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Article

Analysis of Factors Influencing the Use of Extruder for Fish Feed Manufacturing in Benin

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Abstract: Fish feed is a sensitive operation in fish farming, particularly in terms of economics and quality. The aim of this study is to assess the factors affecting fish feed manufacture in Benin and the use of the extrusion process in such manufacture. The survey questioned 385 producers in agricultural development pole 7 about their socio-economic profile and their understanding of the problems encountered in fish feed manufacture. The results showed that fish feed manufacturers accounted for 22.86% of the producers surveyed and the use of pellet extruders accounted for only 1.8% of the total number of fish farmers. The factors "study environment" and "type of feed purchased" determined the choice of fish feed manufacturer. The problems encountered in the manufacturing process are clogging, high energy consumption, buoyancy of the feed produced, and high production costs. For fish farming in Benin, it would be advisable to design a mini-extruder with lower acquisition costs, capable of producing floating pellets in a variety of ranges to meet the needs of small-scale fish farms.

Keywords: *Mini-extruder; fish; floating pellets; Benin.*

1. Introduction

In Benin, fishing and aquaculture are of considerable importance to the economy. They contribute 3% to the national GDP [1] and employ 25% of the working population in the agricultural sector [2]. However, the majority of fisheries production does not come from this sub-sector. The country's large volume of fish products depends on the ever-increasing import of frozen fish [3]. In addition, Benin's fisheries sector is heavily dependent on the contribution of capture fisheries [4]. As specified by [5], "capture fisheries remain essential for the food and nutritional security of the majority of poor populations and often remain their main source of fish".

As in most coastal countries with limited resources, the fisheries resources of the marine and continental ecosystems are under enormous pressure due to growing food needs, poverty, climate change, and irrational fishing practices by fishermen on the water [6]. Today, these factors are gradually ruining the local fishing economy and exacerbating poverty among the fishing population and undernourishment in general. Aquaculture appears to be a suitable way of overcoming the seasonal and geographical availability of fish products by making them available throughout the year and across the country [4].

Aquaculture is the fastest-growing farming method [7]. Once marginalized, this activity has taken off with the support of the government through development programs and projects (PACODER, PADPPA, ADEFIH, PADA, PROVAC, etc.) and professional training for fish farming specialists. Since 2015, there have been 1,089 individual fish farmers and 80 active fish farming groups [8]. In the Government Action Programmed 2016-2021, continental aquaculture is one of the high-value-added agricultural sectors identified to accelerate agricultural growth.

A review of progress in aquaculture in Benin has shown that, overall, Beninese fish farmers are relatively inefficient technically. In addition to the level of education and managerial capacity of producers, the funds allocated to feeding aquaculture species constitute a non-negligible weight for the development of fish farmers. They spend an average of FCFA 240,000 on feed per production cycle, i.e. FCFA 465/m2 [4]: a high investment, according to [9] and [10].

In this respect, high-performance, economically and environmentally sustainable fish feed is one of the main concerns of the fish farming world [11,12]. Feed for aquaculture must have high levels of digestible energy and amino acids available for growth and must be administered in the form of pellets or extrudes [13]. Extrusion is the only technology that allows floating feeds to be manufactured [13]. It provides greater stability on the water surface and improves production efficiency and versatility [14]. In Benin, even though the environment is favorable for aquaculture, the majority of fish farmers are not familiar with extrusion technology, preferring to acquire high-quality seed and feed at a high price [6].

The objective of this work is to analyze the factors hindering the development of fish feed extrusion in Benin and to identify improvement factors for the design of a mini-extruder responding to fish farmers' problems.

2. Materials and Methods

2.1. Description of the study environment

The study area chosen in the Republic of Benin is agricultural development pole 7. This is the fishing and market gardening area of the river-lagoon complex of southern Benin and the Mono and Ouémé valleys. The study area has a Sudano-Guinean climate with two rainy seasons alternating with two dry seasons, with rainfall varying between 900 mm and 1400 mm [15]. The soils in this zone are composed of Vertisols and hydromorphic soils of alluvial or colluvial origin (Fluvisols and Gleysols) that are flooded by river flooding (MAEP, 2020). Tropical ferruginous soils and desaturated ferralitic soils are also found in the northern part of the zone. Aquaculture, rice growing and market gardening are the dominant activities. The area has a unique hydrological feature, with a low water flow and a very slow drying-up period of 60 days. Fishing is much more flourishing here, given the size of the bodies of water. It is a region with a high level of fish farming and fishing activity [15]. This area includes the departments of Ouémé, Atlantique, and Mono.

