EXPERIMENTAL RESEARCH ON PRODUCTION AND USE OF FLOATING PELLETS IN FISH FEED IN AQUACULTURE SYSTEMS

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Abstract. Adequate nutrition practices are essential for the efficient production of superior goods in aquaculture systems. Nutrition is a key component in the aquaculture industry because feed constitutes about 50% of the variable expense of production. Fishmeal and fish oil have traditionally been the main primary materials used to support the aquaculture industry. They have largely been supplanted by plant-based raw materials, but specific techniques are needed to satisfy fish dietary needs. As aquaculture has expanded, people have been searching for alternative farming nutritional sources since fish meal and fish oil are produced from captured wild fish. Fish have different nutritional needs that rely on a variety of variables. This paper describes an experimental study that was completed on the production of pelletized complex feeds with high stability that were used in the feeding technology of some fish species grown in a polyculture system with recirculation and cyclic water supply. The purpose of feed formulation is to mix ingredients of different nutritional quality so as to obtain a balanced diet, which biologically available nutrient profile approximates the nutritional needs of the concerned species. In fish farms, the choice of feeder for different types of fish takes into account the following criteria: the level of stability in the water, the return on investment in feed, efficient conversion of feed and its attractiveness to fish. The high level of feed stability prevents feed losses and reduces water contamination. The results showed a high stability of the pellets associated with an important increase in the size of the fish raised in the polyculture system. Although each feeding recipe showed benefits for certain fish species, the R3 feeder was the optimal mix, leading to 43% average growth for all varieties and being considered the best option for polyculture systems.

Keywords: aquaculture, feed recipe, floating, pellets, growing system in polyculture.

Introduction

Aquaculture is expanding quickly across the globe as a result of two key factors: the rising global demand for shellfish and the diminishing fish stocks in the seas. Aquaculture producers must equally emphasize environmental safety, economic success, and socially acceptable development, which are the principles of sustainability in current and future development, to avoid the errors made in the European agriculture and fisheries sector [1; 2]. A very important criterion for surviving the growing competition in the fish market is the excellent quality of the product associated with the quality of the meat and consumer preferences. Consumers are increasingly concerned about how fish is produced or what type of ingredients are used as feeder [3]. EU regulations and authorities also focus on food safety and traceability of production from "fork to plate". Therefore, modern agricultural systems must be able to adapt to the new conditions of drought caused by climate change [4; 5] and to meet the demanding requirements for ecosystem and environmental protection [6; 7]. Due to their own commercial interests and in order to meet customer expectations while complying with regulatory requirements, most supermarket chains have introduced very strict rules regarding fish products. To sell fish through this important market channel, products must meet high-quality standards [8-10]. The food offered to fish is assimilated and used as energy necessary for vital activities, including growth. The definition is simple, but what needs to be specified is that, in the case of fish, it is not only the abundance and quantity of feeding that are sufficient, but also the quality. The feeder composition in terms of fats, proteins, carbs, vitamins, and trace components is essential. The nature of the food taken by the fish, as well as the conversion coefficient, meaning the transformation of ingested food into fish meat, can vary greatly depending on the period of the year and the growth stage of the fish. In addition to all these, in an ecosystem, competition for food, whether intraspecific or interspecific, can lead to both growth retardation and starvation, as well as the elimination of the species from the food chain [11].

Feeding must provide fish with the necessary nutrients for growth (protein for structural role) and supply the essential energy for physiological processes (through the intake of carbohydrates and lipids for energy role). High-quality feed ensures good development, facilitates reproduction, prevents and treats diseases. Quality and quantity of feed are essential and inseparable aspects of fish feeding.

