Colegio de Postgraduados

Characterization of tilapia (*Oreochromis niloticus*) production system in the Zacatecas, Mexico

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ABSTRACT
Objective: To characterize the tilapia (*Oreochromis niloticus*) production system in Zacatecas, Mexico.
Methodology: Seventeen Aquaculture Production Units (APU) in Zacatecas were analyzed, using a cross-sectional design and qualitative-quantitative method. The instrument used was a questionnaire, and the sampling was non-probabilistic.
Results: Tilapia cultivation is conducted in various types of ponds, with an average of 2340 organisms per pond, yielding a production of 5705.88 kg year^{-1}, and a sale price of $116.47 pesos kg^{-1} of fresh gutted fish at the farm gate. Production costs are primarily associated with concentrated feed and electrical energy. Regarding the financial characteristics analyzed, APUs are categorized into four types of production: basic, as a complementary activity with limited economic resources; pre-intermediate, characterized by basic infrastructure and managed by adult aquaculturists (49-55 years old); Intermediate, full-time dedication with average profitability; and high-intermediate, with optimal infrastructure and activity managed by adult aquaculturists aged 30-55 years with a propensity to adopt technological innovation in aquaculture.
Limitations/ Study Implications: No major limitations were identified.
Conclusions: In general, aquaculturists perceive stagnation in their activity due to lack of promotion, production scheduling, and insecurity. It is necessary to develop an inter-institutional strategy where universities, research institutions, and government agencies participate to promote elements of policy, financing, and training.

Keywords: *Oreochromis niloticus*, sustainability, rural aquaculture.

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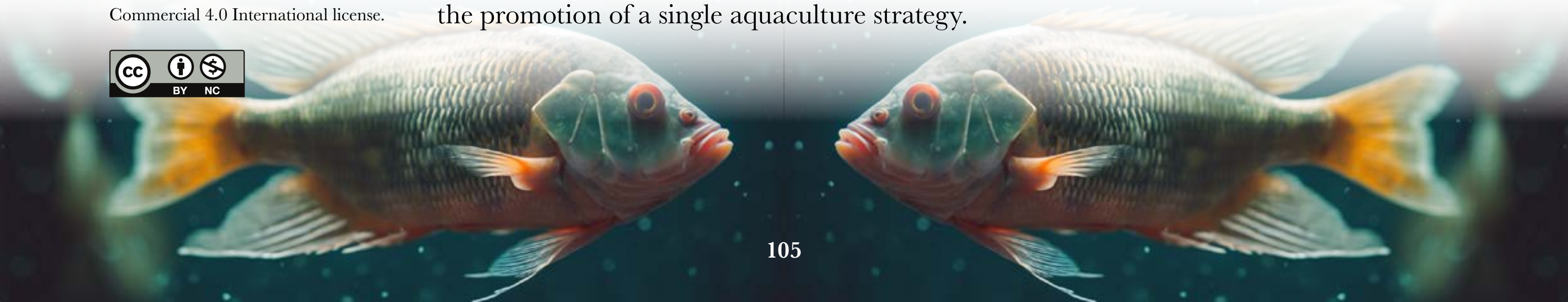
INTRODUCTION

One of the most important challenges of the 21st century is the global need for food. In Mexico alone, the Comisión Nacional de Pesca y Acuacultura (National Fisheries and Aquaculture Commission) reports that an additional supply of food from aquaculture will be necessary to maintain the current level of per capita consumption (12 kg/person/year). Therefore, solutions that include sustainable aquaculture (with the implementation of renewable energy systems, bioculture systems, or polycultures) will be required rather than the promotion of a single aquaculture strategy.



Aquaculture is one of the main sources of protein in the human diet (Naor *et al.*, 2021) and is considered one of the least harmful activities to the environment (Goyal *et al.*, 2021). In addition, fish contains a variety of amino acids (leucine, isoleucine, threonine, methionine-cysteine) and fatty acids such as omega-3 (Khanjani et al., 2022) that are essential for the human diet.