2.2. Sampling method

According to the reports of the Territorial Agency for Agricultural Development (ATDA) 7 of 2019, the sampling frame used indicated 1052 producers listed as fish farmers in the study area, including 341 in the Atlantic, 180 in the Mono, and 531 in the Ouémé. According to statistical data, the population of fish farmers in Benin is 2027 [4]. The formula for calculating the sample size is as follows [16]:

$$n = \frac{Z_{\frac{\alpha}{2}}^2 \times p \times (1-p)}{i^2}$$

n: the sample size

z = confidence level according to the reduced centered normal distribution (for a confidence level of 95%, z = 1.96)

p: estimated proportion of the population that presents the characteristic. Here, p is the proportion between the number of fish farmers in the study area (ATDA 7) by the number of fish farmers in Benin; p = 1052/2027 = 0.519

i = tolerated margin of error or degree of precision (for example, we want to know the real proportion to within 5%).

In this study, the sample size is n = 38.5 people. By department, the sample size is 125 in the Atlantic, 66 in the Mono, and 194 in the Ouémé.

The study took place from June 3 to 15, 2024 in the three targeted departments: Atlantique, Mono, and Ouémé. A total of 11 municipalities were randomly selected and covered at a rate of 4 municipalities (Abomey-Calavi, Allada, Tori-Bossito, Zê) in Atlantique, 4 municipalities (Comè, Grand-Popo, Houyogbé, Lokossa) in Mono and 5 municipalities in Ouémé (Adjohoun, Porto-Novo, Avrankou, Bonou, Dangbo). The choice of districts, villages, and fish farmers was made according to the availability of respondents randomly selected from the ATDA 7 database. The number of fish farmers per municipality is as follows in Table 1.

Table 1. Distribution of fish farmers by municipality.

Departments	Communes	Number of fish farmers
Atlantic	Abomey-Calavi	36
	Allada	41
	Tori-Bossito	07
	Ze	41
	Total 1	125
Mono	Come	21
	Grand-Popo	16
	Houeyogbe	03
	Lokossa	26
	Total 2	**66**
Oueme	Adjohoun	41
	Avrankou	41
	Bonou	38
	Dangbo	44
	Porto-Novo	30
	Total 3	**194**
Total		**385**

2.3. Data collection and analysis

The data collected concerning the socio-economic profile of the fish farmer (gender, age, experience, level of education, production environment, type of fish feed purchased, self-producer status), the type of feed manufacture (extrusion, manual, mechanical), as well as the difficulties associated with fish feed manufacture and their perception of feed extrusion.

The survey data were analyzed using R 4.1.3 software [17]. Mean values were calculated and presented in table or histogram form.

To examine a potential relationship between socio-economic factors and the choice of fish feed manufacture, the Chi-square test was used to study relationships between two qualitative variables. To study the relationship between a qualitative variable and a quantitative variable, the Student test or the Wilcoxon test was used, depending on the results of the normality of the samples and the equality of variances. The significance threshold is 0.05.

3. Results and Discussion

3.1. Socio-economic characteristics of respondents

The respondents were fish farmers, a fish study laboratory, and fish feed production units with modern equipment. The department of Ouémé had the largest number of producers surveyed. Next came the Atlantic department, followed by the Mono department.

Of those surveyed, 85.7% were men, making them the majority in the various departments visited (Table 2). This shows that the activity remains the preserve of men [18], despite the many efforts of gender policies. This could be explained, on the one hand, by the fact that very few women own land [19]. On the other hand, fish farming is a risky and uncertain activity, which explains why it has remained the preserve of men [20].

