Agricultura, Sociedad y Desarrollo

AQUACULTURE AND COVID-19: IMPACTS ON THE PRODUCTION OF TILAPIA IN THE CENTRAL ZONE OF THE STATE OF HIDALGO, MEXICO

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ABSTRACT

The pandemic (COVID-19) caused by the SARSCov-2 virus was a highly important event, with adverse effects in the economies of many countries, mainly developing countries; the event affected most industries, including those in the agriculture and livestock sector. In Mexico, aquaculture is considered a farming activity of recent development, with an important economic potential in some zones of the country; however, its development could have been affected by the COVID-19 pandemic. Because of this, information was gathered through semi-structured interviews to evaluate the effects of COVID-19 in small-scale tilapia producers in Valle del Mezquital, Hidalgo, Mexico. This evaluation evidenced a loss of employment of 23.53%, in addition to 67.41% of the farms, mentioning that their business had losses with a maximum value of $10,335.13 USD in one year of farming. The reductions were associated mainly with discrepancies in sales (35.29%) and the loss of commercialization channels (41.17%). However, the farms mentioned that the economic recovery of their businesses could be supported by actions such as the application of added value to the product (52.94%) and financial backing in the acquisition of fry (35.29%). The effects identified from COVID-19 in tilapia aquaculture showed trends that could be useful in the development of strategies for mitigation and recuperation of this industry.

Keywords: culture, impact, mitigation, pandemic, tilapia producers.

INTRODUCTION

The first case of COVID-19 in Mexico was detected on February, 27, 2020. Facing this situation, the country declared a sanitary emergency status on March 30, 2020; this status derived in the closure of non-essential activities and in the application of social distancing policies in every sector, including those of agrifood production (Gobierno de México, 2020). However, in the 64 days after the first case diagnosed in Mexico, 19,224 cases were confirmed, with a mortality rate of 9.67% (Suárez *et al*., 2020), while by mid-2020, approximately

81 million people had presented the infection in the whole world, and close to one million deaths had been recorded, which represented important variations in the econometric markers of different countries (Sarà *et al*., 2022). The fast and global spread of the disease established a critical scenario for the development of activities and to obtain food resources. Facing this scenario, different reports have been published to evaluate the effects generated by COVID-19, the most recurring are in sectors such as cereal farming, silviculture, or the meat production industry, including some precedents for aquaculture (Islam *et al.,* 2021; Manlosa *et al.,* 2021; Mohanty *et al.,* 2020; Van Senten *et al.,* 2021).

In the food sector, fish has a notable impact on different populations and communities throughout the world, mainly because it provides essential and affordable animal protein for the diet (Okoye *et al*., 2014). The aquatic food industry reported one of the highest projections globally, with a considerable growth in recent decades (Gjedrem *et al*., 2012). Foods obtained from aquatic sources represent around 173 million tons; in this production, the highest contribution comes from the Asian continent, where countries such as China, India and Indonesia stand out, which occupy the first places in global production in that order (Organización de las Naciones Unidas para la Alimentación y la Agricultura-FAO, 2019).

This growth allows fishing and aquaculture to contribute resources that promote food security, job creation, and economic activation around the world (Adugna *et al*., 2020; Chibwana *et al*., 2020). Just in China, there are 5 million aquaculturists and close to 9.4 million fishermen working (Huang & He, 2019), although it is estimated that close to 100 million people are economic dependents on these two activities globally (González *et al*., 2017).

Therefore, this study analyzes the impacts generated by the COVID-19 pandemic in tilapia aquaculture of Valle del Mezquital, focusing on socioeconomic aspects, such as expenditures used for biosafety inputs and adverse effects in the decrease of family economic inputs, based on the aquaculture activity; likewise, the study seeks to evaluate adverse effects in the planning of productive cycles and administrative activities related to tilapia farming. The aforementioned, in search for an evaluation to contribute to the development of mitigation strategies in a food production area, which represents a source of economic income for local families.

THEORETICAL FRAMEWORK

Fish meat is a prominent food source in Mexico and the world (Okoye *et al*., 2014), since its consumption contributes high digestion protein to the diet related to the free amino acids and fatty acids present in its composition, which in addition contribute benefits to health (Ariño *et al*., 2012; Baldissera *et al*., 2020). Its consumption has been reported to have beneficial effects to decrease

the incidence of diabetes type 2, as promoters of brain development, and of the liver in the lactating stage; similarly, it has been associated as a contributor to decrease the risk of cardiovascular diseases, inflammatory disorders, and the development of tumors (Fatel *et al*., 2021; Solomando *et al*., 2020; Zhang *et al*., 2019).

Among the meat products of aquatic origin, tilapia meat stands out as a product of high socioeconomic value; different species and hybrids have been introduced in approximately 90 countries throughout world, initially with aquaculture aims (Gu *et al*., 2019). This species has shown a progression in its farming in recent decades, with an annual contribution of 6 million tons of food, and in addition, projections estimate it will reach 7.3 million tons by 2030 (Abdel-Latif *et al.,* 2020).