Among the main aquaculture crops worldwide are cichlids, such as tilapia, which represent 80% of production (Betanzo *et al.*, 2021) and are the second most cultivated fish, due to their economic viability and pleasant flavor (Le *et al.*, 2022). Their extensive production is attributed to rapid growth, high acceptance of artificial feeding, resistance to stress or diseases, and ability to reproduce in confinement (Mugwanya *et al.*, 2022).

Currently, China is the main producer and exporter of tilapia while Mexico ranks ninth. Furthermore, Mexico is among the main consumers of this product according to CONAPESCA, (2020).

Intensive aquaculture systems provide controlled management involving factors such as feed quality, population density, feeding rate, feeding frequency, and water quality (temperature, dissolved oxygen, pH, salinity, and ammonia) (Khanjani *et al.*, 2022). Tilapia is a cold-blooded fish that requires its body temperature to match the water where it grows, which directly correlates with the growth curve. Under optimal conditions (28 °C to 32 °C) it can multiply its weight tenfold, reaching 500 g fish in six months (Enciso *et al.*, 2019). Therefore, the production of tilapia in a controlled environment represents a complementary development activity for arid areas.

About half of the world's countries have arid and semi-arid regions. In Mexico, 48.3% of its territory are regions that can be used for protein production through aquaculture (Enciso *et al.*, 2019). According to the Instituto Nacional de Geografía y Estadística (INEGI, 2021), 73% of the territory of of Zacatecas consists of regions where tilapia represents a viable option for high-protein food production due to: i) the development of various production models, ii) limitations in fresh water supplies, iii) loss of arable land, and iv) soil degradation resulting from erosion and loss of soil fertility.

In Zacatecas, the promotion of aquaculture began in 2003 as a strategy to diversify farmers' income (CONAPESCA, 2020). This strategy aimed to enhance food security by using water resources as a development alternative. The Food and Agriculture Organization of the United Nations (FAO, 2020) states that aquaculture does not directly consume water but utilizes and recycles it, increasing the organic load of the discharged water (eutrophication of water). This approach aligns with sustainable development, which requires a socially acceptable objective for economic growth and the conservation of natural resources, ensuring their availability for present and future generations (FAO, 2020). The objective of this research was to determine the characteristics of the tilapia (*Oreochromis niloticus*) production systems in Zacatecas, by analyzing the technical, financial and social dimensions, as well as meteorological phenomena, to better understand the adaptability of this fish in the region.

MATERIALS AND METHODS

Study site

Zacatecas is located in north-central Mexico (25° 07’ 31” N, 21° 02’ 31” S, 100° 44’ 32” E, and 104° 21’ 13” W) at a mean altitude of 2,230 meters above sea level.

The study was conducted in Aquaculture Production Units (APUs), located in various municipalities of Zacatecas (Figure 1) over four months, using a cross-sectional design based on non-probabilistic convenience sampling (N=17).

The participating municipalities were Fresnillo (23° 10’ 30” latitude and −102° 52’ 06” longitude), Moyahua de Estrada (21° 15’ 56” latitude and −103° 09’ 57” longitude), Jalpa (21° 38’ 11” latitude and −102° 58’ 37” longitude), Guadalupe (22° 44’ 48” latitude and −102° 31’ 08” longitude), Teúl de González Ortega (21° 27’ 51” latitude and −103° 27’ 43” longitude), Pánuco (22° 52’ 33” latitude and −102° 32’ 27” longitude), Apozol (21° 28’ 15” latitude and −103° 05’ 28” longitude), Huanusco (21° 46’ 20” latitude and −102° 58’ 19” longitude), Villanueva (22° 21’ 15” latitude and −102° 53’ 01” longitude), Jerez de García Salinas (22° 38’ 58” latitude and −102° 59’ 24” longitude), Morelos (22° 51’ 44” latitude and −102° 36’ 34” longitude), Miguel Auza (24° 17’ 40” latitude and −103° 27’ 05” longitude), Jiménez del Teúl (23° 15’ 15” latitude and −103° 47’ 54” longitude), and Tabasco (21° 51’ 55” latitude and −102° 54’ 47” longitude).