The age groups with the highest concentration of producers are 30-39 (37.7%) and 40-49 (48.9%) (Table 2). These results disagree with those of [21], who reported that fish farmers were older. This rejuvenation may be explained by the action of projects and institutions promoting fish farming in these localities. Secondary education was the most common level of education, with 36.7% for secondary 1 and 24.2% for secondary 2, compared with 22.4% for primary education (Table 2). These results are in line with those of [22], which stated that the majority of fish farmers are literate, with more than a quarter having primary education and more than a third having secondary education.

In the Atlantic and Mono regions, few producers expressed a preference for purchasing a single type of feed, whether local or imported. Combining the two types of feed was the predominant choice of producers (Table 2). However, in Ouémé, producers preferred local products. Imported feeds came next (Table 2). In addition, the manufacture of fish feed involved only a small group of producers in the departments concerned. They represented 24.5% of those surveyed (Table 2). The majority of fish farmers in the Ouémé and Mono regions have been farming for between 10 and 14 years, while in the Atlantic region, the majority have less than ten years' experience. These results are corroborated by data from [22], which indicates that overall, fish farmers throughout Benin have less than 10 years' experience.

Table 2. Socio-economic characteristics of respondents.

Settings		**Work environment**		
		Atlantic	Mono	Oueme
Sex (%)	Female	4.7	2.3	7.3
	Male	27.8	14.8	43.1
Age (%)	≤ 29 years old	-	-	0.5
	[30-39 years]	13.5	7.8	16.4
	[40-49 years]	12.2	6.8	29.9
	50 years ≥	6.8	2.6	3.6
Experience (%)	≤ 10 years	16.9	7.8	14.3
	[10-14 years]	12.5	8.6	26.2
	15 years ≥	3.1	0.7	9.9
Level of education (%)	Not in school	4.7	2.3	2.6
	Primary	8.1	6.2	8.1
	Secondary I	9.4	3.9	23.4
	Secondary II	5.7	3.4	15.1
	University	4.7	1.3	1.3
Fish feed buyer (%)	Imported food only	0.8	0.5	39.7
	Local food only	0.3	0	67.5
	Local + imported food	31.4	16.6	3.9
Self-producer of fish feed (%)	No	21.6	12.9	41.0
	Yes	10.9	4.2	9.4

3.2. Factors determining the manufacture of fish feed

This section analyses the factors influencing the use of fish feed manufacturing equipment in Benin. First, it highlights the socio-demographic factors that influence the choice of feed manufacture for farmed fish. Table 3 presents the results of the potential relationships between the choice of fish feed manufacture and the socio-economic criteria identified. The results indicate that the respondent's level of education and sex had no significant influence on the choice of feed manufacturer ($p = 0.7366$ and $p = 0.1829$ respectively).

However, the purchase of feed for their fish production did have a significant influence on producers' choice of fish feed manufacture ($p < 0.001$). Analysis of the residuals from the Chi-square test showed that the variable ‘Fish feed manufacturer’ was over-represented in the ‘Buyers of local feed only’ and ‘Buyers of imported feed only’ groups, and to a lesser extent in the ‘Buyers of all types of feed’ group (Table 3). More specifically, buyers of imported feed only were less likely to produce their fish feed (coeff. = -6.05 ≤ -2) (Table 3). In contrast, local feed purchasers were more likely to produce their feed (coeff = 6.78 ≥ 2). Purchasers of any type of fish feed were also more likely to produce fish feed (coeff = 2.89 ≥ 2). Indeed, according to the survey, the local feeds acquired by producers are based on harvested products (soya, maize, cotton, moringa leaves, etc.) of low quality despite their composition [23,24]. Their protein content is highly variable and unreliable.

Table 3. Relationship between “Self-producer” of fish feed and “Production environment”, “Education level”, “Gender”, and “Feed type buyer”.

