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Evaluation of a pilot sustainable aquaculture module

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ABSTRACT

Objective: The primary objective of this study was to evaluate the effect of an alternative feed throughout the production cycle of a sustainable aquaculture system using basa fish (*Pangasius hypophthalmus*) approximately three months of age.

Design/methodology/approach: The study was conducted during the Fall-Winter 2023-2024 period in the municipality of Paso de Ovejas, Veracruz, in collaboration with a partner aquaculture production unit that provided the necessary conditions for implementation of the experimental protocol. The assessed variables included the nutritional characterization of the formulated alternative feed and morphometric parameters (length, width, and weight) of the cultured organisms. In addition, systematic water quality monitoring was conducted, incorporating key physicochemical indicators essential for optimal species development. Three thousand fish were used per treatment and in the control group, with a stocking density of six organisms per cubic meter.

Results: The alternative feed exhibited a moderately high protein content (21.6%), which corresponded to an approximate 100% increase in body weight relative to initial biomass. Water quality parameters remained within acceptable ranges for the cultivation of this species, thereby supporting appropriate animal welfare conditions. No significant differences were observed between the treatment and control groups.

Limitations/implications: A primary limitation was the difficulty of inducing basa fish reproduction under *ex situ* conditions, as this species requires specific environmental factors that are challenging to replicate outside its natural habitat.

Conclusions: Incorporating alternative feeds into sustainable aquaculture systems can achieve performance comparable to commercial diets while reducing production operating costs by up to 25%.

Keywords: Alternative feed; sustainability; aquaculture; Veracruz.

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INTRODUCTION

The growing urgency to mitigate the environmental, economic, and social impacts associated with the excessive and indiscriminate use of agrochemicals in industrial agroecosystems underscores the need to reconfigure agricultural systems toward more resilient and sustainable models. In this context, the design of self-sufficient agroecosystems characterized by minimal dependence on synthetic inputs and grounded in diversification

through polycultures has been proposed as a viable alternative. This strategy aims to enhance functional biodiversity, thereby contributing to the reduction of multiple challenges associated with conventional agriculture, including global warming (Bianconi *et al.*, 2013; Altieri & Nicholls, 2017; Altieri, 2018). These transformations have prompted significant social and structural changes both within and beyond agroecosystems, revalorizing the strategic role of agrifood production, raw material generation, and the provision of ecosystem services from a sustainability-oriented perspective (Andersen *et al.*, 2013).

Furthermore, per capita fish consumption in Mexico is approximately 12 kg per year. The country ranks as the world's second largest importer of frozen basa fillets from Vietnam and the second largest importer of whole and filleted tilapia from China (Platas-Rosado *et al.*, 2021). Domestically, aquaculture possesses the productive capacity necessary to meet current and future demand for fish and seafood, including export potential. This capacity is partly attributable to the favorable feed conversion ratios of these species compared with other livestock species of agricultural interest (Olsen & Hasan, 2012).

Sustainable food production addresses the environmental, economic, and social challenges generated by high input chemical agriculture (Reganold & Wachter, 2016). In this context, sustainable aquaculture has emerged as an alternative approach aimed at mitigating the environmental, economic, and social limitations that conventional intensive aquaculture systems have been unable to adequately resolve (Sicuro, 2019; Ahmed *et al.*, 2020). Among the strategies applicable to sustainable aquaculture, practices such as zoning and circular economy approaches are particularly prominent. Zoning, in particular, constitutes a spatial planning tool that enables the assessment of the carrying capacity of natural resources within a defined area in order to respond in a balanced manner to the demands for goods and services of local populations. This practice has gained increasing relevance in recent years due to accelerated global population growth, which exerts mounting pressure on finite resources such as land and water. Zoning is therefore essential for anticipating and strategically managing current and future challenges facing productive systems, including food price volatility and imbalances between supply and demand. Its implementation facilitates the rational use of resources, promoting sustainability in terms of ecological balance as well as long-term economic and social viability (FAO, 2007).

The circular economy has emerged as a sustainable and economically viable alternative to the linear economic model, with the primary objective of preserving and enhancing natural capital. It fosters innovation in business models by promoting the valorization of waste and by-products for the development of value-added products. In this way, the circular economy seeks to provide a second life to by-products generated from major agroindustrial activities (Cerdá & Khalilova, 2016; Geisendorf & Pietrulla, 2018).

