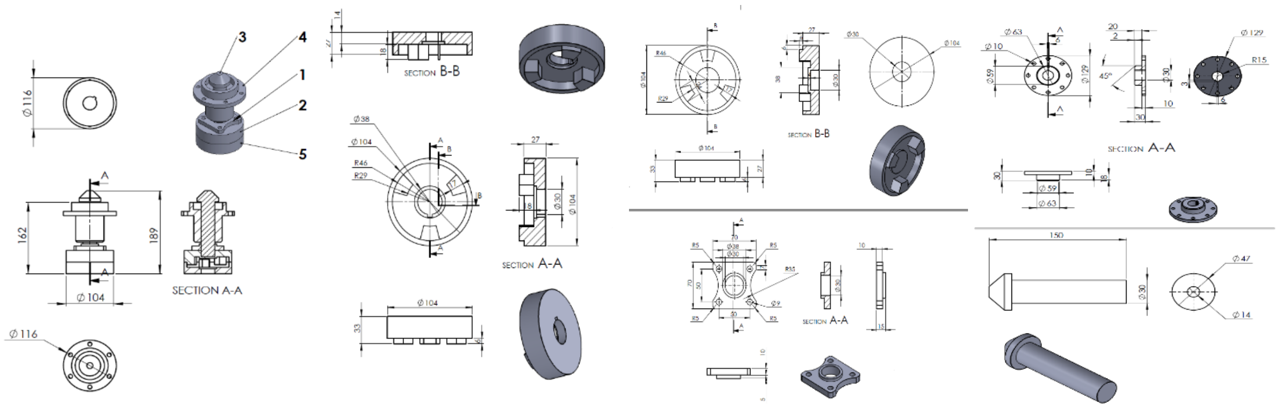


Fig. 3 – Mounting stand subassembly for the pelletizing equipment

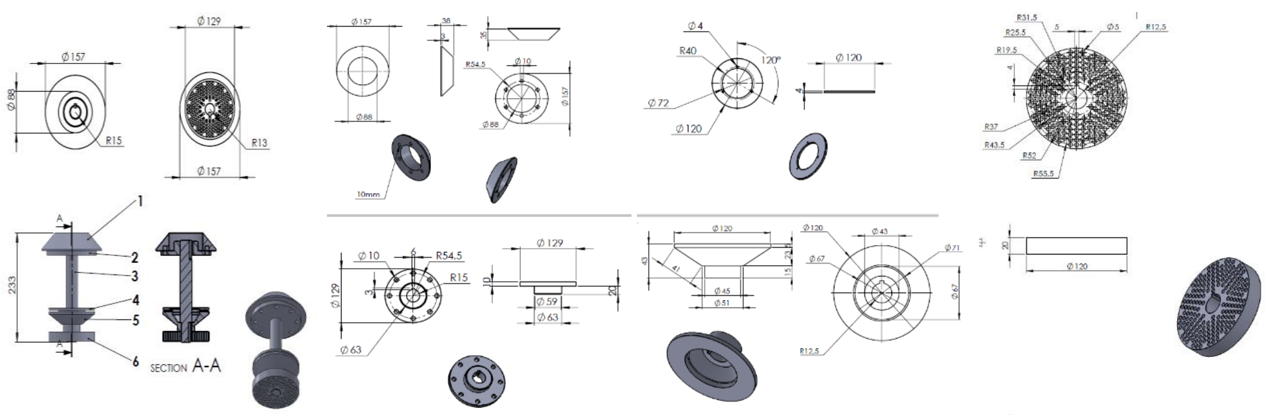
The support subassembly for the experimental model is a welded rectangular construction, consisting of a U6-105 profile and a U6-670 profile, according to figure 3.