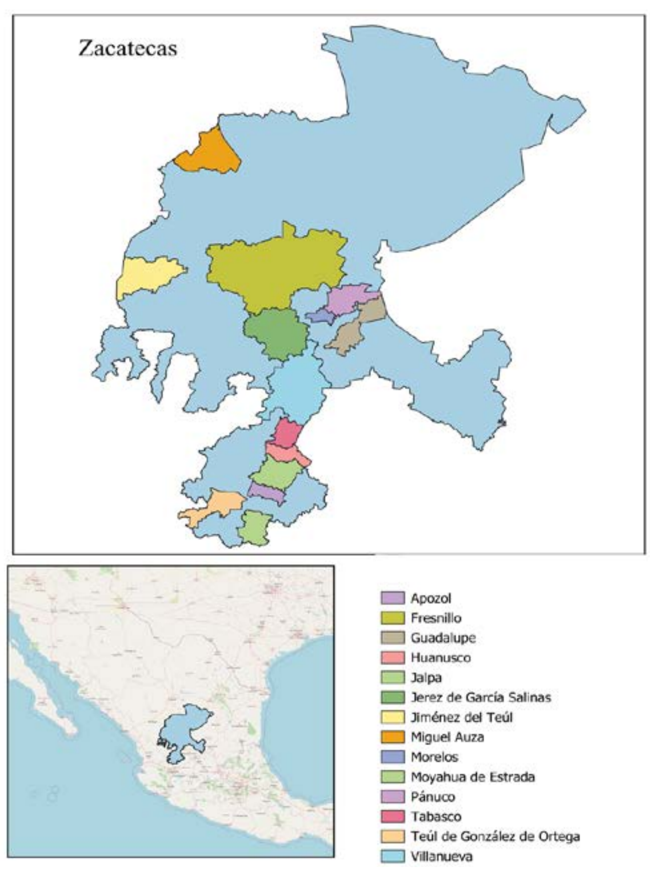


Figure 1. Location of Aquaculture Production Units (APUs, UPAs by its acronym in Spanish) in Zacatecas, Mexico.

Study participants

Participants were selected through non-probabilistic convenience sampling based on the following inclusion and exclusion criteria: i), being of legal age, ii) gender was not a factor, iii) possessing a minimum of one year experience, iv) having the necessary infrastructure for pond production, and v) having engaged in tilapia production in the previous year (2022). Farmers practicing extensive aquaculture systems or operating outside of Zacatecas excluded from the study.

Instrument design

The study was conducted in APUs of the state of Zacatecas using a structured questionnaire that included 65 qualitative and 22 quantitative variables, as described by Hernández *et al.* (2002). These variables covered the following attributes: 1) 11 sociodemographic variables, 2) 10 organizational variables, 3) 40 technical-economic productive variables, 4) 12 marketing variables, 5) 2 financing variables, 6) 6 innovation variables, and 7) 6 meteorological phenomena variables.

Based on financial characteristics, a typology of aquaculturists was developed to relate the profitability of their enterprises. The following indicators were considered to parameterize the behavior of sustainable APUs from the financial perspective: a) benefit-cost ratio (B/C) b) internal rate of return (IRR) c) period recovery d) net present value (NPV). These indicators are used to evaluate the financial performance of sustainable APU.

Instrument application

The research began with a diagnosis of the APUs of the cooperating aquaculturists in Zacatecas. The registry of the Comité de Sanidad Acuícola del Estado de Zacatecas, A.C. (COZAEZ A.C.) served as the basis for non-probabilistic sampling. The aquaculturists were contacted, and appointments were scheduled for interviews. Data was collected over four months, from September 2022 to January 2023.

Statistical analysis

To identify the "normal" variation in the characteristic of the APUs, the frequency distribution was analyzed by identifying the median value of each characteristic. For characterizing the APUs based on quantitative characteristics, a basic data matrix was constructed to calculate the similarity coefficient by computing Euclidean distances between each characteristic. The goal was to identify APUs with similar financial characteristics to propose common development strategies. The data were analyzed using R programming (R Language 4.3.1. and R studio 2023.06.1 Build 524).