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Changes in fish performance due to nutrient intake represent a dynamic response that can be used to estimate adequate requirements for a fish species in different growth stages and different life cycle stages. An important characteristic of fish production is the supply of nutrients in adequate quantities so that performance and efficiency can be optimized. In recent years, mathematical models have been developed, and allow the prediction of growth response and food intake. Under normal conditions, the response to growth or deficiency of vitamins and minerals is the pathogenesis of deficiency or toxicity signs and morbidity [12; 13]. If the requirement for a particular nutrient is met and there are no obvious evident signs, the concentration of that specific nutrient derived from the growth and production model is considered adequate for practical formulation of feed. Animal feed production, including feed for livestock, poultry, and aquatic life, is a multi-step process that includes grinding, mixing, pelleting, and drying operations. The efficiency of small-scale processing equipment used in farming activities is limited, causing difficulties in animal feed production. The term "pellet" has been used in various industries to describe different types of agglomerates made from diverse raw materials. The combination of traditional methods and modern advancements derived from research has greatly helped in the production of animal feed by processing raw food items, [11; 12; 14; 15].

In the aquaculture sector, nutrition is a critical characteristic, as feed accounts for approximately 50% of the variable production cost. With the development of new and balanced commercial diets, fish nutrition has rapidly advanced in recent years, promoting fish growth and health. The development of new diets leads to meeting the demand for safe, quality products at affordable prices. The nutritional content of feed depends on the fish species being cultivated and the stage of life. When fish are grown in high-density indoor systems or confined in cages and cannot freely feed on natural food (such as algae, aquatic plants, aquatic invertebrates, etc.), they must be provided with a complete diet. On the other hand, supplementary diets (i.e. incomplete or partial) are only intended to help sustain the natural food available normally for pond or open water fishing. The fish species being cultivated is closely related to the nutritional content of the feed given and its life stage. A complete diet is provided to fish that are grown in indoor systems or confined in cages. In general, balanced diets for fish provide all the necessary ingredients (proteins, carbohydrates, fats, vitamins, and minerals) for the growth and development of fish. Most fish farmers use complete diets, typically composed of the following components: carbohydrates, 15-20%; proteins, 18-50%; lipids, 10-25%; water, < 10%; phosphorus, < 1.5%; ash < 8.5% and trace amounts of vitamins and minerals. Protein requirements are typically lower for herbivorous (plant-eating) and omnivorous (plant and animal-eating) fish compared to carnivorous (meat-eating) fish.

Protein requirements are generally higher for fish grown in high-density systems (such as recirculating aquaculture) compared to low-density culture (such as ponds). Protein requirements are generally higher for smaller fish and for fish in the early stage of life. As fish grow, their protein requirement typically decreases [10; 16; 17]. Protein requirements also vary based on the growing environment, water temperature and quality, and the genetics and feeding rates of the fish. Proteins and amino acids: fishmeal, soybean meal, fish hydrolysate, defatted milk powder, legumes, and wheat gluten are excellent sources of proteins. In addition, basic protein elements (free amino acids) such as lysine and methionine are commercially available to supplement the diet [18; 19]. Lipids: marine fish oils, such as menhaden, and vegetable oils from canola, sunflower, and flax seeds, are common sources of lipids in fish feed. Carbohydrates (starch and sugars) are the least expensive sources of energy for fish diets. Although not essential, carbohydrates are included in aquaculture diets to reduce feed costs and for their binding activity during feed manufacture. Dietary starches are useful in the extrusion manufacture of floating feeds [20-22]. Vitamins and minerals: the variety and quantity of vitamins and minerals are so complex that they are usually synthetically prepared and commercially available as a balanced, premixed blend known as a vitamin or mineral premix. This premix is added to the diet in generous amounts to ensure that adequate levels of vitamins and minerals are provided to meet dietary requirements. Carbohydrates (starch, cellulose, pectin) and various other polysaccharides, such as extracts or derivatives from animals (gelatin), plants (arabic gum, carrageenan) and marine seaweeds (agar, carrageenin and other alginates) are also popular binding agents [23; 24].

In order to determine an improved fish growing technique for polyculture in closed ponds, the present paper proposed testing several feeding formulas, followed by a statistical analysis of the results. The evaluations were carried out in two pools with different characteristics, for three types of fish, which were raised together. The results of the research make possible to better understand the relative growth of fish populations in terms of mass, length, height, and thickness as well as the proper approach that stimulates the highest growth across different fish species. Descriptive statistical estimators allow illustration of growth differences associated with the adopted feeding recipes, especially in terms of result dispersion and relevance.

