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Prácticas de bioseguridad asociadas a las granjas de tilapia (*Oreochromis* spp.) en la zona semiárida del noroeste del estado de Hidalgo, México

Biosecurity practices associated with tilapia (*Oreochromis* spp.) farms in the semi-arid zone of the northwest of the state of Hidalgo, Mexico

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Resumen: A nivel mundial la producción de tilapia representa una actividad de importante aporte socioeconómico. No obstante, los sistemas de cultivo cursan retos importantes de bioseguridad. En este estudio se realizó la caracterización cualitativa del perfil de bioseguridad en 18 granjas de tilapia. Se observó que la actividad reportó un gasto menor a 5 US$ en servicios veterinarios y una frecuencia de enfermedades del 66.6%. La alta presencia de cercos (100.0%), se relacionó a una baja frecuencia de reporte para enfermedades virales (0.0%). El análisis cualitativo evidencio una alta frecuencia de las formas "does (186) not (171) apply (153)", mientras que el análisis factorial de correspondencia mostró baja relación semántica de las palabras "expense", "dollar", "deworm" y "deworming" enmarcando áreas de oportunidad en la aplicación de gastos y tratamientos preventivos. Los hallazgos evidencian que la bioseguridad juega un papel crucial en el manejo sanitario de estas granjas y que su evaluación continua puede coadyuvar en la mejora de los sistemas de producción de tilapia.

Palabras clave: Productos Primarios, Seguridad de Recursos, Seguridad Ambiental, Comportamiento de Salud, Enfermedades Infecciosas. JEL: Q220, Q560, I120.

Abstract: Tilapia production represents a significant source of employment and high-quality nutritional food. Its socioeconomic importance has driven the farming systems intensification, making biosecurity aspects crucial to supporting industry growth and mitigating health risks. Therefore, the study objective was to characterized the infrastructure and biosecurity measures associated with tilapia farms in *Valle del Mezquital*, Hidalgo, Mexico. 18 farms were selected through intentional sampling during August 2022. Health and biosecurity data were collected through a semi-structured survey, and the data were processed by a text analysis using IRaMuTeQ. Producers aged 40-59 years were reported to participate, reporting an expenditure of less than 5 US$ on veterinary services during the crop cycle and a crops disease frequency of 66.6%. The health events were characterized by their origin in parasitic pathogens (33.3%), and the treatment based on grain salt (44.4%) through immersion baths (50.0%). Perimeter fences were reported in 100.0% and it is evident that their presence can decrease the frequency of viral diseases. The qualitative analysis showed a high frequency of the conjunction of the forms “does (186) not (171) apply (153)”, and it was mainly related to low frequency and association by FAC with the words “expense”, “dollar”, “deworm” and “deworming”, in addition to the word “injection” represented the only active form of the hapax type marking areas of opportunity in the applied expenditure and the application of preventive treatments in the farms surveyed. The observed trends suggest the ongoing evaluation of the health and biosecurity profile to identify areas for improvement and potential enhancements in tilapia production systems.

Keywords: Primary Products, Resource Security, Environmental Security, Health Behavior, Infectious Disease. JEL: Q220, Q560, I120.

INTRODUCTION

Aquaculture represents a significant sector in agri-food production, contributing approximately 182 million tons to global food supply (Assefa and Abunna, 2018; FAO, 2023). In Mexico, production reaches 290,000 tons annually, resulting in a per capita consumption of 13.88 tons (Comisión Nacional de Acuicultura y Pesca, 2023). Among the species produced, tilapia stands out, contributing 6 million tons globally (El-Sayed, 2020). Its cultivation demonstrates high viability due to the species' resilience to unfavorable water quality conditions (Fajer-Ávila, Medina-Guerrero, and Morales-Serna, 2017).

In Mexico alone, production is reported at 77,687 tons, and specifically in the state of Hidalgo, at 3,153 tons annually (Comisión Nacional de Acuacultura y Pesca, 2023). Along with the rapid growth of the sector, new technologies (e.g., RAS systems, aquaponics, and biofloc) have been adopted that allow for increased production (Ornelas-Luna et al., 2017). Unfortunately, this scenario encourages increased stocking density (Valenzuela-Gutiérrez et al., 2021), where poor water quality, increased organism mobility, and even nutritional deficiencies act as

external stressors, exposing organisms to disease outbreaks (Wanja et al., 2020). Given the health risks in tilapia farming, biosecurity standards become crucial to prevent the introduction and spread of diseases in animal populations (Aly and Fathi, 2024).