Tilapia presents production advantages over other species, where a high dietary conversion (Gjedrem *et al*., 2012) and resistance to diseases can be emphasized, and it can be cultivated even under extensive feeding plans. Likewise, it has been reported that these organisms can present good production indices in wide intervals of water quality parameters, with temperatures between 27-30 °C and oxygen availability between 5-23 mg/L (Fajer-Ávila *et al*., 2017; Makori *et al.,* 2017). Unfortunately, the same as the other agriculture and livestock activities, aquaculture has presented impacts derived from the COVID-19 pandemic.

Countries like the United States have reported losses of large-scale trade channels, while Ghana reported a global setback in the aquaculture production chain in the country (Ragasa *et al*., 2022; Van Senten *et al*., 2020). In the presence of the pandemic, unemployment was among the most outstanding social phenomena which had an important effect on food production (Hatayama *et al*., 2021).

In Mexico, tilapia production represents up to 91% of the aquaculture production in some geographic zones (Domínguez-May *et al*., 2020). Its sale and consumption is mainly on the farm, in a broad variety of regional dishes that include presentations such as ceviche, foil-wrapped, baked, and fried fish (Lango-Reynoso, 2011). The state of Hidalgo has water resources that allow the development of aquaculture, based on 24 rivers, 11 dams, 4 streams, 3 lagoons; these bodies of water correspond to the Pánuco and Tuxpan-Nautla water basins (Instituto Nacional de Estadística y Geografía-INEGI, 2017) and they allow the culture of species like tilapia (*Oreochromis niloticus*), trout (*Oncorhynchus mykiss*), catfish (*Ictalurus punctatus*), and carp (*Cyprinus carpio*), based on 610 production units that are registered in the state (Velasco-Amaro *et al*., 2015). The state of Hidalgo borders south with Mexico City (CDMX), characteristic that allows the exploitation of environmental goods and services related to aquaculture and tourism (Organización para la Cooperación y el Desarrollo Económico-OECD, 2019).

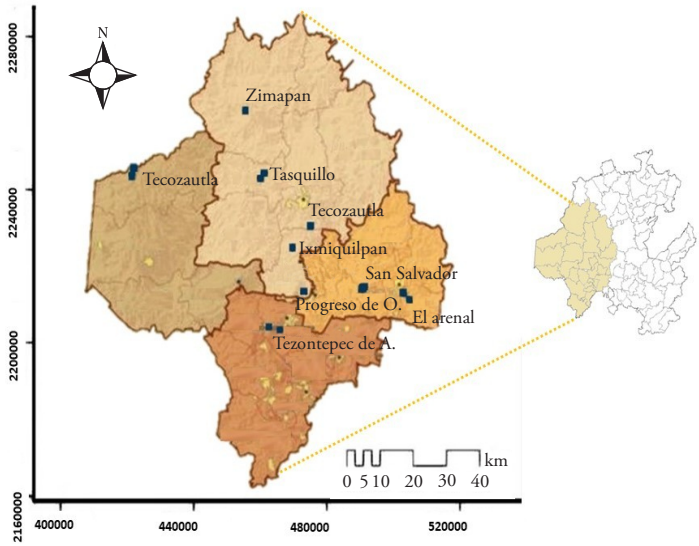
However, this same situation exposed the state of Hidalgo to a status of risk during the COVID-19 pandemic, since the CDMX was the place where the highest number of positive cases was reported in Mexico (Suárez *et al*., 2020). In addition to this, coronaviruses (*CoVs*) have shown infection in humans, and in domestic and wild animals (Decaro *et al*., 2020; Ferri and Lloyd-Evans, 2021); this suggest the evaluation of impacts generated by the COVID-19 pandemic in different productive areas, where the inquiry about the perception of producers can be addressed, regarding the relationship there is between the pandemic and the different systems of animal production. Previously, it has been reported that aquaculture farms exhibit different economic resilience in face of the impacts of COVID-19, depending on the good management of farms, investment, and human capital they have (Murray *et al*., 2021). The response from the aquaculture industry to COVID-19 implied a challenge due to the expenditures generated for the purchase of biosafety inputs (Villarreal-Ríos *et al*., 2021). In addition, the emerging expenditures were added to the loss of jobs that different populations faced during the confinement stage, which derived into a stressor factor for the food system (Van Senten *et al*., 2020). These food systems result from the sum of interactions between actors of the production chain, from input supply, sale, preparation, consumption, and elimination of wastes from a product (Fan *et al*., 2021); therefore, the evaluation of areas that have suffered adverse effects is necessary to maximize the long-term resilience of the aquaculture sector and other food production chains (Sarà *et al*., 2022).

METHODOLOGY

Study area

The region of Valle del Mezquital (Figure 1) is located only 60 km away from Mexico City, in the state of Hidalgo; it covers close to 642,653 ha and has a population of 900,000 habitants, among which 24% of the population is indigenous (Durán-Álvarez *et al*., 2021). The main source of jobs in this region is based on agriculture, which subsists thanks to the input of residual water from Mexico City (Pérez-Díaz *et al*., 2018). In addition, the economic development of this region is complemented with the offer of tourism services associated to the water parks (García-Hernández and Tovar-García, 2012).

Likewise, the zone has water resources such as the sub-basins of the Tula and San Juan rivers (which include the Alfajayucan, Arroyo Zarco, Rosas, Salado, Tecozautla, Tlautla, Actopan, and Tula rivers) (López-Aguilar and Fournier, 2009), allowing the development of aquaculture practices that are focused in the semi-intensive fattening of tilapia (275 tons per year) in rural zones, sustained by nearly 273 culture farms (Velasco-Amaro *et al*., 2015).