RESULTS AND DISCUSSION

The results were grouped into seven attributes: sociodemographic, organizational, technical-economic-productive, marketing, financing, innovation, and meteorological phenomena.

Sociodemographic attributes

The study describes the structure of the APUs in 14 municipalities, validating the structure of aquaculture activity in the state of Zacatecas for the year 2022.

Regarding job position, the majority of aquaculturists are owners (70.58%), followed by managers (17.64%) and the rest are technical advisors or administrators (11.78%). APU aquaculturists are adults with an average age of 54 years (minimum=30 years; maximum=68 years). In terms of education, 58.88% have completed secondary and high school, 29.36% hold a bachelor's degree, and only 11.76% have a postgraduate degree (master's). The majority of aquaculturists are men (82.35%) and 88.23% are married. With an average of 3.4±1.6 S.D., financial dependents. They reported and average of 11.52 years±2.96 S.D. years of experience in aquaculture.

Organization attributes

A total of 58.82% of aquaculturists are organized as a cooperative society, while 41.18% are organized as a rural production society. Most APUs (82.35%) are maintained on private property, with the remainder situated on ejidal land. Aquaculturists typically dedicate 6.1 hours ± 1.9 hours per day to their activities. Additionally, 29.41% of aquaculturists are exclusively dedicated to aquaculture, while the rest work engage in agricultural as a complement to agriculture activities such as farming, livestock, and teaching.

Technical-economic-productive attributes

Production in the APUs is primarily conducted in geomembrane ponds (88.24%) and, to a lesser extent, in concrete ponds (11.76%). Approximately 58.82% of the APUs maintain the temperature with a greenhouse, while the rest produce under open field conditions.

On average, APUs have 6.1±3.5 ponds, each with an average capacity of $81.9 \pm 7.4\,m^3$. Each pond is stocked with an average of 2339.07 organisms, consuming $5714.5\,m^3 \pm 4720.9\,m^3$ of water per production cycle.

The APUs utilize common technologies such as aerator (vanes and blower) (76.47%) to introduce oxygen into the water, motor pump (70.58%), power generators (64.70%), oximeter (64.70%), transformer (52.94%), and thermometer (41.17%).

Regarding problems that affect their aquaculture production, 58.83% of aquaculturists do not identify any issues. However, 17.65% mention the high costs of inputs (fingerlings, concentrated feed, labor, electrical energy), 11.76% cite frequent failures in the supply of electrical energy, and another 11.76% point the shortage of specialized feed within the region and the difficulty in marketing fishing production.

In terms of solutions to technical problems, 88.24% of aquaculturists consider the using of alternative sources of electrical energy as a strategy to lower production costs. Meanwhile, 5.88% mention purchasing equipment with electric storage batteries to cope with frequent electrical failures, and the remaining do not identify a solution to their problems. Additionally, 58.82% of aquaculturists describe UPA production management as conventionally diversified, 23.53% as transition to organic, and 17.65% as diversified organic.

Marketing attributes

Referring sales, 64.71% of aquaculturists sell their fish fresh (whole gutted fish), 35.29% sell prepared dishes, and 94.12% sell their production in the surrounding communities (local sales). In terms of the type of buyer, 64.71% sell it whole gutted fish to the final consumer, and 35.29% sell cooked fish in restaurants associated with the APUs.

The average production in the 2022 crop cycle was 5705.88±2302.84 kg per year, with a sale price of % 116.47±20.97 S.D.

Those responsible for the APUs report no losses, and 35.29% of aquaculturists process part of their production (filleting). Most aquaculturists (94.12%) acquire tilapia fingerlings from the state of Jalisco, while the rest (5.88%) source from Sinaloa. The balanced feed used in tilapia production is purchased from local suppliers (70.59%), foreign suppliers (23.53%), and direct from the factory (5.88%).