In this context, biosecurity in aquaculture refers to the set of activities, protocols, and regulations that a region adopts to protect its aquatic resources from potential adverse effects, which can be caused by the introduction and spread of high-impact diseases (MacKinnon et al., 2023). Its implementation involves multiple actors throughout the livestock production chain and presents challenges that require specific attention (Subasinghe et al., 2023).

The development and application of biosecurity procedures and strategies should consider aspects such as: a) practicality and economy, b) focus on infections and contagious diseases, c) consider the prevention, control and eradication of diseases in defined epidemiological units, d) base actions on veterinary procedures and scientific methodologies, e) demonstrate compliance with international standards such as those of the WOAH (World Organization for Animal Health), and f) include all interested parties, such as producers, and public and private institutions (Palić, Scarfe and Walster, 2015).

Biosecurity measures are essential in tilapia farming, as a wide variety of viruses, bacteria, fungi, and parasites can compromise production. Among viral infections, the one caused by the Tilapia Lake virus stands out, which can cause mortality rates of up to 90.0% (Contreras et al., 2021; Aich et al., 2022). Regarding bacteria, *Streptococcus agalactiae*, *Francisella orientalis*, *Flavobacterium columnare*, *Aeromonas* spp., and *Vibrio* spp. have been identified as the main causes of outbreaks and mortality in farmed cichlids (Haenen et al., 2023). Fungal infections have also been reported; the most prevalent of these is caused by *Saprolegnia parasitica* (El Gamal et al., 2023).

Furthermore, there is a wide diversity of opportunistic parasites that affect farmed cichlids, including species of trematodes, nematodes, cestodes, monogeneans, protozoa, crustaceans, and acanthocephalans (Martínez Cruz et al., 1989; Scholz and Salgado-Maldonado, 2000; Ashmawy et al., 2018). These pathogens significantly affect production parameters in the sector, causing the greatest damage to fry and juveniles (MacKinnon et al., 2023). The wide diversity of pathogens affecting tilapia farming makes these fish populations a highly relevant group in the

emergence and spread of pathogens, due to their high mobility for farming in more than 90 countries worldwide (Fajer-Ávila, Medina-Guerrero, and Morales-Serna, 2017; Gu et al., 2019). Given this importance in health aspects, it is necessary to continue analyzing health risks and biosecurity aspects present at different temporal and spatial scales related to tilapia farming, prioritizing the local adaptation of systems (MacKinnon et al., 2023; Mazzucato et al., 2023). This is in order to reduce the introduction and spread of pathogens that affect the health of farmed fish and even human health (Zulbainarni and Megawati, 2019).

In particular, the state of Hidalgo has 610 aquaculture production units, 29.0% of which focus on the production of Nile tilapia (*Oreochromis niloticus*) in semi-intensive systems. The vast majority of these farms (69.0%) are located in areas with varying degrees of marginalization (Velasco-Amaro et al., 2015). This situation hinders access to and health monitoring of the farms, compounded by the limited availability of reports related to aquaculture activity at the state level. Given this context, the present study focuses on a qualitative description of the biosecurity profile applied to tilapia farming in the semi-arid region of the state of Hidalgo. This is part of an investigation to identify strengths and areas for improvement in local tilapia production systems.

1. MATERIALS AND METHODS

1.1. TYPE OF STUDY

This study presents the results of a non-experimental, cross-sectional investigation based on qualitative data collection. The approach focuses on describing elements related to biosecurity in tilapia production, while data analysis relied on inductive reasoning derived from mention frequencies and a lexicographical analysis of the collected information (Firdaus et al., 2020; Rodríguez-Rodríguez et al., 2024).