(B1) *(B2)* *(B3)* *(B4)*

Fig. 4 - Detailing of the coupling subassembly

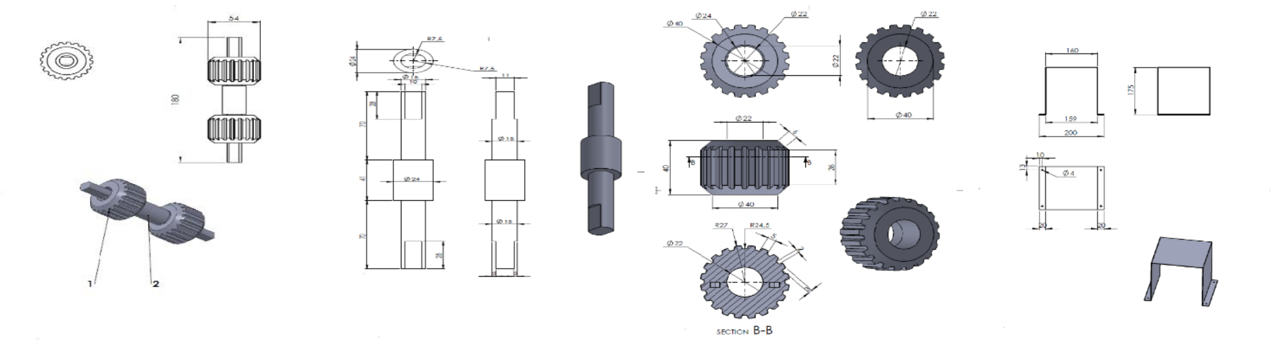
B1 – Overview of the coupling subassembly; B2 – Technical details of the coupling element part 1; B3 – Technical details of the coupling element part 2 and Coupling-shaft connecting element; B4 – Technical details on the Connecting flange and Pinion gear



(C1) *(C2)* *(C3)* *(C4)*

Fig. 5 - Detailing of the Driving shaft subassembly

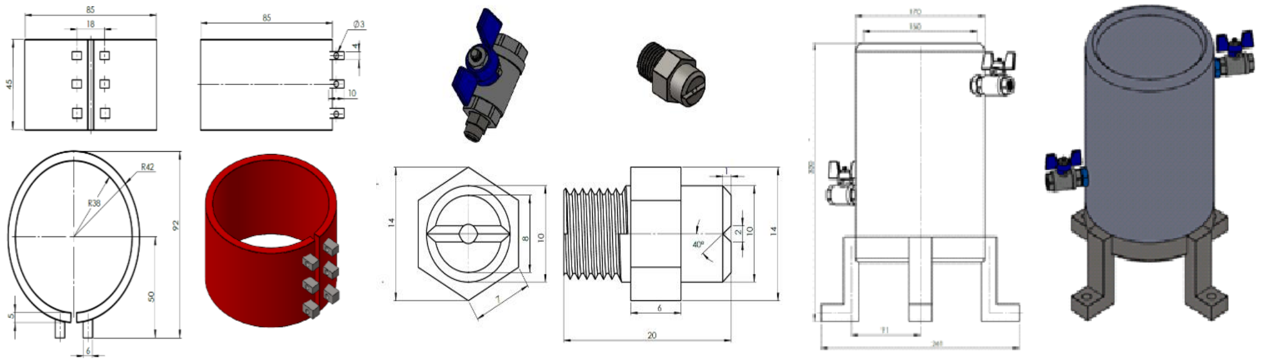
C1 – Overview of the Driving shaft subassembly; C2 – Technical details of the tapered wheel; C3 – Technical details of the pellet exhaust element; C4 – Technical details for the pellet extrusion mold



(D1) (D2) (D3) (D4)

Fig. 6 - Detailing of the pressing roller subassembly

D1 – Overview of the pressing roller subassembly; D2 – Technical details of the roller mounting shaft; D3 – Technical details of the raw material pressing rollers; D4 – Technical details of the coupling protection



(E1) (E2) (E3)

Fig. 7 - Steam generation subassembly

D1 – Technical details of the heating jacket; D2 – Technical details of the nozzle spray system; D3 – Technical details of the additive mixing vessel;

Testing the technical performance of the pelletizing system

After design and construction, the system has been evaluated in order to assess the production performance, the consumed energy, and the quality of the obtained pellets. The ingredients for each recipe were grinded using a hammer mill, and were afterwards adequately blended. The combined materials weighed a total of 50 kg on each batch. The mixture was put into the hopper, the equipment was then turned on until the batch was fully completed. The compressed pellets have been discharged through the die and have been gravitationally evacuated into a container. The testing procedure was carried out five times using the identical components in order to acquire the required averages.