Innovation attributes

Most of aquaculturists (47.75%) report applying the official Mexican standards (NOM) of aquaculture health in the APUs as the main innovation (Figure 2), which is considered acceptable. Another practice related to water quality, such as biofloc, promotes the rapid growth of tilapia; however, this practice was abandoned due to lack of technical assistance (15.38%).

Regarding the perception in the development of their activity, 58.82% of those responsible for the APUs consider that it stagnant, while 41.17% believe it is declining. Additionally, 88.24% perceive the activity to be in "apparent stability", and 11.76% view as "deteriorated and unproductive".

Among the main limitations, 23.53% of those responsible for APUs identify the expansion strategy of their product as a significant constraint (Figure 3).

Attributes related to meteorological phenomena

Regarding the meteorological factors causing cultivation losses (Figure 4), aquaculturists first mention hail (61.53%), followed by strong regional winds (23.09%), and diseases affecting tilapia (15.38 %). According to those responsible for the APUs, the intensity of the meteorological phenomena is mild (52.94%), moderate (23.53%), or critical (5.88%), with

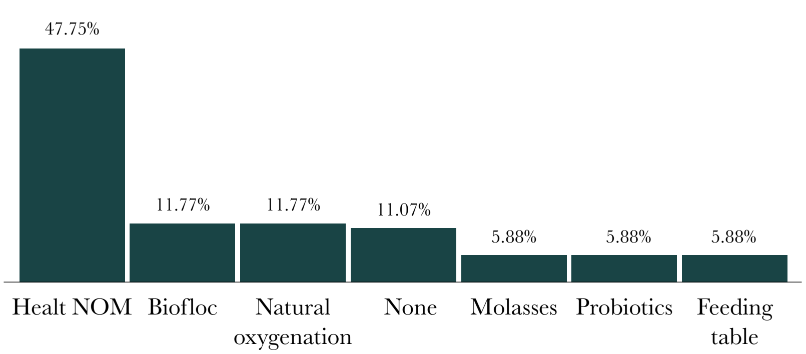


Figure 2. Innovations implemented in the productive management of Tilapia (*Oreochromis niloticus*), in Zacatecas.

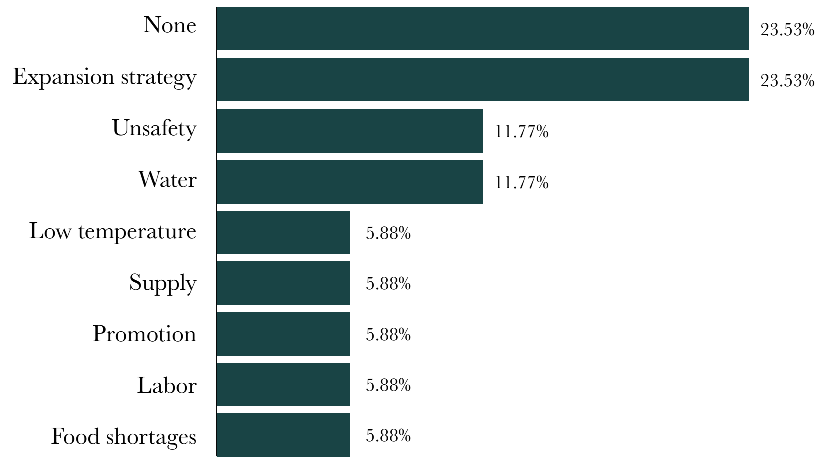


Figure 3. Limitations for Tilapia (*Oreochromis niloticus*) cultivation identified by aquaculturists in Zacatecas.

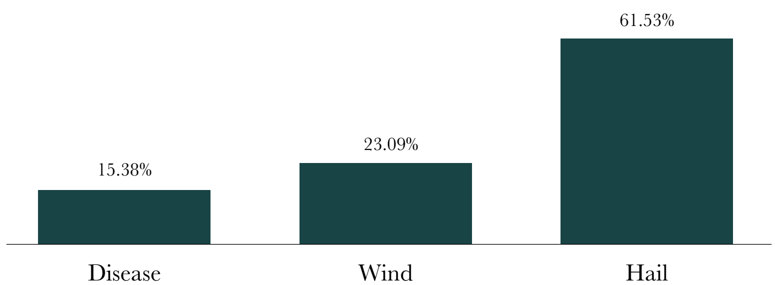


Figure 4. Meteorological factors that cause losses of Tilapia (*Oreochromis niloticus*) harvest in the state of Zacatecas.