Materials and methods

Fish feeder is an essential element of fish husbandry and is critical for maintaining the health and vitality of fish raised in captivity. Fish are cold-blooded animals that belong to *phylum Chordata* and are found in virtually all aquatic environments, including rivers, lakes, and oceans. Fish play a significant role in aquatic food chains and are an important source of food for humans. To maintain healthy and thriving fish populations in captivity, it is essential to understand their dietary requirements and provide them with a balanced diet. There are many types of fish food available on the market, each with its own set of nutritional benefits and drawbacks. In general, fish food can be divided into two broad categories: natural and artificial. Natural fish food refers to food that is sourced from the natural environment, such as live or frozen fish, worms, crustaceans, and plant material. Artificial fish food refers to food that is manufactured and processed, such as flakes, pellets, and frozen cubes. Natural fish food is often considered the best choice for fish because it closely resembles the diet that fish would consume in their natural environment. Live or frozen fish, for example, provide a balanced diet of proteins, fats, and other nutrients that are essential for fish growth and survival. However, natural fish food can also carry parasites and disease, which can be transmitted to captive fish populations. It is important to thoroughly rinse and disinfect natural food sources before feeding them to fish. Artificial fish food is a more convenient and safer alternative to natural fish food. Artificial food is usually processed to remove parasites and disease, making it a safer option for captive fish populations. Artificial food is also formulated to provide fish with a balanced diet that meets their nutritional requirements. Flaked fish food, for example, is often formulated to provide a balanced diet of proteins, fats, and other essential nutrients. Pellets and frozen cubes offer similar benefits and are a convenient and easy-to-use alternative to flaked food.

The two fish breeding basins that are being used in the study are made of reinforced concrete and were constructed for experimental uses. They are 7 meters long, 4 meters broad, and 3 meters deep. The basins are equipped with two aeration systems each, a continuous monitoring system to control process parameters and water quality.

In the article on the production of feed pellets, an existing technological line at INMA Bucharest was used, consisting of a mill for fine grinding of cereal food products, a homogenization system for powdered raw materials, and equipment for pelleting pulverized materials to produce feed pellets. The pelleting equipment is equipped with a spraying system for additives and other liquid components that are part of the different fish feed pellet recipe mixtures. To produce the pellets used in the experiments, an extruder designed and executed by the institute was used. The pelletizer is composed of a feed inlet component (hopper) and a pelletizing chamber, which is a shaft equipped with rollers that transports and presses 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 [13]. The capacity of the technological line used is small, only 100 kg of finished material per hour for feed pellets, and its role is to produce and optimize various feed recipes for the aquaculture sector. Depending on the raw materials used in the manufacturing process, the feed pellets can either float on the surface of the water in the basin/tank or sink to provide fish feed on the substrate (bottom) of the basin/tank. For the current experiment, floating pellets were produced using the technological line. One of the key benefits of floating pellets for fish feed is that they can help improve feeding behavior in fish populations. Floating feed pellets remain on the surface of the water, making them more visible to fish and encouraging them to feed more readily. This, in turn, can result in improved growth rates, higher survival rates, and better overall health in fish populations. Floating feed pellets, on the other hand, remain on the surface of the water, where they are more readily consumed by fish, reducing waste and improving feed efficiency.

The raw material used in the production of floating pellets was a cereal mix made from corn, wheat, soy, sunflower, and fish meal. Sunflower oil mixed with flaxseed oil and an adjacent oil rich in omega-6 and omega-3 fatty acids (fish oil) was used as a source of lipids. Fat is a rich source of energy and is also essential for maintaining healthy skin and scales, as well as supporting healthy reproductive and immune systems. Fish oil provides a balanced ratio of omega-3 and omega-6 fatty acids, which are important for maintaining the overall health of fish populations. A complex formulated mix, containing vitamins A, D, E, and K, as well as minerals such as calcium, phosphorus, and iron were used as a source of vitamins. In addition to these essential ingredients used in the manufacturing recipe, a buoyancy extract based on cuttlefish/octopus/crustacean/mollusk/oyster extracts containing phospholipids and valuable amino acids for fish nutrition was also used (Fig 1.).