	Pearson's Chi-squared test						
	X-squared	df	p-value		Residue analysis		
Self-producer vs. Production environment	9,3233	2	0.009		"Imported Power Supply"	"Local Power Supply"	“Imported or local power supply”
				" Yes "	3.44*	-3.85*	-1.64
				" No "	-6.05*	6.78*	2.89*
Self-producer vs. Level of education	1.9955	4	0.7366				
Self-producer vs. Sex	1,774	1	0.1829				
Self-producer vs. Food buyer	120.26	2	< 0.001		"Atlantic"	"Mono"	"Ouémé"
				" Yes "	-1.18	0.02	0.94
				" No "	2.08*	0.03	1.65

*Food: Fish feed; *: Coefficient significant if greater than the absolute value of 2*

Imported feeds (Biomar, Aliaqua, Raanan, Aqua-fish) are of better quality, with higher protein levels that promote rapid fish growth [9,24]. They are generally buoyant and have a good texture and shape, according to the buyers surveyed. The high cost of acquiring these imported feeds [9] is therefore not a barrier for these producers [6], who are less likely to produce fish feed themselves (Table 3). Nevertheless, feed manufacturing is the preserve of fish farmers who adopt both types of feed (local and imported) (Table 3). This production choice may be explained by the fact that fish feed manufacturing is financially and economically profitable [9]. It may also be the result of a trade-off between producer income, feed quality, feed availability, and the dietary sensitivity of the fish being reared.

In addition to the purchase of fish feed, the production environment had a significant influence on producers' choice of feed manufacture ($p = 0.009$) (Table 3). Feed manufacturing was over-represented only among Atlantic producers (coeff. = 2.08 ≥ 2) (Table 3). This may be explained by a higher proportion of self-producers in the Atlantic, despite their large number of modern functional feed manufacturing facilities, compared with the other départements. The study identified 11 functional extruders, including 6 in Ouémé and 1 in Mono, out of the 11 in ATDA.

In Table 4, the factors ‘age’ and ‘experience’ had no significant influence on producers' willingness to manufacture feed ($p = 0.906$ and $p = 0.89$ respectively).

Table 4. Relationship between the fish "Self-producer of fish feed" variables and the producer's "Age" and "Experience".

	Self-producer of food vs Age		**Self-producer of food vs. Experience**	
Variables	" No "	" Yes "	" No "	" Yes "
Shapiro-Wilk normality test	W = 0.97306 p-value = 2.76e-05	-	W = 0.96508 p-value = 1.739e -06	-
Conclusion	Non-normal distributions		Non-normal distributions	
Equality of variance	F = 0.98029 p-value = 0.8831		F = 0.8466 p-value = 0.3033	
Conclusion	Equal variances		Equal variances	
Wilcoxon test	W = 13566 p-value = 0.9061		W = 13548 p-value = 0.8908	
Conclusion	Independence between producer age and feed production		Independence between the number of years of experience of producers and feed production	

3.3. Fish feed production equipment

Among the 88 fish feed producers surveyed, mechanical equipment was the main feed manufacturing tool in the various departments (Figure 1). This equipment includes mills and mixing mills (Photo 1). The extruder made available to laboratories and producers in each department is part of the electrical feed production equipment. Seven extruders were found to be operational during the survey, but very little use was made of them due to various constraints (Photo 2).

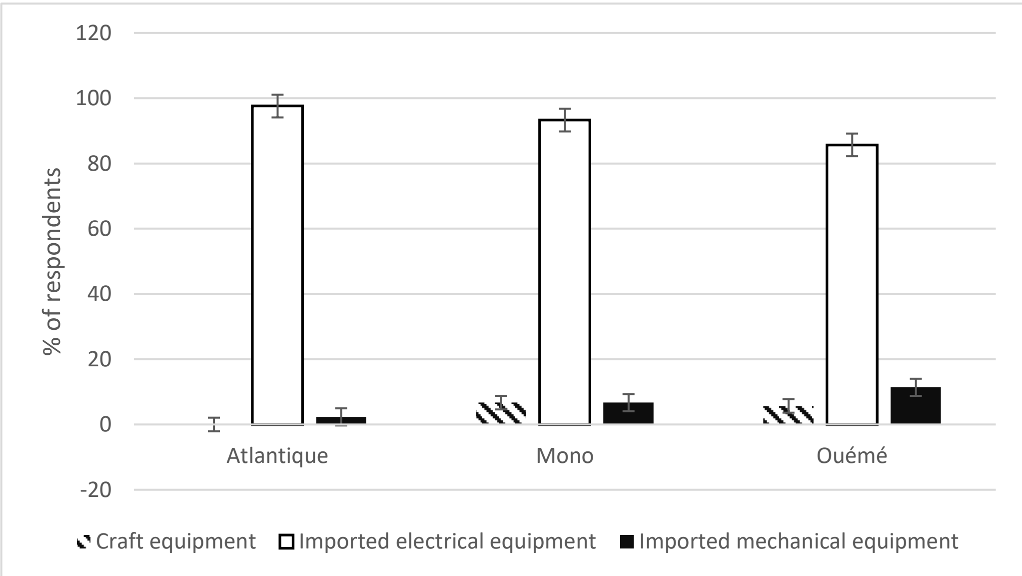

Figure 1. Fish feed manufacturing equipment by production environment.