Source: prepared by the authors.
Figure 1. State of Hidalgo with close-up to the Valle del Mezquital; the tilapia farms where the surveys were applied are marked with blue dots.

Information collection

Semi-structured surveys were applied between August 1 and 30, 2021, with tilapia producers of the geocultural region of Valle del Mezquital, in the state of Hidalgo, Mexico. The survey applied showed a Cronbach α of 0.7945, as a measure of covariance between the elements of the instrument, calculated through formula (1) (Sniukas, 2020). The index shows results between 0-1, evidencing a strong relationship between the questions of the instrument when the index obtained is higher than 0.7 (Dacto *at al*., 2017).

$$\alpha = \frac{K}{K-1}\left[1-\frac{\sum V_i}{Vt}\right] \quad (1)$$

The surveys were applied through in-person individual interviews, with an average duration of 4 hours, with intermediate rests after 2 hours of application (one survey per farm). The municipalities selected for the application were those where there is aquaculture. The questionnaires are focused in information collection about the impacts generated by the COVID-19 pandemic, because of the Sar-Cov-2 virus, on the socioeconomic characteristics of the producer, the effects in administrative actions, trade channels, and in the strategies to mitigate the adverse effects. The sample size (*nh*) was obtained by optimal stratification, considering expenditures of sample taking and production level,

based on a sampling universe of 273 tilapia farms, located in seven out of ten geocultural regions of the state of Hidalgo. The sample size (*nh*) was calculated for each geocultural region, through the formula (2), based on Brus *et al*. (2019) (Table 1).

$$n_h = n \frac{\frac{N_h \sigma_h^2(y)}{\sqrt{\overline{C}_h}}}{\sum_{h=1}^{L} \frac{N_h \sigma_h^2(y)}{\sqrt{\overline{C}_h}}} \quad (2)$$

The region of Valle del Mezquital was selected for this study, due to the characteristics that connect it to Mexico City and because it presented the highest number of aquaculture production units in the state of Hidalgo. The *nh* was 17 farms; finally, the farms were selected completely randomly for the survey application (Table 2).

Information analysis

The information obtained through application of the surveys was classified into four sections: 1) perception of COVID-19, 2) socioeconomic effects in producers, 3) effects in the production chain, and 4) mitigation strategies. The data were captured and tabulated for their analysis through descriptive statistics (Antwi *et al.*, 2017). The data that correspond to the economic impact were expressed in American dollars (USD), considering the exchange rate (20.44 pesos MXN for 1 USD) on March 18, 2022. These data were analyzed according to their geography, through the elaboration of maps from shape files processed with RStudio (Boston, MA, USES) (Mardones, 2020). The unit of analysis was geographic at the municipal level, because farms from the region under study are cataloged as rural semi-intensive aquaculture production units (Vega *et al*., 2010; Velasco-Amaro *et al*., 2012, 2015); this condition in the farms selected for the study was confirmed when the visits were carried out, the farms shared similarities in management defined by social networks for rural development, which are supported by the government.

RESULTS

Perceptions of COVID-19 among tilapia producers

The surveys were applied to tilapia producers from 17 rural semi-intensive production farms that belong to 15 localities in the geocultural region of Valle de Mezquital (*nh*=17; Table 1) (Table 2). The survey respondents were men (70.6%) with an age range between 29 and 73 years old, who mentioned having had 2 to 30 years of experience in tilapia aquaculture.

Table 1. Optimal stratified sampling by geocultural regions, which have tilapia aquaculture activity in the state of Hidalgo, Mexico.

Elements	Farms per region	σ (production in tons)	Cost of survey application	Interaction (farms-σ production-cost of application)	Interaction of components/sum of the interactions of all the strata	Size of the optimized sample
Regiones	n	$\sigma_h^2(y)$	$\overline{C}_h$	$\frac{n_h \sigma_h^2(y)}{\sqrt{\overline{C}_h}}$	$h = \frac{\frac{N_h \sigma_h^2(y)}{\sqrt{\overline{C}_h}}}{\sum_{h=1}^{L} \frac{N_h \sigma_h^2(y)}{\sqrt{\overline{C}_h}}}$	n_h
Huasteca	37	2.2094	828.0890	2.8407	0.3163	11.7061
Sierra Alta	21	0.2524	689.3909	0.2019	0.0224	0.4722
Sierra Gorda	25	1.7893	879.1018	1.5087	0.1680	4.2008
Sierra Baja	38	0.5686	613.0345	0.8727	0.0972	3.6936
Valle del Mezquital	120	0.2002	1,012.3245	0.9817	0.1093	17.0658
Comarca Minera	4	1.4856	256.6869	0.3709	0.0413	0.1652
Sierra de Tenango	21	0.2805	438.3327	0.2814	0.0313	0.6582
Valle de Tulancingo	7	4.4761	267.4916	1.9157	0.2134	1.4943
Total	273		$\sum_{h=1}^{L} \frac{N_h \sigma_h^2(y)}{\sqrt{\overline{C}_h}}$	8.9789		

Source: Prepared by the authors based on the sample universe, 2020.

Table 2. Identification of the 17 tilapia farms in Valle del Mezquital that were included in the study.