1. 2. STUDY AREA

The study was conducted in the northeast of the State of Hidalgo, in the geocultural region of the *Valle del Mezquital*, a semi-arid zone with xerophytic scrubland (Pérez-Serrano et al., 2021). It has an altitude between 1700 and 2100 m.a.s.l., comprises 28 municipalities, and is located 60 km from CDMX. For the past 100 years, the region has received

discharges of untreated wastewater from the Metropolitan Area of the Valley of Mexico for agricultural use (García-Salazar, 2019). In the region, different municipalities have a long tradition in aquaculture, focused on the cultivation of teleost fish for consumption, such as *Oreochromis niloticus* (Nile tilapia), *O. aureus* (blue tilapia) and *O. mossambicus* (mossambique tilapia), mainly in semi-intensive self-consumption farms (Velasco-Amaro et al., 2012, 2015).

1. 3. DATA COLLECTION

120 production units in the region with current operations for the cultivation of tilapia (*Oreochromis* spp.) in semi-intensive systems were identified from the Registro Nacional Pesquero y Acuícola (CONAPESCA, 2021). Eighteen of these were included in this study through purposive sampling; those located in the study area, dedicated to tilapia production, and that consented to data collection were included (Obilor, 2023). Each production unit included in the study met the following inclusion criteria: 1) it has been established for at least one year, 2) it has completed at least one full cultivation cycle, 3) it maintains sanitary records for the production unit under the supervision of professional personnel, and 4) the owner signs the informed consent for data collection and handling. The sample size cutoff was determined a posteriori based on data collection saturation, identified through similar, repetitive, and monotonous responses, as well as the identification of units that did not participate in data collection (Esquivel-Grados, 2025). At each farm, a data collection instrument was used to obtain data segmented into the following categories: 1) socioeconomic profile of the producers, 2) health history reported by the state health authority through the farm's records, 3) preventive biosecurity measures and actions, and 4) corrective biosecurity measures and actions. The instrument consisted of 61 items and was based on the biosecurity and good practice requirements established in the Good Practices Manual for Tilapia Production, developed by the Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria for application in Mexico (SENASICA, 2008). Finally, between August 1 and 30, 2022, semi-structured interviews were conducted with aquaculture farm owners to gather information; the interviews were individual and lasted an average of 2 hours.

1. 4. DATA ANALYSIS

The data obtained were organized in a Microsoft Excel 2019® spreadsheet. For descriptive and percentage analysis, a value of 1 was assigned when producers responded positively and 0 when they responded negatively (Adah et al., 2023). The frequency analysis was expressed using a mosaic plot created in RStudio 2025.09.1 Build 401. A lexicographical analysis was also performed, including word cloud diagrams, correspondence factor analysis (CFA; Chi^2), and network diagrams based on co-occurrence analysis. For this purpose, 18 texts were organized into a .txt file (**** G1*), resulting from information collected through interviews. The text analysis was developed using IRaMuTeQ software (R Interface for Multidimensional Analysis of Texts and Questionnaires) version 0.8 alpha 7, as reported by Rodríguez-Rodríguez et al., 2024.

2. RESULTS

2. 1. PRODUCER SOCIOECONOMIC PROFILE

The characteristics of the tilapia farming population were heterogeneous (Table 1). The farmers reported being between 20 and 79 years old, with a mean of 50.94 ± 11.72 years. Among them, the largest groups were producers between 40 and 49 years old and those between 50 and 59 years old, representing 33.3% in both age ranges. The farmers had a mean of 14.61 ± 6.69 years of experience in the activity; however, 38.8% of them indicated having less than 10 years of experience in aquaculture, which was the most frequent response. The educational level of the farmers was primarily secondary (44.4%), followed by 27.7% who reported a bachelor's degree. Finally, 22.2% of the farms indicated that they spend ≥5.50 US$ on veterinary services at least once per farming cycle. Unfortunately, 38.8% of farms indicated that they spend ≤5.50 US$ or no amount on veterinary services during their growing season (Table 1).

Table 1. Socioeconomic and demographic characteristics of the population of tilapia producers.