Photo 1. Mr. Tinigo's grinder-mixer.

Photo 2. Mr. Kpossou's extruder.

3.4. Constraints on fish feed production

Fish farmers in Benin do not produce their feed, as can be seen from the feed production rate recorded among producers (22.85%). This self-production is not regular or periodic, and fish farmers devote most of their budget to systematically buying feed (100% of them prefer to buy fish feed). This is one of the obstacles to the ecological sustainability of fish farming systems in the sub-region [25]. Several factors have had a significant influence on feed production, whether artisanal or modern. These factors are technical, technological, and even economic (Figure 2). In this study, only the factors influencing modern fish feed manufacture were taken into account.

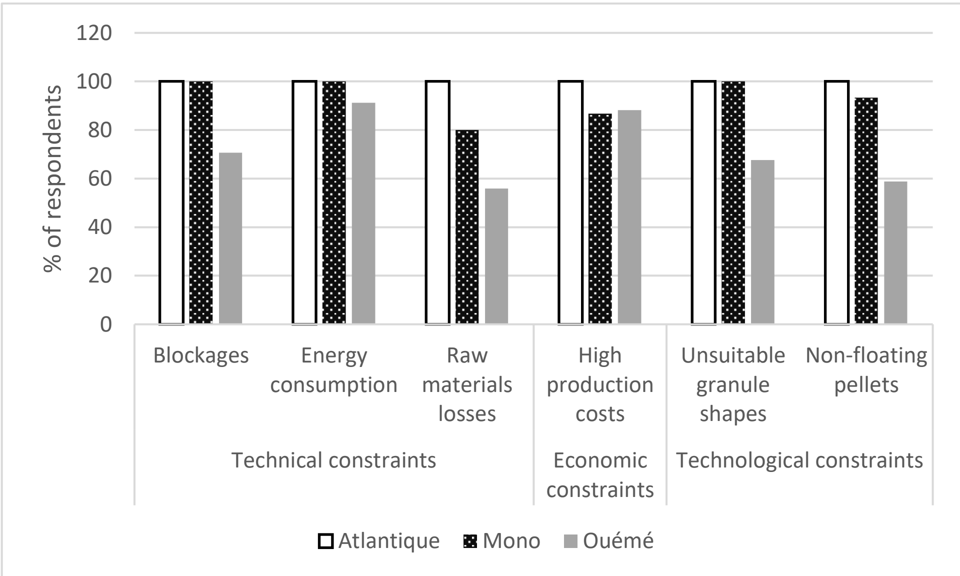

Figure 2. Constraints perceived by fish farmers in the feed manufacturing process.

3.4.1. Technical constraints

The most frequent technical problems include high energy consumption, equipment jamming, and loss of raw materials. Blockages occur when raw materials get stuck inside the machines during processing. Depending on the producer, there are various causes: the presence of foreign particles (sand, bits of wood), the introduction of a relatively large quantity of material into the equipment, or an excess of material in the machine. A high-tech design company integrating scientific research, design, and manufacture of feeding machines, including pellet feeding machines, etc., blockage or clogging of the food pellet production line is a common problem caused by the presence or appearance of certain sticky substances during the production process. This constraint causes significant downtime and can have an impact on equipment productivity [26].

Apart from clogging in the production machine, the other major constraint is energy consumption, whether electrical or mechanical (fuel). [26] considers this constraint to be a “major burden on production costs”.

The fish feed manufacturers added that the quantity of feed leaving the machine was generally less than the quantity of raw materials introduced. However, most of them estimated the loss at less than 10%.