Some of these by-products can be used to formulate fermented and/or pre-digested feeds for aquaculture. Feed costs in aquaculture production systems account for approximately 50% to 70% of total operational expenditures (Khan *et al.*, 2018). The use of conventional compounded feeds may be reduced by approximately 20% to 50% through the implementation of fermented and pre-digested feeds produced from raw materials generated by aquaculture producers themselves or derived from local agro-industrial residues. This substitution has the potential to lower feeding costs by up to

50%, while simultaneously improving fish gut microbiota and metabolic performance (Gamble *et al.*, 2015; Samaddar, 2018; Yin-Mo *et al.*, 2020; Yao *et al.*, 2020; Omont *et al.*, 2021). In addition, these alternative feeds may enhance protein availability and reduce anti-nutritional factors, thereby improving the environmental and economic performance of aquaculture systems (Li *et al.*, 2019; Moniruzzaman *et al.*, 2020; Dawood & Koshio, 2020).

In addition, biofloc technology can address challenges such as water scarcity. This system is primarily composed of microorganisms that enhance intestinal enzyme activity in cultivated aquatic species, thereby significantly reducing the need for water exchange. The use of these microorganisms has been shown to improve feed conversion ratios in fish and shellfish. Moreover, biofloc has been reported to contribute to disease control due to its function as a natural probiotic, potentially reducing the use of antibiotics, antifungals, and other feed additives (Ahmad *et al.*, 2017; Khanjani & Sharifinia, 2020). This technology offers advantages that enhance both production and productivity in aquaculture systems by improving water quality through the regulation of carbon and inorganic nitrogen levels within culture ponds (Crab *et al.*, 2012; Bossier & Ekasari, 2017). The objective of the present study was to evaluate the effect of an alternative feed produced *in situ*, compared with commercial feed, during the production cycle of a sustainable aquaculture system using basa fish approximately three months of age.

MATERIALS AND METHODS

Study area

The design and implementation of the sustainable aquaculture module were conducted in the municipality of Paso de Ovejas, Veracruz (Figure 1). The municipality is located between 19° 08' and 19° 22' N and 96° 20' and 96° 38' W, at elevations ranging from 10 to 400 m (SEFIPLAN, 2021). Project implementation was carried out in collaboration with a local aquaculture production unit, which served as the cooperating farm throughout the operational phase of the study.

The municipality is located in a humid tropical climate zone, predominantly characterized by the AW1 climate type, which covers approximately 60% of the municipal

Figure 1. Geographic location of the municipality of Paso de Ovejas, Veracruz, and satellite view of the cooperating aquaculture farm.

territory, and the AW0 type, present in the remaining 40%. Both correspond to variants of a warm subhumid climate, characterized by a mean annual temperature of approximately 22 °C and annual precipitation ranging from 1,000 to 1,500 mm (CONABIO, 2022).

Treatments

The experimental design included one treatment (T_1) and one control (T_0). The treatment consisted of a sustainable alternative feed and included two replicates (R_1 and R_2). This feed was administered to basa fish approximately three months of age until completion of the production cycle during the Fall-Winter 2022 season. The T_1 diet consisted of a mixture of fermented and pre-digested corn, taro, and cassava, whereas T_0 received a commercial feed.

For the preparation of the sustainable alternative feed, guidelines developed by Bioaquafloc were used as a reference. The raw materials for T_1 were first ground and then boiled at 100 °C for 1 hour. Subsequently, the mixture was placed in containers located in a covered area exposed to sunlight. Whey was added as an additional protein source and probiotic agent to accelerate fermentation and predigestion. The mixture was allowed to ferment for three to five days under aeration until it developed a dark coloration and a sour odor.

During the fermentation process, fly larvae appeared and were incorporated as an additional protein source in the diet of the cultured organisms. Once the process was completed, the feed was supplied to three tanks. Additionally, biofloc technology was applied to reutilize residual organic matter within the tanks and to improve water quality.

Variables evaluated

A physicochemical analysis of the alternative feed was conducted in accordance with the standards of the Association of Official Analytical Chemists (AOAC) (Helrich, 1990). Monthly biometric measurements were performed on 32 organisms per tank from three circular tanks (25 m in diameter), each stocked with 3,000 organisms. Sampling procedures were designed to minimize stress and prevent negative effects on growth and development. Fish total length, body width, and weight were recorded (Figure 2).

Figure 2. Biometric measurements of basa fish.

Water quality parameters were also monitored weekly, including alkalinity, chloride, hardness, iron, pH, sulfite, and temperature.

Statistical analysis

Statistical analyses were performed using the open-access software RStudio. Descriptive statistics were calculated, and a one-way analysis of variance (ANOVA) was conducted to compare treatments evaluated on the same sampling date in order to determine differences or similarities among the studied variables.