Attribute	Description	Percentage (Frequency)
Farmers age (year's)	20-29	5.5% (1/18)
	30-39	5.5% (1/18)
	40-49	33.3% (6/18)
	50-59	33.3% (6/18)
	60-69	16.6% (3/18)
	70-79	5.5% (1/18)
Farmers experience (year's)	<10	38.8% (7/18)
	11-19	33.3% 6/18)
	>20	27.7% (5/18)
Farmers studies	Primary	11.1% (2/18)
	Secondary	44.4% (8/18)
	Technical	16.6% (3/18)
	Degree	27.7% (5/18)
Expenditure on veterinary services	≥5.5 US$	22.2% (4/18)
	≤5.5 US$	38.8% (7/18)
	No expense	38.8% (7/18)

Source: Prepared by the authors using field data

2. 2. HEALTH AND BIOSECURITY BACKGROUND OF TILAPIA FARMS

66.6% of farms reported some type of disease in their tilapia populations during the last year of cultivation. These diseases were classified by pathogen groups, with parasitic and fungal diseases being the most frequent, at 33.3% and 27.0%, respectively (Table 2). Although producers' knowledge of specific diagnoses is limited, 100.0% of farms reported receiving technical assistance from the government aquaculture health agency. They also stated that government health monitoring allows them to understand the nature of the health history. Regarding biosecurity measures, the most frequent were perimeter fencing (100.0%), access to

potable water on the farm (88.8%), area identification signs (83.3%), and the use of personal protective equipment for workers (83.3%), specifically aprons, boots, gloves, and masks. On the other hand, only 16.6% of producers mentioned the installation of sanitary vehicle fords. In the biosecurity practice report, the filling of logs and the application of pest control protocols stood out with 88.8% application in both cases (Table 2).

Table 2. Health background and biosafety implements reported in tilapia production.

Source: Prepared by the authors using field data

Attribute	Frequency
Fish disease	**66.6% (12/18)**
Parasitic disease	33.3% (6/18)
Fungal disease	27.0% (5/18)
Bacterial disease	5.5% (1/18)
Viral disease	0.0% (0/18)
Other disease	16.6% (3/18)
Biosafety implements	**100.0% (18/18)**
Siege	100.0% (18/18)
Drinking water	88.8% (16/18)
ID Sings	83.3% (15/18)
Biosafety equipment	83.3% (15/18)
Pedestrian ford	77.7% (14/18)
Washbasin	77.7% (14/18)
Vehicular ford	16.6% (3/18)
Biosafety practices	**94.4% (17/18)**
Logbooks	88.8% (16/18)
Pest control	88.8% (16/18)
Chlorination system	77.7% (14/18)
Fish analysis	77.7% (14/18)
Operator analysis	77.7% (14/18)
Receive government technical assistance in aquaculture health	100.0% (18/18)

Regarding the profile of elements and therapeutic actions linked to tilapia production (Table 3), 88.8% reported performing parasitological analyses at least once per culture cycle, although only 38.8% applied a deworming protocol during the same period. Furthermore, 72.2% reported having substances or medications available for use in their tilapia farming. Among these, the most frequently used were coarse salt and vitamins, at 44.4% and 22.2%, respectively. 11.1% reported having antibiotics

available for potential use, specifically mentioning oxytetracycline and florfenicol. Additionally, treatments applied to the fish are administered recurrently through immersion baths in 50.0% of the farms. The second most common method was through feed (38.8%).

Table 3. Availability and methods of application of therapeutic measures for the sanitary control of tilapia farming.

Attribute	Frequency
Preventive practices	**88.8% (16/18)**
Parasitological analysis	88.8% (16/18)
Deworming	38.8% (7/18)
Substances and medications available	**72.2% (13/18)**
Grain Salt	44.4% (8/18)
Vitamins	22.2% (4/18)
Acetic acid	16.6% (3/18)
Garlic	16.6% (3/18)
Antibiotics	11.1% (2/18)
Dewormer	11.1% (2/18)
Potassium permanganate	11.1% (2/18)
Onion	5.5% (1/18)
Application of treatments	**83.3% (15/18)**
In bath	50.0% (9/18)
In food	38.8% (7/18)
Injection	5.5% (1/18)
Oral medication	0.0% (0/18)
Topical application	0.0% (0/18)