Testing of fish feed pelletizing equipment for 4 nutritional mixes (4 different recipes)

In order to analyze the behavior of the equipment when processing different types of nutritional mixtures, 4 pelletizing recipes were defined, as follows:

- **Recipe 1**, 50% sunflower, 25% corn, 10% wheat, 5% soybean, 10% additives (fish flour; vitaminized calcium; black dye Arabic gum; fried hemp; yeast extract; starch);
- **Recipe 2**: 65% corn, 15% sunflower, 5% wheat, 15% additives (fish flour; vitaminized calcium; yellow dye Arabic gum; vitamin C; sweet corn syrup with starch integrated; yeast extract; starch).
- **Recipe 3**: 20% sunflower, 50% corn, 10% wheat, 10% soybean, 10% additives (fish flour; vitaminized calcium, red dye Arabic gum; krill flour; yeast extract; starch)
- **Recipe 4**: 10% sunflower, 10% corn, 10% wheat, 10% soybean, 60% additives (20% was represented by fish flour; vitaminized calcium; green dye Arabic gum; vitamin C; fried hemp; yeast extract; and 40% starch; seaweed extract; spirulina; buoyancy extract).

Recipe 1 Recipe 2 Recipe 3 Recipe 4

Fig. 8 - Production of mixtures by grinding and mixing compounds, before the pelletizing stage

The methodologies listed below were used to calculate the equipment efficiency and the losses attributed to non-pelletized components.

Determining the electricity consumed (*W*) during the operation of the pelletizing system. The electricity consumed is measured using relation (1):

$$\boldsymbol{W} = (P_c \text{ x } t) \,/\, 3600 \quad \text{[kWh]} \tag{1}$$

Where: Pc is the power absorbed from the network, [kW];
t is the operating time, [s].

Specific electricity consumption per unit of processed product (*q*) is calculated with relation (2)

$$\boldsymbol{q} = \frac{P_c}{Q \text{ } x \text{ } \eta_{me}} \quad \text{[kWh/t]} \tag{2}$$

Where: Pc is the consumed power, [kW];
Q is the quantity of processed product, [t/h];
η_{me} is the efficiency of the electric drive motor.

The evaluation of the raw energy of the pellets is determined using the calorimeter CAL3K-F type. After weighing approximately 0.5 grams of the sample to be analyzed using the precision analytical balance, a cotton thread was attached to the center of the ignition wire and inserted with the other end into the nacelle so that it is in contact with the sample, in order to propagate the combustion. The calorimeter is then inserted into the special support connected to the oxygen tank and is filled with oxygen at a pressure of 20-30 bar. The parameters of the calorimeter were set, the measured raw energy value was displayed on the device screen.

Ash content evaluation is performed by burning the pellet samples in porcelain crucibles in the calcination furnace. A sample for analysis of at least 1 gram was weighed into a crucible at the 4 decimal precision balance and the mass was recorded. The crucible and the sample were placed for 60 minutes in the oven at 105 ^{0}C to remove the moisture content from the sample to be analyzed. After one hour, the sample was cooled to room temperature and weighed again, calculating the moisture content of the sample.

The crucible with the sample was placed into the calcination oven and heated according to the following temperature ranges: increased the oven temperature to 250^{o}C in a time of 30 to 50 minutes (heating rate of 4.5^{o}C to 7.5^{o}C / minute). The temperature at this level has been maintained for 60 minutes to allow the volatiles to be released from the test sample before ignition. Continued to raise the temperature to 550 ± 10^{o}C for 30 minutes (heating rate 10^{o}C / minute). The temperature has been maintained at this value for 120 minutes. The sample crucible is then removed from the oven, allowed to cool for 5-10 minutes in the collection tray and then transferred to the desiccator where it is allowed to cool completely. After the crucible with the sample has reached room temperature, it is weighed to the 4-decimal precision analytical balance and the mass is recorded.

The ash content (A_d) is expressed as a percentage by mass in the dry base and is calculated using relation (3).

$$A_d = \frac{m_3 - m_1}{m_2 - m_1} \times 100 \times \frac{100}{100 - M_{ad}} \tag{3}$$

Where: m_1 is the mass in grams of the empty crucible;
m_2 is the mass in grams of the crucible with the sample to be analyzed;
m_3 is the mass in grams of the creed with the ash resulting from the burning;
M_{ad} is the percentage of moisture content of the analyzed sample.

The moisture content of the pellets is obtained by placing 5 samples from each pellet recipe in an oven at 105 °C, and maintained for 60 minutes, until the weight stabilizes. The moisture content (*MC*), is then calculated using the following equation (4).

$$MC = \frac{wet\ mass - dry\ mass}{wet\ mass} * 100 \quad , \% \tag{4}$$

The unitary density of the pellets is determined by analyzing the products having a perfect cylindrical shape, by measuring their length and diameter; they are weighed and then the volume is calculated with relation (5).

$$V = \pi r^2 h \tag{5}$$

Where: V is the volume of the pellet, [m³];
r is the radius of the pellet, [m];
h is the length of the pellet, [m].