RESULTS AND DISCUSSION

Physicochemical analysis

The physicochemical analysis of the alternative feed included moisture, ash, lipid, and protein content. Each sample was analyzed in triplicate. The results are presented in Table 1.

The results indicate that the protein content provided by the alternative feed was 21.6%, which falls within the range suggested by Zulfikar *et al.* (2005) and Sayeed *et al.* (2008) to support the growth and development of basa fish. These authors reported protein requirements ranging from 16% to 23.9%.

Biometric measurements

The evaluated variables (length, width, and weight) of basa fish during the Fall-Winter 2022 season did not show substantial differences between treatments. These results are presented in greater detail in Table 2, which displays the mean values and standard deviations of the data obtained from *Pangasius hypophthalmus* over a six-month period.

The final length values recorded for T_1R_1, T0, and T_1R_2 were 30.2, 30.5, and 30.3 cm, respectively. Similarly, final weight values were 429.8, 433.8, and 442.0 g, respectively. For width, however, T_0 (8.9 cm) was greater than T_1R_1 (8.4 cm) but equal to T_1R_2.

The biometric results obtained during the Fall-Winter period differed from those reported by Khan *et al.* (2009), who recorded final length values of 29.86, 31.79, and 32.94 cm, with higher values in two of their treatments. However, their reported final weights (271.63, 340.12, and 386.55 g) were lower than those observed in the present study.

These findings indicate that the alternative feed adequately met the nutritional requirements of basa fish, comparable to the commercial feed, allowing continued growth and development. No significant differences were observed between replicates (R_1 and R_2) or between the treatment and control groups (T_1 and T_0), as illustrated in Figure 3.

Table 1. Physicochemical analysis of the alternative feed.

	Moisture (%)	**Ash (%)**	**Lipid (%)**	**Protein (%)**
Corn	73.0	1.7	2.2	12.8
Taro	83.4	5.8	0.4	5.5
Cassava	91.3	7.0	2.8	3.3

Table 2. Biometric measurements conducted during the production cycle of basa fish.

Date	**24/09/2022**			**22/10/2022**		
Treatment	T_1R_1	T_0	T_1R_2	T_1R_1	T_0	T_1R_2
Length (cm)	25.3±2.3a	25.2±4.4a	26.7±2.1a	27.3±2.3a	27.0±2.0a	28.2±1.9a
Variance (cm^2)	5.4	19.8	4.5	5.5	4.0	3.9
Width (cm)	6.3±0.5b	6.5±0.5b	7.1±0.6a	7.3±0.5a	7.4±0.9a	7.7±0.7a
Variance (cm^2)	0.3	0.3	0.5	0.3	0.9	0.6
Weight (g)	219.6±45.8b	250.7±30.8a	248.5±37.6a	273.7±40.7b	283.9±60.8ab	311.5±51.6a
Variance (g^2)	2104.7	950.2	1419.7	1662.9	3691.5	2668.4
Date	**19/11/2022**			**17/12/2022**		
Treatment	T_1R_1	T_0	T_1R_2	T_1R_1	T_0	T_1R_2
Length (cm)	28.4±1.9a	27.8±1.7a	28.2±1.6a	27.6±2.2b	29.5±1.8a	28.4±1.6ab
Variance (cm^2)	3.7	3.0	2.8	5.2	3.4	2.6
Width (cm)	7.5±0.6a	7.5±0.7a	7.7±0.5a	7.5±0.7a	7.5±0.6a	7.7±0.5a
Variance (cm^2)	0.4	0.5	0.4	0.5	0.4	0.3
Weight (g)	318.7±36.4a	308.5±45.7a	315.9±41.6a	371.5±53.9a	374.2±56.7a	369.5±45.5a
Variance (g^2)	1325.8	2095.5	1734.6	2908.8	3209.9	2073.2
Date	**14/01/2023**			**11/02/2023**		
Treatment	T_1R_1	T_0	T_1R_2	T_1R_1	T_0	T_1R_2
Length (cm)	30.3±1.4a	30.1±1.7a	29.2±1.4b	30.2±2.2a	30.5±1.9a	30.3±1.7a
Variance (cm^2)	2.1	3.1	2.0	5.0	3.8	3.1
Width (cm)	8.6±0.5ab	8.7±0.7a	8.3±0.6b	8.4±0.7b	8.9±0.7a	8.8±0.9ab
Variance (cm^2)	0.3	0.5	0.4	0.6	0.6	0.9
Weight (g)	411.7±53.1a	423.8±66.5a	396.2±53.2a	429.8±83.2a	433.8±70.9a	442.0±75.8a
Variance (g^2)	2826.8	4419.4	2837.1	6916.9	5022.6	5743.3

*Mean value of 32 organisms ± standard deviation.