Fig. 1. **Complex mix recipes and 8 mm floating feed pellets**

To observe the effectiveness and high nutritional contribution to the fish population, measurements were taken of the length of the fish, maximum body height, and body thickness. All of these operations were carried out periodically throughout the experiment without harming the fish during the collection of experimental data. The equipment used for weighing included an electronic scale with a range of 0-2.5 kg, a tape measure with a range of 0-2 m, and a digital caliper with a range of 0-0.25 m.

To evaluate the characteristics of fish growth, samples were taken weekly with the fishing net (keeping 12 fish for measurements), and the average value was noted in the statistics. To be able to catch fish from all the pool's heights in one pass, the option of employing a net for sampling was selected.

Four different fish feeding recipes were used in the present study, having the following composition: R1- cereal material + fish meal + yeast extract + krill meal + buoyancy extract; R2- – cereal material + fish meal + yeast extract + starch + cardamom flour + buoyancy extract; R3- – cereal material + fish meal + yeast extract + algae extract + buoyancy extract; R4- – cereal material + fish meal + yeast extract + garlic extract + buoyancy extract.

Calculating the performance indicators

In order to highlight the performances of the four types of fish feeding recipes, relative estimators have been used, as follows.

a) Average relative increase of fish mass:

$$\delta m_{rel}(p,b,R)=\frac{m(p,b,R)-m_0(p,b)}{m_0(p,b)}\cdot 100, \quad (1)$$

where $m(p, b)$ – average final mass of fish (after four months of growth);
p – type of fish (common carp, Asian carp and Prussian carp);
b – is the growth basin (1 or 2);
$m_0(p, b)$ – average initial mass of the fish;
$\delta m_{rel}(p, b, R)$ – average relative mass growth of the fish, which is expressed in percentages;
R – type of the feeding recipe used.

b) Average relative increase of fish length:

$$\delta L_{rel}(p,b,R)=\frac{L(p,b,R)-L_0(p,b)}{L_0(p,b)}\cdot 100, \quad (2)$$

where $L(p, b)$ – average final length (after four months of growth) of the fish;

$L_0(p, b)$ – average initial length of the fish;
$\delta L_{rel}(p, b, R)$ – increase in the average relative length of the fish, which is expressed in percentages.

c) Average relative increase in the height of the fish:

$$\delta h_{rel}(p,b,R) = \frac{h(p,b,R) - h_0(p,b)}{h_0(p,b)} \cdot 100, \tag{3}$$

where $h(p, b)$ – average final height (after four months of growth) of the fish;
$h_0(p, b)$ – average initial height of the fish;
$\delta h_{rel}(p, b, R)$ – increase in the average relative height of the fish, which is expressed in percentages.

d) Average relative increase in fish thickness:

$$\delta g_{rel}(p,b,R) = \frac{g(p,b,R) - g_0(p,b)}{g_0(p,b)} \cdot 100, \tag{4}$$

where $g(p, b)$ – average final thickness (after four months of growth) of the fish;
$g_0(p, b)$ – average initial thickness of the fish;
$\delta h_{rel}(p, b, R)$ – increase in the average relative thickness of the fish, which is expressed in percentages.

Results and discussion

The main fish-size results that were obtained during the surveys are shown in Table 1, while the variations were analyzed for the three types of fish and as an average in Figures 2-9.

Table 1

Descriptive statistical characteristics for fish weight growth

Fish type	Mean value	Standard deviation	Mean deviation coefficient
Common Crap (*Cyprinus carpio*)	288.563	24.765	8.582
Asian Crap (*Ctenopharyngodon idella*)	266.500	43.053	16.155
Prussian carp - CARAS (*Carassius gibelio*)	215.800	34.991	16.215

Using equations (1)-(4), we obtained the representations of mass increases, the increase in length, height and thickness, depicted in Figures 2-5. It is observed that the mass growth is comparable in the two fishing ponds, but differs appreciably depending on the feeding recipes administered. Mass growth is high in carp, more homogeneous in common carp (coefficients of variation and average standard deviation lower than in Asian carp) and has a greater spread in the case of the R4 feeding recipe, in Asian carp. Prussian carp has final mass distribution characteristics similar to Asian carp.