ID	Farm data					Producer's data		
	Municipality	Locality	Latitude	Longitude	Type of farm	Gender	Age	Seniority
S1	Zimapán	El Cuarto	20.685085	-99.354951	Semi-intensive	F	44	15
S2	Tasquillo	Remedios	20.529587	-99.309382	Semi-intensive	F	29	18
S3	Tasquillo	La Vega	20.54342	-99.298828	Semi-intensive	F	30	10
S4	Ixmiquilpan	Maguey Blanco	20.423024	-99.164611	Semi-intensive	F	61	20
S5	El Arenal	El Rincón	20.270059	-98.89466	Semi-intensive	M	56	7
S6	El Arenal	El Rincón	20.254684	-98.876271	Semi-intensive	M	56	6
S7	San Salvador	El Bondhó	20.283618	-99.007561	Semi-intensive	M	44	10
S8	San Salvador	San Salvador	20.281176	-99.012722	Semi-intensive	M	73	2
S9	San Salvador	El Olvera	20.277841	-99.016137	Semi-intensive	M	57	20
S10	Tezontepec de Aldama	Mangas	20.186298	-99.253231	Semi-intensive	M	67	30
S11	Tezontepec de Aldama	Santiago Acayutlán	20.192371	-99.285684	Semi-intensive	M	44	10
S12	Chilcuautla	Tlacotlapilco	20.372733	-99.217742	Semi-intensive	M	40	15
S13	Progreso de Obregón	Los Manantiales	20.273672	-99.184239	Semi-intensive	M	60	10
S14	Tecozautla	Gandho	20.553687	-99.677095	Semi-intensive	F	57	20
S15	Tecozautla	Gandho	20.555123	-99.679767	Semi-intensive	M	54	16
S16	Tecozautla	Tecozautla	20.535839	-99.684407	Semi-intensive	M	42	16
S17	Ixmiquilpan	Maguey Blanco	20.421881	-99.164953	Semi-intensive	M	54	21

Source: prepared by the authors based on data from the sample universe, 2020.

In the information related to the perception of COVID-19 by producers, it was found that 94.1% of the survey respondents identified the disease by listing names such as COVID, COVID-19 and coronavirus, to refer to the causal agent, a relevant aspect for the adaptation to the changes generated by the disease. Likewise, 23.5% of the survey respondents believe that there are possibilities for the disease to affect their fish under culture, due to the disinformation in the sector and, therefore, that it could affect the quality in the market. In the dynamics of disease spreading, 17.6% of the survey respondents manifested having presented infection from COVID-19.

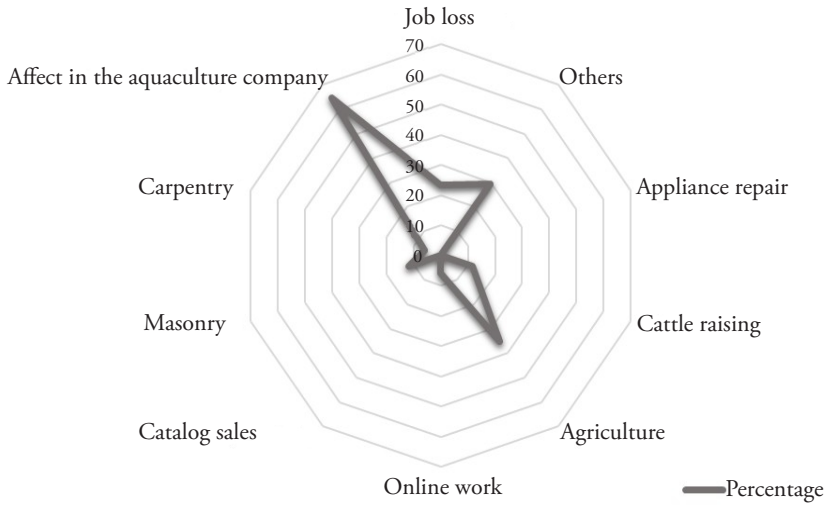
In addition, it should be mentioned that up to 76.5% of the farms studied are in contact with at least one person who had presented the infection: 41.2% with neighbors (others), 17.6% with their parents, while contact with siblings and clients with the infection represented 11.8%. The farmers mentioned TV news programs as the most recurring information channel (88.2%), followed by the use of social networks through the internet (29.4%). As complement, the information channels of the local and health authorities, and neighborhood information, were used by 5.8% of the farms surveyed; the high percentage of producers who had information about the disease gave credibility to the sanitary situation and a better position to face the adverse effects that COVID-19 caused in the sector.

Socioeconomic effects of the COVID-19 pandemic on tilapia producers

Of the producers, 35.5% were devoted to agricultural activities, 29.4% to diverse activities (others). Trades such as bricklaying and breeding other backyard species were mentioned 11.76% of times and, complementarily, 5.9% of the survey respondents resorted to carpentry and online work (Figure 2). Regarding the COVID-19 pandemic, it generated socioeconomic damages among tilapia producers; 23.5% of aquaculturists reported having lost their source of employment, when they maintained a work relationship outside tilapia production. In addition, 64.7% manifested that the pandemic somehow affected their aquaculture business, where one of the impacts of greatest worry was its economic losses derived from social distancing. This reduction in economic income to the farmers' households fostered their inclusion in alternative paid activities, and in this sense, aquaculture is a secondary activity for many people, which allowed mitigating the decrease in resources in producers' families.