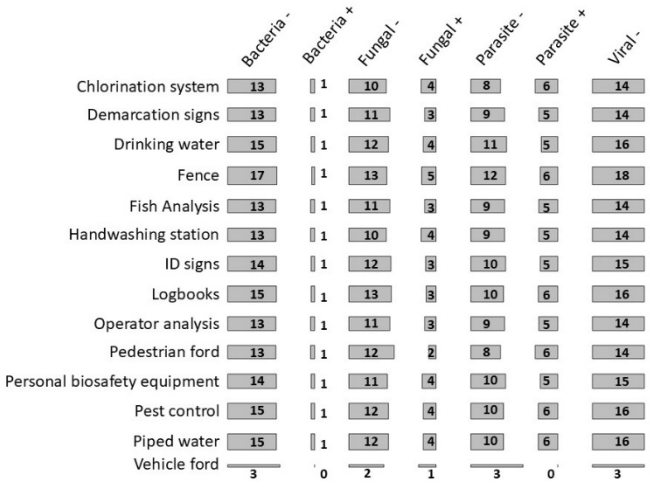
Source: Prepared by the authors using field data

2. 3. Frequency analysis between biosecurity elements and the presentation of diseases in fish farms.

The relationship between biosecurity measures and disease incidence in tilapia farms is shown in Figure 1. In this context, the installation and application of biosecurity measures can be linked to a decrease in the frequency of disease outbreaks. The installation of perimeter fences was associated with 17 farms that reported no outbreaks of bacterial diseases, 13 that reported no fungal diseases, and 12 that reported no parasitic diseases. No farms reported the presence of viral diseases, and

unfortunately, a greater number of farms reported parasitic diseases, despite the application of biosecurity protocols such as fish testing (5), worker testing (5), use of personal protective equipment by workers (5), and the implementation of pest control programs (6).

Figure 1. Frequency relationship matrix between biosecurity implements and the presentation of diseases in tilapia farms.



Source: Prepared by the authors using field data

2. 4. Analysis of biosafety profile texts using IRaMuTeQ

The lexicographical analysis revealed a total of 54 text segments with 2,084 occurrences. Among these, 72 forms were identified. Words with a frequency of 1 resulted in 2 hapaxes, corresponding to 2.7% of the forms and 0.1% of the occurrences. The word "injection" stood out as an active hapax form. Figure 2 shows the word cloud analysis of the texts. This analysis revealed that the words "not," "apply," and "does" were the most frequent, with 186, 171, and 153 mentions, respectively.

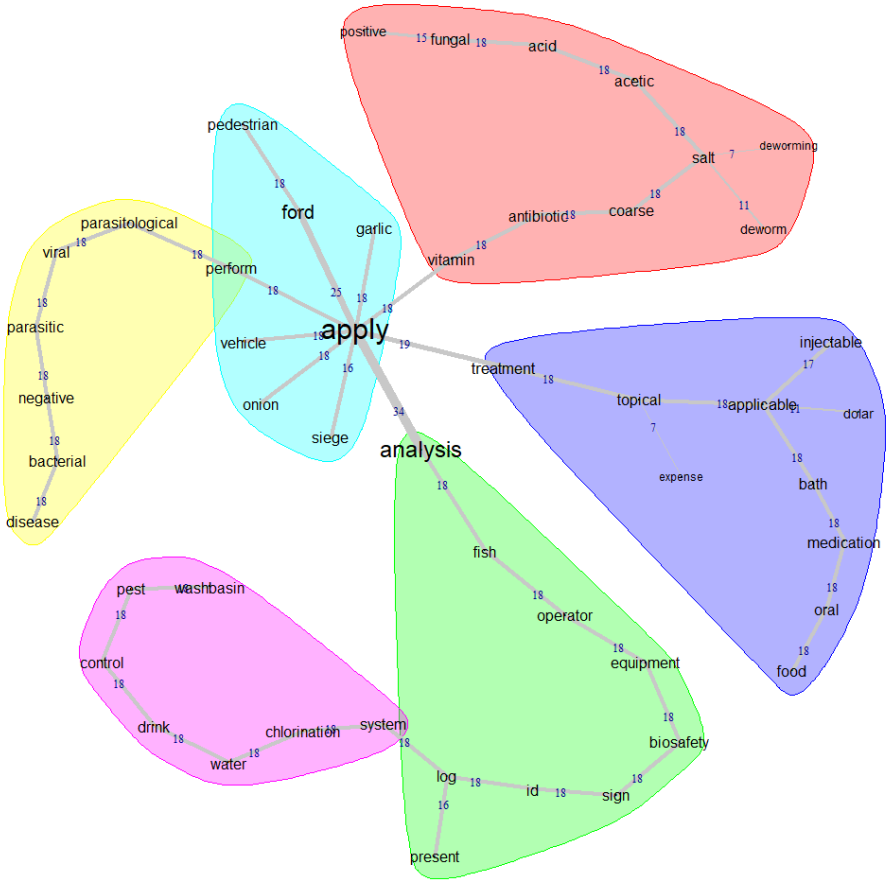
Figure 2. Word cloud, the size of each word is proportional to the frequency of mention in the analysis of texts on biosecurity practices in tilapia farms in the Valle del Mezquital.