The density of pellets is calculated with the relation (6):

$$\rho = m / V \tag{6}$$

Where: ρ is the pellet density, [kg/m³];
m is the pellet mass, [kg];
V is the volume of the pellet, [m³].

The bulk density is determined in a steel cylinder of a certain volume, by filling a standard cylindrical container with a volume of material up to a certain value (by free fall) and its subsequent weighing, using a precision electronic balance.

RESULTS

To determine the effectiveness of the designed equipment and the areas that might require improvement, a laborious evaluation phase was performed, operating with different nutritional compounds.
Raw ingredients (the four proposed recipes) were finely ground using a mill and blended before being placed in the feeding system of the extrusion equipment.

The action on the rollers moves the feed products forward and transform the constituents mix into a viscous dough-like mass. The feed product is subjected to high pressures as it is taken and compressed by the action of the rollers. Long molecules tend to align in the feed constituents giving rise to cross-linking or restructuring, resulting in the extruded foods characteristic texture. Figure 9 shows how the pellets produced using the extrusion equipment and the 4 mix recipes look like.

Recipe 1 pellets Recipe 2 pellets Recipe 3 pellets Recipe 4 pellets

Fig. 9 – Pellets obtained from the four recipes used

The moisture level of the extruded product is a key factor that affects other characteristics of the extrudate including durability, water absorption, and water solubility.

Fish feeds with moisture content lower than 8% have a longer life span when stored, therefore the goal was to keep the moisture after processing below this value. Figure 10 displays the four different types of recipes relative moisture levels, which ranged from 6.50 to 7.58 percent. Bulk and unitary density evaluation (Figure 11) depends on the shape, size, and extent of expansion during extrusion and it has an influence on the transportation and storage costs of extruded feeds.

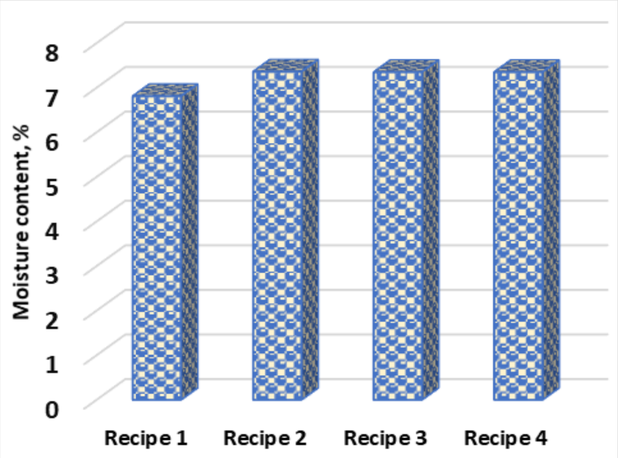


Fig. 10 - Moisture content assessment

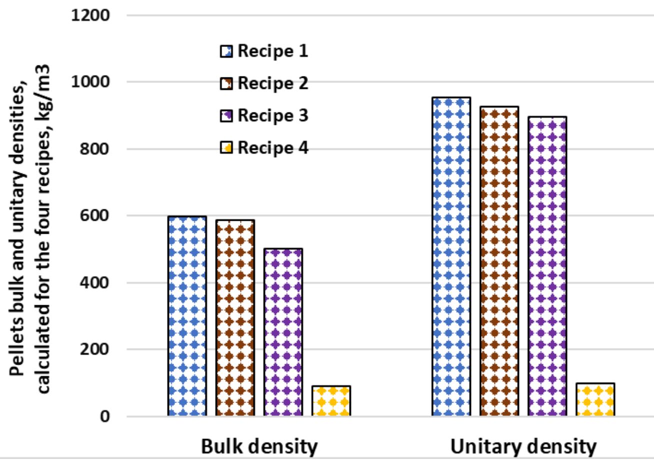


Fig. 11 - Bulk and unitary density evaluation, for the four recipes

Since previous assessments have shown that the moisture content increases proportionally to the die size, the experiments were carried out using a 5 mm die. The expanding that occurs as the moisture and other binding compounds rush out, as a result of a quick reduction in pressure at the die exit, causes the micropore structure of the extrudate. As a result, the expansion, texture, and final moisture levels substantially affect the extrudate capacity to spread and hold on evaporating water. The interactions between water and other chemical feed components are also impacted by the high temperatures, stress distribution, and tensions experienced during extrusion processing, which in ultimately changes the internal structures. Figure 10 shows very small differences in the moisture value for the four recipes; however, Figure 11 shows a significant difference for recipe number four in term of density, due to the higher starch content (added to achieve a higher flotation level).