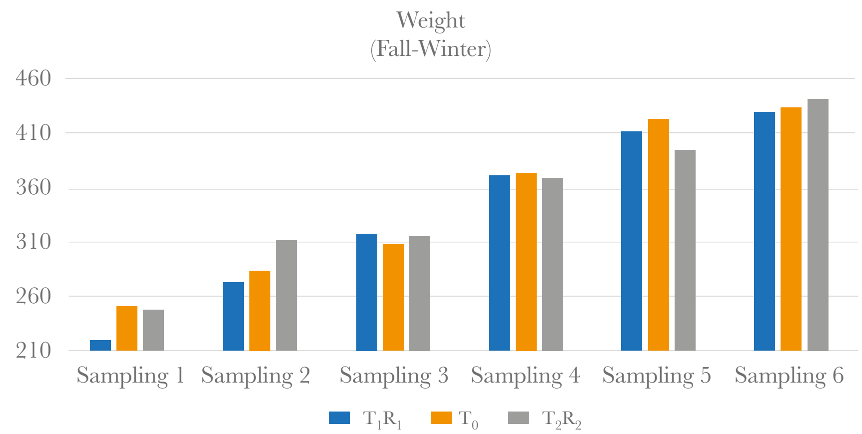

Figure 3. Monthly weight gain of basa fish. T_1R_1, T0, and T_1R_2 correspond to Treatment 1, Replicate 1; Treatment 0 (control); and Treatment 1, Replicate 2, respectively.

Water quality analysis

Water quality analysis indicated that the measured parameters remained within normal ranges according to the classification criteria established by HANNA® Instruments. The detailed results are presented in Table 3.

The pH and temperature values were similar to those reported by Khan *et al.* (2009), who obtained pH values of 7.4, 7.3, and 7.2, and temperature values of 28.9 °C across their three treatments. These findings are consistent with the water quality parameters required for the optimal development of basa fish. In contrast, chloride and hardness levels differed between the treatment and control groups. These differences may be attributed to the greater incorporation of organic matter associated with the farm-produced feed.

Production costs

Table 4 presents the production costs of both systems. The cost of commercial feed was $30,000 MXN, whereas the feed produced on the farm totaled $11,500 MXN, plus $3,000 MXN in labor costs, resulting in a total of $14,500 MXN. This amount represents 48.3% of the cost of commercial feed.

Labor and energy (electricity and fuel) were also among the highest cost components in both systems. Commercial feed accounted for 60% of total production costs, while farm-produced feed represented 39.19%, reflecting an approximate 20% reduction in feed-related expenses.

Table 5 shows that the total reduction in production costs was 25.85%, making the farm-produced feed system more economically viable. This reduction is partly attributable to the lower cost of locally sourced ingredients and agricultural by-products used as raw materials. In contrast, commercial feeds often rely on imported ingredients, such as soybean meal, which increases costs for producers.

CONCLUSIONS

Fermented and pre-digested feeds produced on-farm using low-cost local and regional ingredients within sustainable aquaculture systems support growth and development in basa fish comparable to those achieved with commercial diets. This approach enables a reduction in production costs of up to 25%, thereby improving producers' income and overall economic performance.

Table 3. Water quality results.

mgL^{-1}	T_1R_1	T_0	T_1R_2
Alkalinity	27	18	24
Chloride	40	80	40
Hardness	180	165	183
Iron	0	0	0
pH	8	7.9	7.9
Sulfite	6	6	10
Temperature (°C)	28.6	28.1	28.2

Table 4. Production costs of both systems (MXN).

Item	Comercial	% of Total	Farm-Produced	% of Total
Fingerlings	3500	7.01	3500	9.46
Feed	30000	60.12	11500	31.08
Labor	5400	10.82	6000	16.22
Energy	4000	8.02	6000	16.22
Health Supplies	2000	4.01	2000	5.41
Infrastructure Depreciation	5000	10.02	5000	13.51
Feed Production Costs	0	0.00	3000	8.11
Total Cost	49900	100.00	37000	100.00

Table 5. Production costs of both systems.

Indicator	Comercial	Farm
Production (kg)	1,000.00	1,000.00
Cost per kg (MXN)	49,900.00	37,000.00
Total Savings (MXN)	-	12,900.00
Reduction (%)	-	25.85

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