Source: Prepared by the authors using field data

Co-occurrence analysis allowed the formation of a network of relationships among the active words (Figure 3). The analysis allowed the recognition of 6 words communities: in red and blue, the forms related to the application of treatments; in green and pink, those related to biosecurity elements; and in yellow, those related to the occurrence of diseases. Furthermore, it was observed that the key word in the network is "apply" given its high frequency of mention, which presented co-occurrence with the word "analysis" (34), which was initially related to "fish," showing a high frequency in the analysis of fish in situ. In contrast, the word community associated with the application of treatments showed low co-occurrence of the words "deworming" and "deworm" (community in red), while the words "oral" and "food" showed less relationship with the word "applicable", showing their low co-occurrence in the analyzed texts. Likewise, in the community of words in yellow, the co-occurrence of the words "disease", "bacterial" and "negative" is observed, evidencing their conjunction in the analyzed information. Overall, parasitic diseases were observed to be the most prevalent; furthermore, the frequency of mention and co-occurrence of the words "does," "not," and "apply"—specifically the phrase "does not apply"—indicate that there is still room for improvement in the implementation of biosecurity measures, particularly regarding the application, availability, and expenditure associated with treatments for the detected pathogens.

Figure 3. Co-occurrence analysis, the network expresses keywords by word communities, and the co-occurrence index it presents with other words within the community's halo.



Source: Prepared by the authors using field data

3. DISCUSSION

The socioeconomic profile of the producers showed a lower mean age (50.94 ± 11.72) than that recorded in other production areas, such as Tanzania, where a higher age range (56-65 years) was observed (Mulokozi et al., 2020). This factor may be crucial for the continuity of aquaculture and prevent the abandonment of livestock farming due to aging (>60 years) (Lazos-Chavero and Jiménez-Moreno, 2022). The surveyed producers had a low level of formal education, a relevant characteristic since education level is essential for maintaining high production standards. In

aquaculture, greater technical efficiency has been reported when the educational level of operational staff is higher (Lind et al., 2015; Islam, Mitra, and Khan, 2023). This suggests that integrating trained personnel into this productive activity can contribute to its sustainability and growth in the coming years.

On the other hand, tilapia producers in the *Valle del Mezquital* reported investing only 5 US$ or less in veterinary services. Likewise, the lexicographic profile showed that the word "dollar" had low frequency and association with other words in network flow diagram, a situation that demonstrates a low spending profile on the farms, a trend that could contribute to the spread and occurrence of diseases (De Briyne, 2016).

In this context, 66.6% of respondents reported a history of disease outbreaks in their farmed fish during the last year, mainly of a parasitic nature. It should be noted that, although parasitic loads in tilapia farming are common, their presence can lead to problems in the farm. In Veracruz, Mexico, the presence of *Gyrodactylus cichlidarum* has been reported to affect the body conformation of tilapia fry, while the parasitic community composed of *G. cichlidarum*, *Trichodina* sp., *Chilodonella* sp. and *Ambiphrya* sp. has shown adverse effects on the weight of the fish (Jiménez-García, Rojas-García and Mendoza-Franco, 2020).

Furthermore, in the qualitative analysis, the word “deworming” showed a weak association with the community of words comprising application methods (community in blue), whereas the word with the highest co-occurrence was “salt,” suggesting a low profile for deworming processes in the fish, aspects that may be related to a low availability of therapeutic alternatives for exclusive use in fish (Lieke et al., 2019).

In the case of fungal diseases, these ranked second in frequency of mention, while the qualitative analysis profile showed that the word "fungal" had a high co-occurrence with the word "positive". These mentions may be related to a wide range of pathogenic fungi; however, it has been documented that *Oomycota* fungi are the most recurrent pathogens in farmed fish (Sarowar et al., 2019).