Calculating the efficiency of the feed extruding process helps to measure the performance achieved by the designed equipment. The percentage efficiency is the ratio between compliant and non-compliant pellets extruded in a batch, and ranged from 89.7 to 91.5%. This indicator usually decreases with the increase of the mold holes, the primary factor in the increased efficiency being the quality and type of the mixtures used. Other quality indicators being evaluated were the pelletizing time per batch (Figure 12) and production capacity (Figure 13).

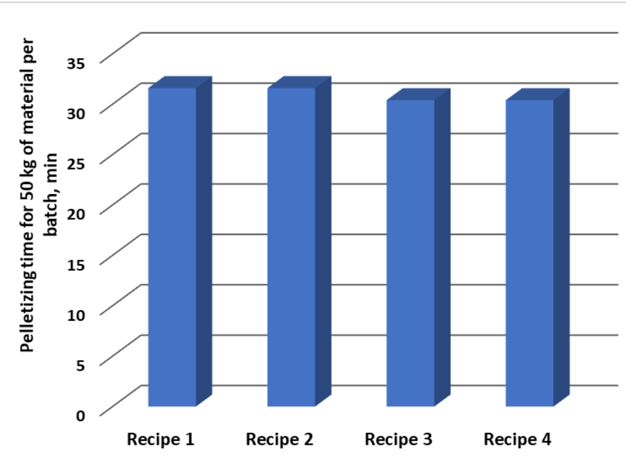


Fig. 12 - Pelletizing time per batch (for 50 kg of material)

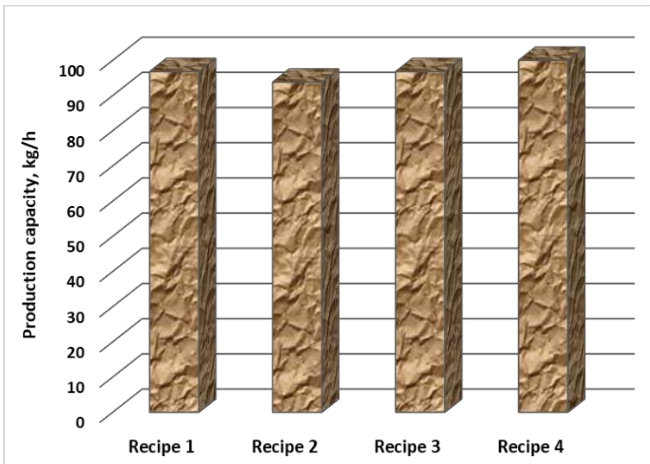


Fig. 13 - Production capacity

All 4 recipes were framed in around 30 minutes per batch, resulting in approximately 100 kg per hour. Therefore, it can be deduced that a small farmer can easily obtain 0.8-1 tons of feed per day using the equipment. Carp generally requires between 30 - 35 % protein in their diets (12 grams of protein for every kilogram of body weight), 5 - 15% fat and 30–40% carbohydrate.

The carbohydrate content is significantly greater than carnivorous species diets since carp have longer intestines. The fish diet is influenced by the species, age, water temperature, the growth system and the type of pond used. For the juvenile carp fish, an initial feeding rate is 2.5-12 kg/10 000 fish daily and is gradually increased according to the demand of the fish.

Two energy indicators used in this study on the operation of the pelletizer are pelletizer energy consumption (figure 14) and Specific mechanical energy (figure 15).