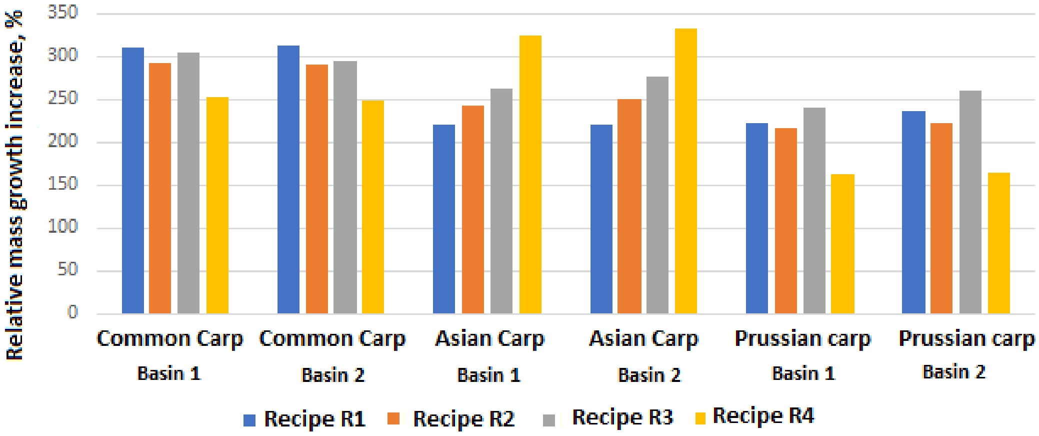

Fig. 2. **Variation of relative mass growth, depending on the type of fish and the fishing basin used**

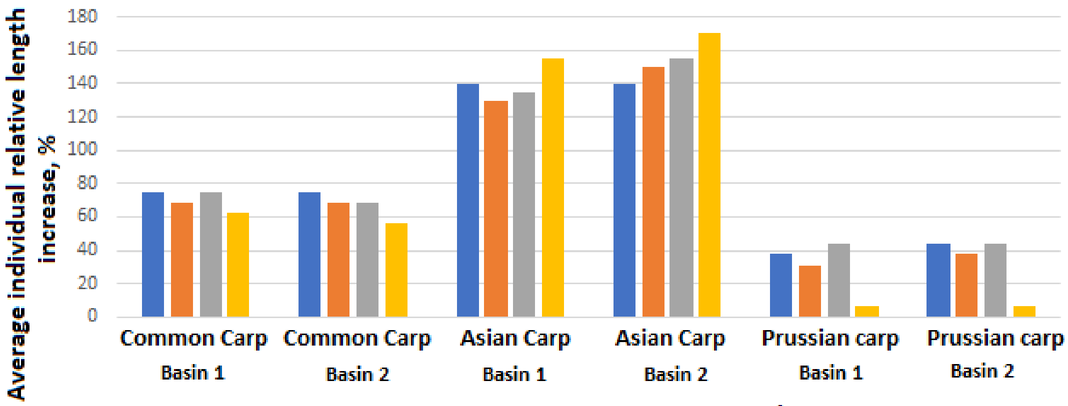

Fig. 3. **Variation of relative length increase with the type of fish and the pool used**