Among the most relevant fungi in the aquaculture industry, *S. parasitica* has been reported as the most prevalent species. This fungus exhibits low host specificity and causes focal skin lesions with cottony hyphae (Derome et al., 2016; Mahboub and Shaheen, 2021). Fish can also be affected by other fungi, such as those belonging to the genera *Exophiala* spp. and *Pythium* spp. (Armwood et al., 2021; Tedesco et al., 2021). It is

worth noting that, in the co-occurrence analysis, the word "topical" had a value of 7 compared to the word "treatment," suggesting an opportunity for addressing diseases in tilapia farming, such as skin conditions.

The producers did not mention the pathogens related to their crops at the species level; however, during the interviews, they relied on previous farm records provided by the state health authority. Therefore, specialized technical monitoring, whether governmental or private, is of paramount importance for local aquaculture. Similarly, biosecurity is an important system in aquaculture farms, which seeks to reduce the risks associated with crop pathogens, food safety, public health, pests, genetic risks, and environmental, financial, and social risks (Arthur et al., 2009).

In this context, respondents reported a high frequency of compliance with facilities such as handwashing stations, sanitizing mats, biosecurity equipment, and signage, as well as a 100.0% presence of perimeter fences. These elements are established in the good practices manuals for tilapia production that the Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA) establishes for Mexico (SENASICA, 2008). It is worth noting that the qualitative analysis showed that the phrase "does not apply" was the most frequent in this study, which is relevant since it has been previously reported that the presence of infrastructure, actions, and protocols related to biosecurity prevents the entry of diseases or potential vectors into aquaculture farms (Lillehaug, Santi, and Østvik, 2015). In contrast, the farms mentioned a low presence of vehicle fords. The co-occurrence analysis revealed that the word “vehicle” did not serve as a connecting node between word communities, positioning it as a term of low semantic value for producers within the context of biosecurity. The low frequency of vehicle access points can represent a pathway for the introduction of diseases into aquaculture (Jia et al., 2017). In Nigeria, for example, it was reported that vehicle access to farms represents an odds ratio of 2.71 with respect to observed mortality in fish populations (Adah et al., 2023).

On the other hand, up to 17 out of 18 farms reported carrying out aquaculture activities under biosecurity practices such as record keeping, pest control, chlorination systems, as well as the periodic application of laboratory tests to fish and operators. In addition, these words together showed the formation a co-occurrence community as a central theme of this study. The profile of these mentions can be related to the actions implemented in Mexico with a view to obtaining certificates in aquaculture

health and safety, actions established by the Ley General de Pesca y Acuacultura Sustentables, and developed by SENASICA (DOF, 2007).

SENASICA is also the entity responsible for operating aquaculture and fisheries health and safety programs in Mexico, which promote the application of biosecurity measures in Mexican aquaculture (Martínez and Hernández, 2025). These regulations establish the basis for the application of biosecurity and require continuous training and active participation from aquaculture farms in the *Valle del Mezquital* and other regions in Mexico. Regarding therapeutic and preventive actions, respondents reported conducting on-site parasitological analyses, but with low frequency for deworming fish populations. These actions highlight the importance of identifying and calculating the cost of animal health interventions, given that these interventions can provide socioeconomic benefits to the aquaculture production system and the sector's econometric indicators (Peeler et al., 2023).

In addition, producers reported specific therapeutic strategies, the most frequent being the application of coarse salt. This substance is commonly used in aquaculture for the prophylaxis and treatment of parasitosis caused by protozoa such as *Costia* spp., *Epistylis* spp., *Trichodina* spp., *Chilodonella* spp., and by monogeneans such as *Dactylogyrus* spp. and *Gyrodactylus* spp. (Swarm and Fitzgerald, 1992). Besides salt, other substances such as garlic and onion were reported as alternative strategies for use in aquaculture; although the frequency of mention was low, these plant resources have been reported as therapeutic elements in aquaculture due to their antimicrobial and antiparasitic properties attributed to organosulfur compounds such as alliin (Krstin et al., 2018).