Effects in the tilapia production chain

The general mean of expenditures from the pandemic in rural semi-intensive farms (for example, sanitary carpets, face masks, antibacterial gel, and other

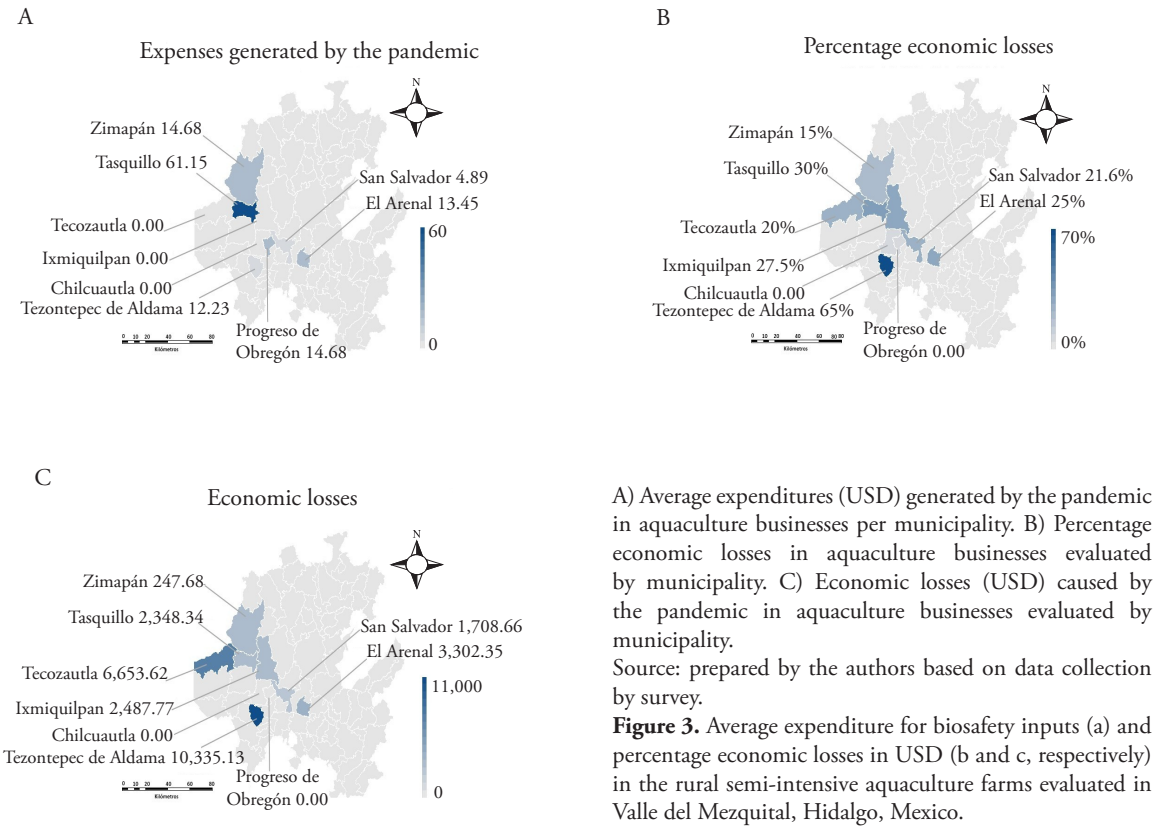


Source: prepared by the authors.
Figure 2. Impacts on socioeconomic performance of tilapia producers due to the COVID-19 pandemic; the data are expressed as percentage of mention.

sanitizing inputs), was $13.4 USD in a single payment (Figure 3A). In particular, farms located in the municipality of Tasquillo reported a higher investment for biosafety, with $61.15 USD as mean. In contrast, three municipalities (Tecozautla, Ixmiquilpan and Chilcuautla) manifested not having invested in this aspect. In the municipalities of Tecozautla and Ixmiquilpan, economic losses of 20% and 27.5% were reported, corresponding to one year of production (Figure 3B). The greatest economic loss was manifested in Tezontepec de Aldama, with a reduction of 65% of the expected income; neither Chilcuautla nor Progreso de Obregón reported a percentage economic reduction. The highest economic impact was described in the municipality of Tezontepec de Aldama, with a deficit of $10,335.13 USD, followed by Tecozautla with an economic loss of $6,653.62 USD (Figure 3C).

Economic losses were related by the producers with the discrepancy in programmed activities (Table 3); sowing was delayed in 35.3% of the farms, with a mean discrepancy of 1.3 months. This is related to the fact that the product on the farm could be traded and activities such as partial and total harvests were delayed in 17.6% and 29.4% of the farms, respectively. The pre-established sales of the product in trade agreements presented a discrepancy in 11.8% of the farms, because the buyers postponed their orders in face of the uncertainty of being able to sell them.

As a whole, this made the development of other activities in the farms difficult, such as deep cleaning that was postponed in 23.5% of the farms, prior to the beginning of the next production cycle. These operative difficulties



A) Average expenditures (USD) generated by the pandemic in aquaculture businesses per municipality. B) Percentage economic losses in aquaculture businesses evaluated by municipality. C) Economic losses (USD) caused by the pandemic in aquaculture businesses evaluated by municipality.
Source: prepared by the authors based on data collection by survey.