17.65% considering the climate effects not relevant. Concerning the level of damage caused by the climate, those responsible for the APUs consider slight (41.18%), moderate (29.41%), or critical damage (11.76%), while 17.65% consider the damage non-relevant.

Identification aquaculturists type

The APUs were classified with the following variables: education level, age, experience in aquaculture, type of production, production volume, sales price, innovation activities, number of direct jobs, and financial indicators such as benefit-cost ratio (B/C), net present value (NPV), internal rate of return (IRR), and payback period.

Four groups of APUs were identified (Figure 5), explaining 53.2% of the total variance. The first dimension explains 30.1% of the variance, defined by B/C, NPV, IRR, and payback period, and places groups 2, 3, 4, and 1 in order of increasing B /C, NPV and IRR, and decreasing payback period. The second dimension explains 23.1% of the variance, dominated by the time dedicated to the activity and sales price, thus describing the ascending order of groups 1, 4, 2, and 3.

Additionally, group one is characterized by low production and profitability. Group two is noted for basic experience and average profitability. Group three is distinguished by full-time dedication by medium profitability and a high payback period- Finally,

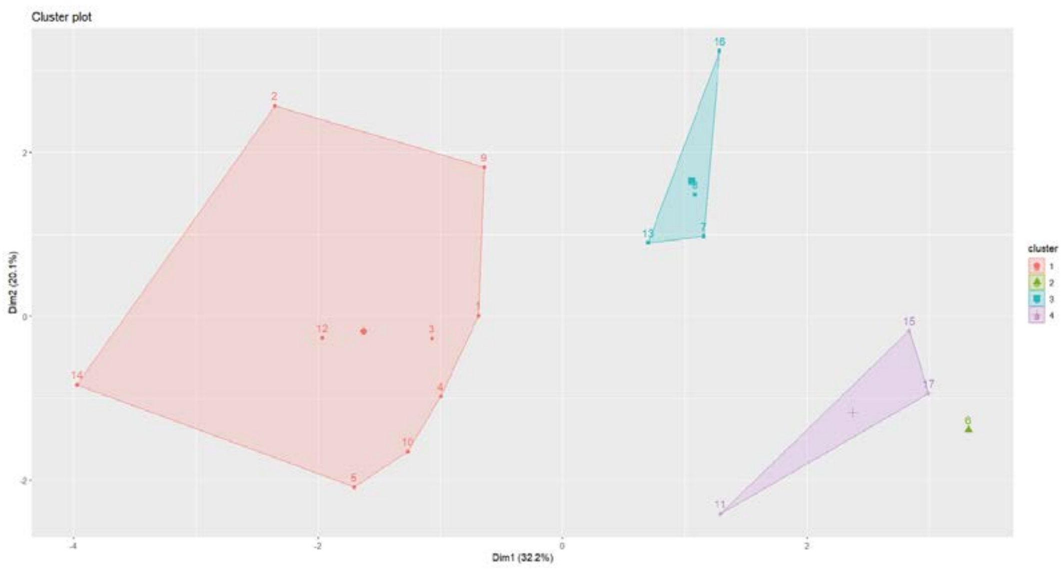


Figure 5. Profile of the groups extracted from the cluster analysis.

group four is marked by a medium production, high sales price, and medium job creation (Table 1).

In the rural areas of Zacatecas, tilapia production is predominantly managed by men, with 82.35% of aquaculturists being male and 17.65% female. This gender distribution is consistent with regional agricultural trends, as reported by Avadí *et al.* (2022), who found that 60-84% decision-makers in agricultural production are men, often the heads of the families and landowners where APUs are located. The average age of these aquaculturists is 54 years, indicating a mature demographic, as noted by Rachel *et al.* (2022). Most are organized as a cooperative society, reflecting findings by Avadí *et al.* (2022).