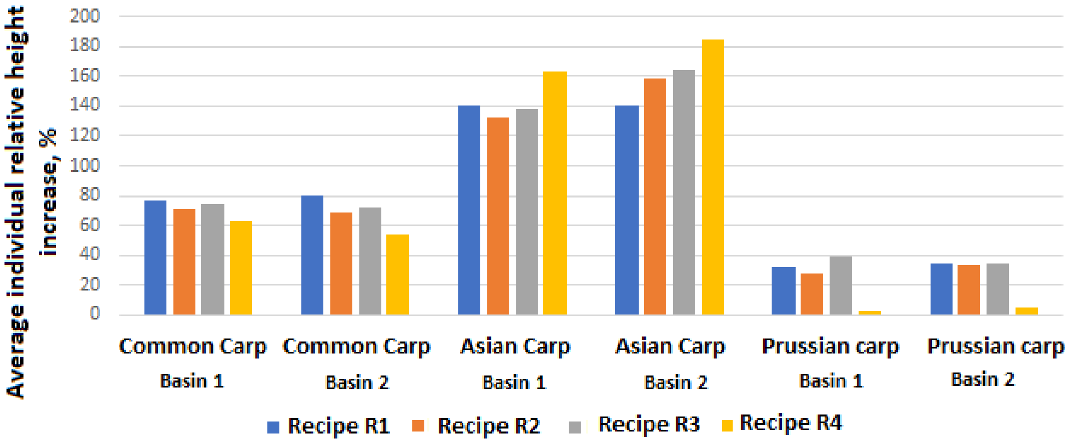

Fig. 4. **Variation of relative height increase with the type of fish and the pool used**

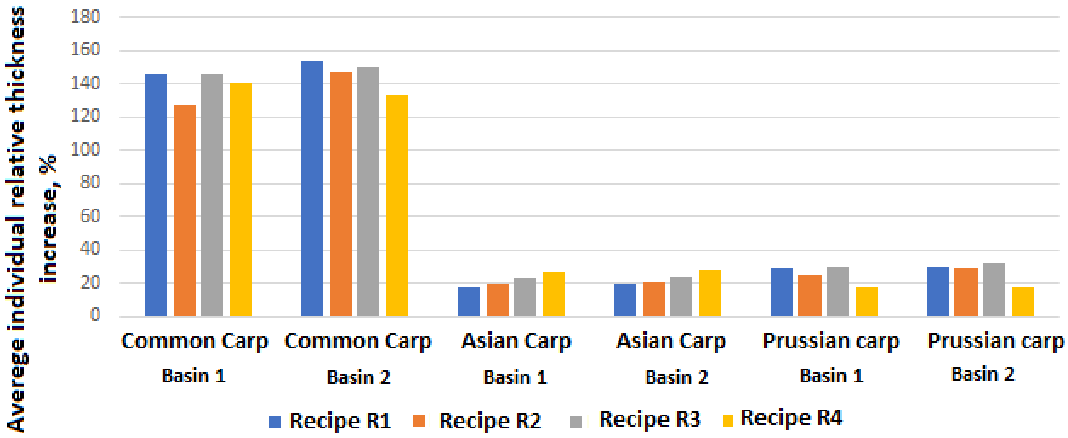

Fig. 5. **Variation of increase in relative thickness with the type of fish and the pool used**

In a similar way, the variation of the score recorded by each type of feeding treatment for each type of fish was conducted. The score is calculated by assigning a maximum score of 4 points to the method that achieves the highest performance for fish (mass, length, height and thickness, for each category of fish) and in descending order, 3, 2 1 points for places 2, 3 and 4. In case of a tie, the points of the places are added up and distributed equally to each treatment that achieves the same performance.

Conclusions

1. The experimental results obtained from the study enable for a better understanding of the relative increase in mass, length, height, and thickness of the grown fish, related to various feeding strategies. The evaluation was carried out according to three categories of fish and two breeding basins.
2. The developed descriptive statistical estimators allow highlighting growing differences associated to the adopted feeding recipes, especially regarding the dispersion of the results. The score of the nutritional feeding practices shows that, on the whole of the two basins, in the case of the relative mass growth estimator, the common carp grows more by applying the R1 recipe, the Asian carp prefers the R4 recipe, the crucian carp prefers the R3 recipe.
3. However, the average estimation over the three fish species shows that the R3 feeding-treatment is better accepted by all three families.
4. Regarding the relative increase in the length, the conclusions are similar, with the observation that in the case of mediation, nutritional treatments R1 and R3 register close relative scores, so that the application will depend on the cost price and/or the clients' options. Similar conclusions are obtained in terms of the relative increase in the height and thickness of the fish.
5. Growing fish in polyculture brings economic benefits through a better management of the fish pond. However, it is frequently preferred that the most expensive fish in the pond to be raised quicker, and this aspect further complicates the optimization calculation regarding the polyculture systems.

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