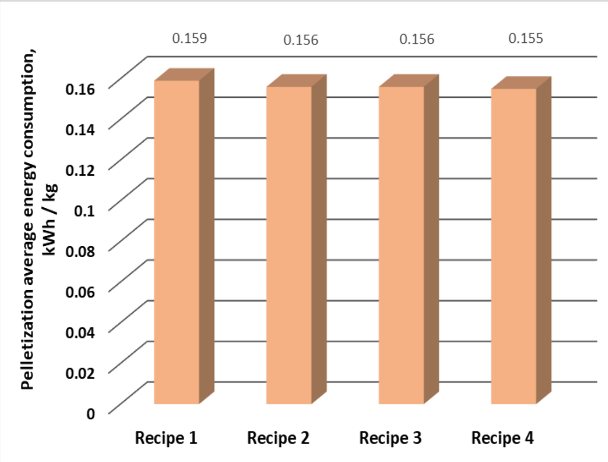


Fig. 14 - Palletization energy consumption

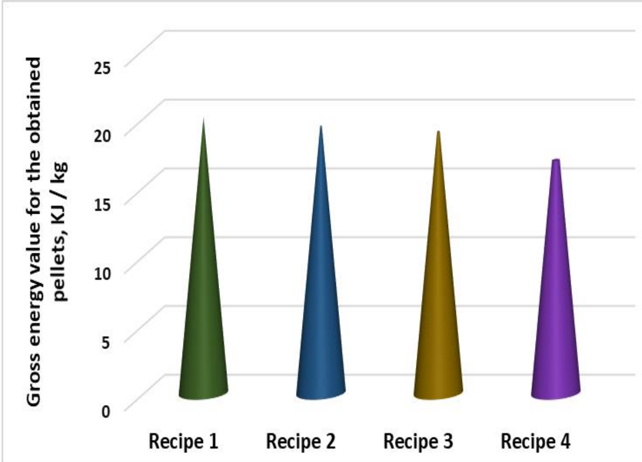


Fig. 15 - Specific mechanical energy for production

The net amount of energy used by the extruder to create a unit mass flow rate from the mixed components is known as specific mechanical energy, and is highly important because it is an integration of the extrusion reactions such as net torque, rollers speed, and the product mass flow rates. The energy consumed to obtain the unit quantity of pellets is in the normal parameters, however the specific mechanical energy for pellet production is a little higher than expected. This is due to the 5 mm orifice die used for testing, which gives strong barrier to the material passage.

The values of fats present in the pellets can decrease during processing, if in the extrusion process, they are eliminated, leaching with water.

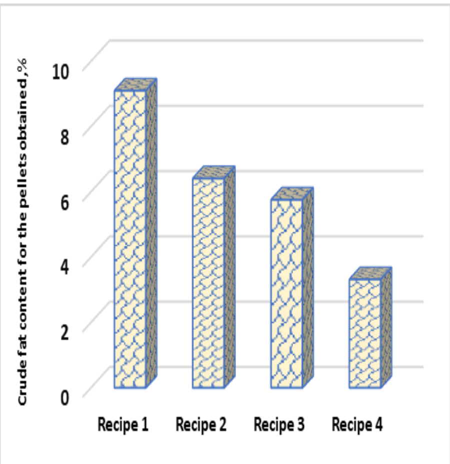


Fig. 16 – Pellet crude fat content for each recipe used

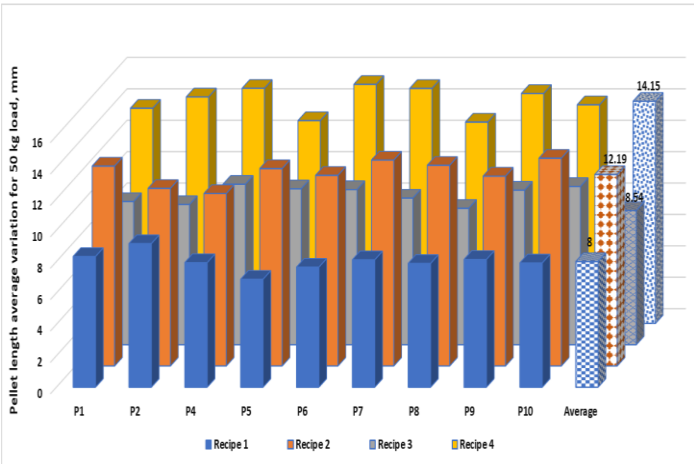


Fig. 17 - Pellet length for samples from each recipe used

CONCLUSIONS

In order to develop more affordable and convenient technologies and methods for feed production for medium and small-sized fish farms, this article examines the design, construction, and testing of a new pelletizing equipment. The equipment showed a high daily potential for producing pellets for 4 different recipes of nutrient mixes. The capacity of 0.8-1 tons / day is enough to grow both juvenile and adult fish, considering a maximum pelletizing efficiency of 91.5%. The advantages of using a pelletizing equipment do not consist only in reducing the acquisition costs but also in reducing the dependence on traders, in a more efficient control of the fish feeding depending on the season, age and type of fish in the pond.

By pelletizing, the product stability can be greatly improved, the volume is reduced by 20-30%, the risk of contamination with pathogens is considerably reduced, the air is eliminated from the nutrient mix, and a protective film is formed on the pellets surface, increasing the shelf life of the final product. In addition, the equipment design is simple and operation does not require any high technical expertise.

ACKNOWLEDGEMENT

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