Aquaculture in Zacatecas os often a complementary activity to agriculture (47.05%) (Rachel *et al.*, 2022; Berg *et al.*, 2021), contributing between 26% and 51% of the aquaculturists' economic income. This suggests that aquaculture has promoted the diversification of economic activities in semi-arid areas, positively impacting sustainable rural development in the region (García-Mondragón *et al.*, 2013, Montijo *et al.*, 2016).

Most tilapia farming in Zacatecas is conducted in geomembrane ponds with a diameter of 9 meters and an average depth of 1.20 meters. These ponds are typically fed with well water and sometimes aerated using blower-type aerators, along with other equipment such as motor pumps and oximeters. On average, each pond contains 2340, which reach

Table 1. Description of the identified clusters.

Aquaculture production units	Members	Distinctive feature
Basic	9	Low production and low profitability
Pre-intermediate	4	Basic experience and average profitability
Intermediate	2	Full-time dedication, average profitability and high recovery period
Intermediate-high	2	Average production, high selling price and average creation

average harvest weight of 0.50 kg per organism with a 95% survival rate. This result is an expected production of 5.90 tons per year^{-1}, sold at $116.47 MXN per kg of fresh gutted fish at the farm gate. This aligns with Vega *et al.* (2010), who reported that low density and minimal management practices reduce risks and enhance the production of high-quality protein. There is a recognized need to add value to the production through processing into frozen products, nuggets, steaks, and others items, allowing access new market niches.

Production costs are mainly attributed to concentrated feed and electrical energy, consistent with studies on aquaculture in southern Mexico (Platas *et al.*, 2018; Delfin *et al.*, 2023), Tanzania (Berg *et al.*, 2021), and Honduras (Lee *et al.*, 2022). Health advice for aquaculturists in APUs is provided by field professionals from the Comité de Sanidad Acuícola del estado de Zacatecas (COSAEZ) highlighting the need for training, technical assistance, innovation extension, and actions that strengthen and integrate the productive chain to enhance competition of APUs. This need is supported by finding from other studies (Bueno *et al.*, 2020; Malcolm *et al.*, 2016; Rachel *et al.*, 2022; Avadí *et al.*, 2022; Guilhermino *et al.*, 2019).

Regarding meteorological factors, APUs are particularly sensitive to hail and strong winds. However, most aquaculturists consider the level of damage to be minor. Additionally, the owners of the APUs do not have insurance coverage, as their minimum profit margin makes them unattractive to insurers. Some aquaculturists supplement their income by operating a restaurant, which can significantly enhance the unit's profit margin.

Based on the characteristics analyzed, APUs are grouped into four types of production: 1) Basic, as a complementary activity with limited economic resources; 2) pre-intermediate, complementary activities with basic infrastructure, managed by mature adult aquaculturists (49-55 years), who view the activity as profitable with long-term growth (Avadí *et al.*, 2022); 3) Full-time intermediate, aquaculturists with experience and average profitability. This group has a higher cultural, allowing access to information systems and the adoption of innovations, consistent with Mogíca *et al.* (2002); finally, 4) High-intermediate, APUs with optimal infrastructure, managed by adult aquaculturists (30-55 years) inclined to adopt technological innovation in aquaculture.

CONCLUSIONS

Aquaculturists perceive a stagnation in their activity due to the lack of product promotion, production scheduling, and insecurity. These limitations highlight the need to create an inter-institutional strategy involving universities, research institutions, and government agencies that promote policies, financing, and training. The characterization of the tilapia production system in Zacatecas will help develop specific programs tailored to each identified cluster based on the unique characteristics of the APUs. The results can aid in understanding and analyzing the production systems and adaptability of tilapia (*Oreochromis niloticus*), in the Zacatecas region, steering the activity towards profitable and sustainable aquaculture. Thus, aquaculture could become a productive alternative with significant social and economic impact in the state of Zacatecas.

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