While these compounds represent alternative therapeutic strategies in aquaculture, the application of drugs such as antibiotics and anthelmintics was also observed to be limited, at only 11.1%. Furthermore, in the qualitative analysis, the phrase "does not apply" was the most frequent. In the co-occurrence analysis, the words "expense" and "dollar" belonged to the community of words (blue) associated with application methods; however, they showed low co-occurrence with the word "application," suggesting limited allocation of financial resources on the farms evaluated. This may be related to the lack of medications specifically for use in aquatic organisms at the local level and other therapeutic challenges, such

as insufficient training in recognizing the routes of administration (Bader et al., 2019; Lieke et al., 2019).

Consequently, although the treatment profile was low, the most frequently mentioned therapeutic compounds were those intended for parasite treatment and applied via immersion baths, a strategy that is not very sustainable when considering the application of highly oxidizing molecules such as triphenylmethane, copper, acriflavine, and formaldehyde. These compounds, in addition to controlling parasite loads, can pose a risk to fish, the pond microbiome, and even the end consumer (Lieke et al., 2019), thus jeopardizing the sustainability of production systems and the ecological aspects that contribute to agri-food production (Sarita, 2024). It is worth noting that, within the treatment category, the word "injection" was the only active form categorized as a hapax, demonstrating a weak semantic connection between these application methods and the surveyed producers. Therefore, the development and technological transfer of therapeutic strategies constitute an area of opportunity in local aquaculture, and even on a global scale (Pirarat et al., 2015; Wang et al., 2018).

Frequency analysis showed that biosecurity measures and protocols may be related to a lower frequency of diseases in tilapia farms, fulfilling their function by preventing the entry of pathogens and diseases that initially spread through the culture water (Georgiades, Jones, and Fraser, 2016). Furthermore, lexicographical analysis—as evidenced by the word cloud—reveals that the word "negative" was among the most frequent in this study; additionally, the co-occurrence analysis shows that the words "negative," "parasitic," "bacterial," and "viral" belong to the same cluster of forms and are associated with the cluster related to the implementation of biosecurity measures. This suggests that the presence of biosecurity infrastructure and management practices can reduce the occurrence of pathogens and diseases in the surveyed farms.

Biosecurity programs and their implementation have shown a positive effect on fish farms, decreasing mortality rates (Khor et al., 2024). However, this study observed only partial compliance with biosecurity measures such as vehicle access points, medication procedures, and the application of preventive expenditures, which could be associated with a lack of knowledge regarding the fundamentals and benefits of their application (Zulbainarni and Megawati, 2019).

In contrast, 100.0% of the farms reported having access to specialized technical assistance provided by the government, suggesting that the sector

may show improvements in biosecurity systems in the coming years. Therefore, it is necessary to continue multidisciplinary intervention in the sector, as well as the development of studies that characterize biosecurity systems and identify sanitary limitations. This approach can contribute to the development of locally applicable strategies, as well as to the prevention and management of infectious diseases in aquaculture production systems (Assefa and Abunna, 2018).

CONCLUSIONS

Tilapia aquaculture in the *Valle del Mezquital* is an inclusive livestock activity in terms of age. However, the educational level of participants fluctuated. Farms showed heterogeneity in disease occurrence, with parasites persisting despite compliance with biosecurity measures. In contrast, the presence of implements such as perimeter fencing can reduce the occurrence of bacterial, fungal, and viral pathogens; nevertheless, areas for improvement were identified, such as the need to refine the profile of applied expenditures, available treatments, and application methods. Lexicographical analysis revealed a high frequency of the phrase "does not apply," suggesting that various biosecurity elements and actions are not frequently implemented, including deworming protocols for fish. Therefore, their application could strengthen biosecurity systems in local aquaculture. In light of these findings, it could prove useful for various stakeholders in the tilapia production chain to open marketing channels that improve the availability of therapeutic products, and to focus training for producers and operators on the administration of treatments under the supervision of animal health professionals, as well as on the benefits derived from implementing biosecurity systems at various geographic scales. In this context, professional support can contribute to the implementation and maintenance of biosecurity plans in the sector. Furthermore, it is relevant to continue developing studies that allow for situational analysis and the focusing of efforts to improve aquaculture health in areas with a long tradition of tilapia farming, such as the *Valle del Mezquital*.

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