Figure 3. Average expenditure for biosafety inputs (a) and percentage economic losses in USD (b and c, respectively) in the rural semi-intensive aquaculture farms evaluated in Valle del Mezquital, Hidalgo, Mexico.

Table 3. Adverse effects derived from the COVID-19 pandemic in the planning of farming activities in tilapia farms of Valle del Mezquital.

Activities with discrepancy	Percentage of mention	Minimum	Maximum	Mean±StdDev
		Discrepancy in months		
Sowing	35.29	0	12	1.35±2.93
Partial harvest	17.64	0	12	0.17±2.95
Total harvest	29.41	0	12	0.29±3.37
Pre-established sales	11.76	0	12	0.11±2.95
Deep cleaning	23.52	0	12	0.23±2.95
Expansion of infrastructure	11.76	0	12	0.11±3.98
Cancelled events	Percentage of mention	Cancellation of events		
Training courses	64.70	0	3	1.29±1.10
Sales	0	0	0	0.0±0.0
Gastronomic	5.88	0	1	0.05±0.24
Promotion	0	0	0	0.0±0.0
Commercial arrangements	5.88	0	1	0.05±0.24

Source: prepared by the authors based on data gathered through survey.

induced 11.8% of producers to postpone the expansion of infrastructure in their farm. The tilapia producers described the cancellation of activities related to improving production and sale of their products (Table 3). Of the survey respondents, 64.7% mentioned cancelling their attendance to training courses, with up to three courses cancelled during the year of the pandemic. Meanwhile, attendance to gastronomic events and meetings for commercial agreements were cancelled in 5.9% of the farms surveyed.

Likewise, trade channels presented isolated difficulties. Of the farms, 35.5% of the farms could not acquire tilapia fry, because of the indications of social distancing, which decreased the entry of fry to the state from suppliers in the states of Veracruz and Michoacán, primarily; 29.4% manifested the loss of purchasing channels of feed for culture. Other channels of input acquisition were affected to a lesser extent; the acquisition of inputs, such as biosafety equipment, fishing crafts, chemical substances, medications and technical and veterinarian services, were blocked for 5.8% of the survey respondents. Complementarily, the survey respondents manifested the loss of sale channels: 41.2% of the farms lost local sale channels (product on the farm), while 35.3% manifested loss of sales to tourists; likewise, the loss of trade channels was mentioned for municipalities (17.6%), states (17.6%), and restaurants (5.9%).

Strategies for mitigation of the impact from COVID-19 in the tilapia production chain

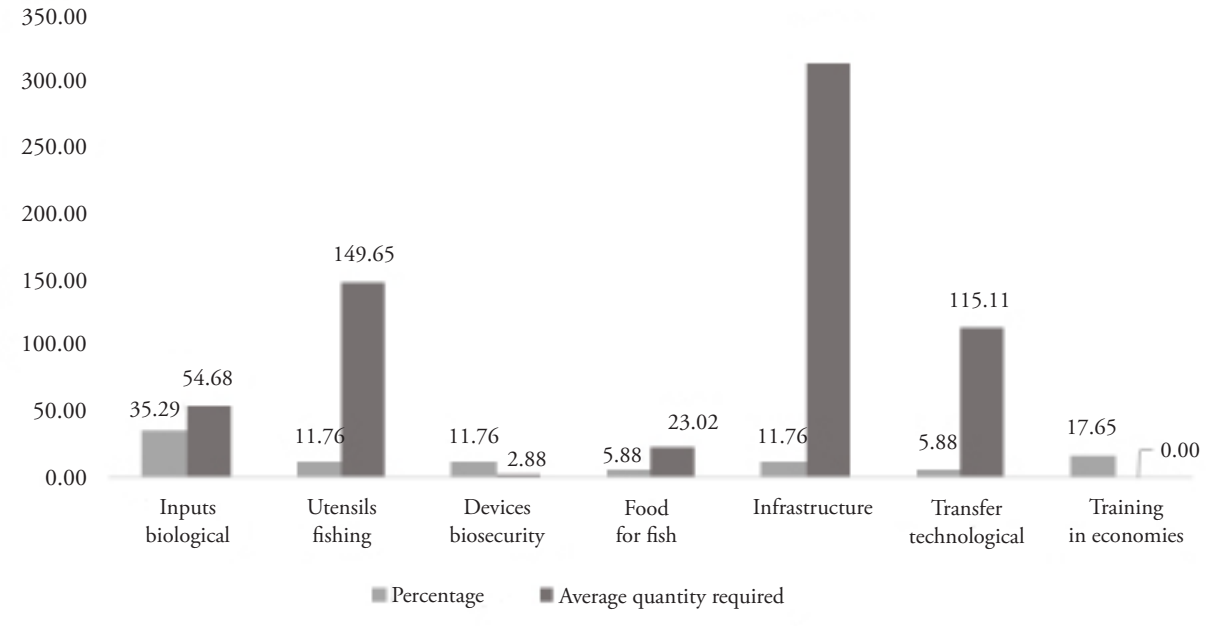
In the presence of adversities generated by the pandemic, the producers applied and have attempted to apply various mitigation activities. However, only 17.6% of the farms have complied with health protocols according to indications issued by different levels of sanitary authority. On the other hand, 52.9% of the producers reported that applying added value to their products can contribute to mitigate the decrease in tilapia sales; this strategy is accompanied by alternatives such as using family savings (23.5%), expanding the client portfolio (17.6%), requesting credits (11.7%), and other options with fewer mentions such as expanding a client portfolio and searching for investors, both with 5.8% of the mentions. It should be highlighted that some options such as selling or pawning belongings, as well as modifying the sale costs of the product, were not considered as an option to mitigate the impacts produced by COVID-19.