3.4.2. Economic and technological constraints

In addition to the high cost of acquiring feed production equipment, the production costs were widely praised by producers. These costs are often linked to the purchase of raw materials, but more specifically to the costs of maintaining and repairing machinery during the feed manufacturing process. These conclusions are supported by those of [27], who indicate that maintenance costs are high when the technology is not available in developing countries. Indeed, in the case of extruders, production generally requires the assistance of a mechanic because of persistent jams.

Technologically, the problem of the buoyancy of the feed produced remains a major one for the fish farmers surveyed. This is also the conclusion of [24]. Indeed, for aquaculture rations, buoyancy durability, and stability in water are essential physical properties that impact feed quality [28,29]. The content of important constituent materials is usually at the origin of the non-flowability of manufactured fish feed. Indeed, depending on the age, size, and species of fish, aquaculture feeds often require between 26 and 50% protein [30] and are starch-based (corn, rice, etc.). Given that aquaculture feeds require large quantities of protein, the formulated feeds generally contain large quantities of protein and starch [30]: this negatively affects the buoyancy result of the products obtained.

3.4.3. Fish pellet extruder

The study revealed very little use of the extrusion process in the manufacture of fish feed. Barely 8% of feed manufacturers use extrusion as a manufacturing process. Among the fish farmers surveyed, the rate of use falls to 1.8%. Food extrusion is a process by which raw materials (maize meal, rice flour, etc.) are mixed, heated, and cut through a die designed to form an edible product (Harahap, 2019). This process is not new, since it dates back to 1935, when tools in the food industry began to diversify, particularly in processes requiring cooking or gelatinization [31]. The first extruded feeds for aquaculture were produced from the 1990s onwards [32].

Extrusion is, therefore, a high pasteurization method: a food or food material is pushed through a die of a given shape using a piston or screw [33]. As the most commonly used thermal process to produce aquaculture feeds [14], extrusion has the advantage of improving energy and nutrient digestibility in pigs [34] and poultry [35]. This process has several advantages over conventional steam cooking and pelletizing processes, including the ability to make in-line adjustments and achieve the desired physical characteristics, the manufacture of a wide variety of food products, the absence of effluents in the product, energy savings, and the processing of a wide range of materials, from the driest and most viscous to the wettest [36].

In fish farming, extrusion is the only technology that makes it possible to manufacture floating feeds for carp and tilapia, among others [37,38], thus meeting the technological problems of size and buoyancy (Figure 2) [39]. Finally, extruded feeds have other characteristics sought after in aquaculture nutrition, such as the inactivation of anti-nutritional factors present in plant ingredients in particular [40,41]. Several studies have concluded that extruded feeds are of superior quality. This is particularly true of the work by [42], which compared the effects of pressed and extruded feeds on the growth performance of rainbow trout (*Oncorhynchus mykiss*) and their environmental impact. The best conversion rate and the best efficiency coefficient were obtained with the extruded feed, which therefore proved to be more effective and less polluting. Further research showed that extruded feed contained more protein and fat and less moisture than pressed feed [42].

Given the possibility of producing a varied range of fish feeds adapted to the nutritional needs of the species grown, the design of a mini-extruder for manufacturing fish feed is, therefore, relevant in Benin. The machine would have to operate with as little energy as possible. The design would be based on a single-screw extruder, which is more widespread on the market and less expensive due to the high manufacturing and maintenance costs of twin-screw extruders [43]. Less imposing than the [10] device, the mini-extruder to be designed would be capable of producing the quantity of pelleted feed needed for a small-scale farm. This will be done using local materials, purchased at local markets, to overcome the problems of buying expensive imported extruders.

4. Conclusions

This study shows that aquaculture in Benin is in great need of modernization. The fundamental problem facing this activity is the production of low-cost, high-quality feed for the fish. Feed production is currently hampered by several technical, technological, and economic factors. To boost production and increase producers' incomes, it is therefore necessary to motorize the feed manufacturing process. It is possible to design a mini pellet extruder, using local materials and with a high production capacity, at a lower cost than imported extruders. The design, construction, and performance analysis of this extruder will be the subject of future research reports.

Conflicts of Interest: The authors declare no conflict of interest.

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