Finally, 35.3% of the survey respondents mentioned that they will require support in the purchase of biological inputs, with a mean average of $54.7 USD per farm, which represents the acquisition of close to 1,000 fry to develop a production cycle, amount used in small semi-intensive production systems of Valle del Mezquital. On the other hand, 17.6% of the producers mentioned that training was required regarding economic aspects, although they manifested

not knowing the cost for this concept. Another 11.8% mentioned requiring support in infrastructure and a similar percentage in the purchase of fishing utensils. For these concepts, the producers manifested requiring backing of $316.56 USD and $149.65 USD, respectively (Figure 4). In a global analysis, the experience of producers in aquaculture (14.4 years) and their age (50 years) were decisive to show resilience, in face of the socioeconomic impact caused by the COVID-19 pandemic; however, as was mentioned by producers, backing is required to prevent deserting the activity.

DISCUSSION

The perception there is of coronavirus has a significant impact on mental health aspects and in the probability of people respecting confinement regulations. The high percentage of tilapia producers in Valle del Mezquital who identify the causal agent of the pandemic plays an important role (Cori *et al*., 2020; De Saint Laurent *et al*., 2022), because it has been reported that coronaviruses (*CoVs*) can develop infection in humans, as well as in domestic and wild animals (Decaro *et al*., 2020; Ferri and Lloyd-Evans, 2021). In fact, among the four families of coronaviruses, those grouped as *Deltacoronavirus* can infect some fish species (Tiwari *et al*., 2020). However, there are reports that indicate that the union of Sars-Cov-2 (*Betacoronavirus*) and *ACE2* receptors is unlikely



Source: prepared by the authors from information collected by survey, the data were expressed as percentage of mention and average amount required in USD.

Figure 4. Inputs and costs proposed by survey respondents to mitigate the effects of the COVID-19 pandemic in their businesses.

in most fish (Ferri and Lloyd-Evans, 2021). This information is determinant in the risk perception that producers can relate with SARSCov-2, regarding health and quality of their fish.

In the presence of erroneous perceptions of the populations about SARSCov-2, communication channels played an important role; unfortunately, the outbreak of COVID-19 has been accompanied by a large amount of fake information provided to the population, primarily by social networks, a recurring means of consultation by the survey respondents (Apuke and Omar, 2021; Van der Linden *et al*., 2020). This scenario invites to improve the availability and the content of information by the sanitary authority in Mexico. In Valle del Mezquital, the search for information was related to indications for the peak of social distancing, because impacts on the industry were evident.

On the other hand, unemployment was among the most outstanding problems related to the COVID-19 pandemic. In geographical areas such as Georgia, USA, up to 10.9% of permanent discharges and 19.3% of unemployment in the informal private industry was because of COVID-19, datum that is lower than the unemployment reported by tilapia aquaculturists and the impact in their businesses in our study (23.53%) (Hatayama *et al*., 2021).

Likewise, unemployment in aquaculture in Valle del Mezquital reflects the situation at the national level in Mexico, where between March and April 2020, nearly 12 million jobs were lost in the economically active population, 21% from COVID-19 (Campos-Vazquez *et al*., 2021). Because of this, aquaculture producers and other field workers will have to adhere to alternative sources of employment, which unfortunately are informal and have precarious work conditions (Hoehn-Velasco *et al*., 2022). This transition of occupation and income reduction in farms reflects that COVID-19 has generated an economic crisis in different industries, including emerging activities such as aquaculture (Meza and Hernández, 2020).

However, the response of producers was discreet according to the expenditures applied in biosafety implements (maximum $61.15 USD annually), since other regions in Mexico, such as the city of Querétaro, reported a mean annual family expenditure of $527.27 USD, for the acquisition of biosafety elements (Villarreal-Ríos *et al*., 2021). The low investment by producers contrasts a market value of the tilapia industry estimated in 132 million MXN for the state of Hidalgo (Servicio de Información Agroalimentaria y Pesquera-SIAP, 2020). In addition to social distancing, producers reported losses of up to $10,335.13 USD per production cycle, situation that has been observed in other industries, such as livestock production and meat processing (Chen and Yang, 2021).

The information collected suggests that aquaculture in Valle del Mezquital is an industry susceptible to economic losses, situation that leaves producers unprotected, in face of occasional expenditures of prevention and attention

to the disease (Islam *et al*., 2021). The economic losses found in aquaculture present multiple origins, among them the closing of non-essential activities established at the national level in Mexico (Gobierno de México, 2020), and the low activity in trade channels; these particularities derived into high densities of stagnated crops and neglect in production standards (Marchant-Forde and Boyle, 2020; Murray *et al*., 2021). The difficulties that came up evidenced a very variable response from producers in Valle del Mezquital, since the activities planned reported discrepancies in an interval of 0 to 12 months, where some producers did not modify their planning and others had a substantial effect.

For example, in Bangladesh, a decrease of 28% was reported in chicken prices from January 1 to March 25, 2020. These changes were influenced by the restriction of mobility and the interruptions in supply chains (Sattar *et al*., 2021). For aquatic products in Thailand, government financial stimuli were required, in face of the low demand for their products (Chanrachkij *et al*., 2020). These restrictions can have an impact, to a greater extent, if the product in question is consumption on the farm in large proportion, such as the case of tilapia in Mexico (Lango-Reynoso, 2011). Globally, Asia reported adverse effects from the pandemic in tilapia aquaculture and other species; in China, Bangladesh and the Philippines, the main ones were: discrepancies in the beginning of the production cycles, difficulties for food acquisition, in addition to restrictions for the transport of products (Islam *et al*., 2021; Manlosa *et al*., 2021; Yuan *et al*., 2022).

In addition, the loss of channels for input purchase and sale were added, loss of suppliers of chemical substances, medications, biosafety equipment, technical services, and veterinary services. All of this caused a negative impact for the development of aquaculture (Islam *et al*., 2021). The impacts reported suggest the need to identify actions to mitigate the post-pandemic effects (Mohanty *et al*., 2020) and to develop intervention strategies for the economic recovery in zones with aquaculture activity (Islam *et al*., 2021; Manlosa *et al*., 2021; Yuan *et al*., 2022).

In this study, the main areas of opportunity reported by producers were improving biosafety protocols and giving added value to the product on sale. In China, the addition of added value has been reported, in addition to the formation of cooperative associations for product sale, which can potentiate the recovery of the aquaculture sector (Organización de las Naciones Unidas para la Alimentación y la Agricultura-FAO, 2022).

It is important to continue with training programs for the aquaculture sector, which have shown their functionality in the progression of aquaculture, even before the pandemic (De *et al*., 2013; Lind *et al*., 2015). However, producers from Valle del Mezquital ignore the acquisition value of this concept. As complement, it has been reported that the participation of governments as

mediators for financing can be essential. Their participation can be through loans with subsidized interests and longer payment installments, backing that allows tilapia producers to carry out the acquisitions that they consider relevant for their businesses to continue functioning (Yuan *et al*., 2022).

It should be highlighted that the evaluation of impacts from COVID-19 has been reported with different approaches, given the complexity of a production chain such as aquaculture. Erol (2022) reported that the COVID-19 pandemic derived in the decrease of total external resources in aquaculture in Turkey, with a decrease of 13% of the total assets, effects lower than those reported in this study. In addition, aquaculture in Turkey responded to the pandemic with an increase in the participation of external resources, making evident that in Valle del Mezquital, the refusal to search for investors can decrease economic resilience. In a regionalized context, aquaculture in Thailand evidenced an impact from COVID-19 in 89% of the farms evaluated, value higher than 64.7% of farms affected in Valle del Mezquital; in addition, the effects were similar, including decreasing the number of market channels and mitigating the economic impacts through income from agricultural production (Chumchuen *et al*., 2022).

In Japan, an economic recession of the aquaculture sector derived from COVID-19 was evidenced, and these adverse effects were accentuated in May, 2020, associated mainly to stagnation of the demand (Kobayashi, 2022); this condition was evidenced in the producers of Valle del Mezquital, such as the loss of sale channels in up to 35.3%. This type of impacts was evaluated even in countries of the European Union; the reports showed that the loss of sale channels to tourists, markets and restaurants were highly important in the challenge of the pandemic for the aquaculture sector (Nielsen *et al*., 2023). In addition, other regional studies in rural aquaculture agree that the main impacts of COVID-19 in the aquaculture sector were the restrictions of mobilization of the product, reduction of the demand, and loss of jobs (Atalay *et al*., 2024; Avento *et al*., 2024); in face of these situations, the diversification of strategies is determinant to mitigate the impacts generated by this adverse environment, caused by an anthropogenic stressor (Wang *et al*., 2024); because of this, the mitigation proposals described by aquaculture producers from Valle del Mezquital can be essential for the socioeconomic resilience of aquaculture businesses.

The adverse effects identified in this study and which were caused by COVID-19 in rural semi-intensive aquaculture in Valle del Mezquital, Hidalgo, Mexico, can provide useful information for the elaboration and adjustments of intervention programs and policies, to contribute to the industry of aquatic meat products. Their monitoring and study in the medium and long term is an undertaking that will allow being better prepared in the presence of high-impact events, such as the one caused by the COVID-19 pandemic.

CONCLUSIONS

The COVID-19 pandemic showed the vulnerability that presents the aquaculture production systems, from a particular approach to a regional one; its impact in aquaculture is associated with commercial aspects, which have been threatened in vulnerable areas such as Valle del Mezquital. The main effects were observed at the socioeconomic and planning level.

In addition, the changes generated imply particular challenges that can derive into financial and functionality risks of the microbusinesses. Because of this, the tilapia producers demand, as in other production areas, reliable information and training channels, as well as logistic support regarding the trade channels. Finally, this and other studies attempt to analyze useful information for the formulation of public policies, directed at contributing to the reactivation of food production integrally.

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