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Article

# Knowledge and absorption capacity for innovation process in the aquaculture sector: A case study in the Mezquital Valley-Mexico

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**Abstract:** As the population's demand for food continues to increase, aquaculture is positioned as a productive activity that provides high-quality protein. Aquaculture activity is characterized by its socio-economic impact, the generation of jobs, its contribution to food, and constant growth worldwide. However, in the face of threats of competition, producers must quickly adapt to market needs and innovate. Given this, this research aims to analyze the impact of the knowledge absorption capacity with the adoption of innovations by aquaculture producers in the Mezquital Valley in Hidalgo, Mexico. The methodological strategy was carried out through structural equation modeling using partial least squares and correlation tests. The findings show that knowledge absorption capacities explain 77.8% of the innovations carried out in aquaculture farms. Both variables maintain a medium-high correlation; the more significant the absorption capacity, the greater the innovation.

**Keywords:** knowledge; organizational competences; absorption capabilities; innovation aquaculture farms; Mexico; PLS-SEM

## 1. Introduction

Aquaculture, a rapidly growing sector globally, is not just a source of aquatic foods for human consumption but a key player in enriching nutrition with high protein content, ensuring food security, and contributing to poverty alleviation and income growth (FAO, 2020a; Ottinger et al., 2016). However, the study of aquaculture efficiency has not grown at the same time around the world. Research is consolidated in countries such as Norway, Bangladesh, and Vietnam. The same is not the case for other producing countries, such as Mexico (See et al., 2021). The sector faces significant challenges due to historical lag in planning and regulatory structuring, institutional instability, complex regulatory structures, and lack of investment in scientific and technological development (Vázquez-Vera and Chávez Carreño, 2022).

The aquaculture industry is facing challenges and a multifaceted crisis that demands immediate adaptability and resilience to capitalize on emerging opportunities responsibly and sustainably. The sector is grappling with substantial obstacles, including the global food crisis, rapid population growth, and the repercussions of climate change, which have led to declining business performance and posed significant hurdles in achieving enduring sustainability (Maulu, 2021).

Much of the economic activity in Mexico occurs informally, without proper title or, authorization or license, making it difficult to regulate and control. Small-scale aquaculture projects often need help maintaining interest because global competition hinders industry growth and sustainable development (Cuéllar-Lugo et al., 2018).

Despite not being officially recognized as one of the top ten economic activities, aquaculture plays a vital role in creating employment, fostering community ties, and supplying high-quality food. Its significant social impact should be acknowledged, and steps should be taken to support its growth and sustainability in the country (Quiñones et al., 2022). Likewise, Mexican producers face an increasingly competitive and changing market, mainly because of the competition between aquaculture and fishery products (Vázquez-Vera and Chávez Carreño, 2022), increasing their risk of leaving it. In this sense, innovation of product, process, organization, or marketing (OECD, 2007), could be fundamental for the exit of farms. Innovation in aquaculture tends toward technologies that are simple to understand and apply. Consequently, there is a strong preference for adopting fewer complex innovations, which can stagnate technological progress. Innovations can manifest themselves in various ways, such as incremental changes in existing technologies, modular modifications of management processes, design changes that require adjustments in management practices, and radical innovations that radically transform technology and management approaches (Kumar et al., 2018). Therefore, producers must develop new capabilities and skills to innovate and eliminate the difficulty of systematizing teaching and for innovation to have a multiplier effect (Vélez et al., 2018).

Innovation in aquaculture is driven by several economic (Samat et al., 2024) and environmental factors, highlighting the impact of climate change (Falconer et al., 2025) and the complexity of the technology adoption process, which varies according to the method of information transfer, the characteristics of the technology and the particularities of each farm (Kumar et al., 2018). This phenomenon becomes more intricate than other sectors, as individual producer perceptions deeply influence adoption decisions. Therefore, this study focuses on producer competencies as a key element in aquaculture innovation.

Competencies are developed in response to an organization's need for change. They represent companies' ability to create new organizational knowledge by reevaluating and enhancing their skills through knowledge acquisition, learning, and fostering innovation (Garzón, 2015). The concept of competencies originates in the theory of Resources and Capabilities, which was first introduced by Penrose (2009). This theory emphasizes the high value of a firm's specific resources (Barney, 1991).

For this work, research was conducted to choose the organizational capabilities best adapted to aquaculture innovation. Based on this, the following question arises: How does the absorption capacity of external knowledge impact innovation on aquaculture producers in the Mezquital Valley in the State of Hidalgo?

One of the main conclusions is that absorption capacities indeed explain the innovation of producers and that there is a direct correlation between them. The following sections of the document present the contextual framework of the aquaculture sector. This section mainly discusses the world's aquaculture production and the employment generated. Next is the theoretical framework; this section includes the leading theory and representative authors for elaborating this work. The methodology presents the instrument, the sample, and the methods and programs used. The results show the correlation between the variables and the structural equation model. In the discussion section, some papers are cited to compare the results. Within the conclusions, some recommendations are presented, and finally, the limitations of this work are discussed.

## 2. Challenges and innovation in the aquaculture

Global aquaculture production maintained constant growth in 2020; the total for that year amounted to 87.5 million tons of fish products in live weight for human consumption, 35.1 million tons of algae, and 700 tons of pearls and shells for ornamental use, a total of 122.6 million tons. This represented an increase of 6.7 million tons compared to 2018 (FAO, 2020b). Aquaculture has had unprecedented growth, mainly because per capita fish consumption has increased at an average rate of 3.0% annually since 1961, while the demographic growth rate is 1.6% (FAO, 2020a), and consumer preferences have changed (Kim et al., 2020).

The global food sector faces significant challenges in meeting the nutritional needs of a growing world population. As a result, global aquatic food consumption, excluding algae, has experienced a remarkable increase. Today, demand is more than five times the amount consumed approximately 60 years ago, reflecting a significant transformation in consumption patterns. (FAO, 2020a).

The production of intensive and semi-intensive aquaculture is expected to be crucial in ensuring global protein supply. In the context of Latin America and the Caribbean (LAC) region, reported production of 4.3 million tons of aquatic animals, representing a remarkable 12.8% increase over the 3.8 million tons recorded in 2020. This growth was mainly driven by Ecuador and Brazil, which contributed 348,400 and 108,000 tons, respectively. Countries such as Colombia, Chile, and Venezuela have also contributed significantly. Despite being the region's leading producer, Chile increased its production modestly by only 1.5%. However, decreases in production were recorded in Mexico and Cuba, with falls of 16.9% and 40.66%, respectively, compared to 2020 (FAO, 2024).

A significant portion of aquaculture in Mexico is carried out without proper rights or permits (Cuéllar-Lugo et al., 2018). There is a pressing need for better management plans and economic policies to re-evaluate the industry (Quiñones et al., 2022). According to the Instituto Nacional de Estadística y Geografía (2019), aquaculture in Mexico lacks essential components such as structure, equipment, financing, consultancy, research, and development.

Mexico has potential environments for fish farming (Campos et al., 2016). It is the fourth producer by volume in live weight in Latin America, after Chile, Ecuador, and Brazil (Wurmann, 2022). Aquaculture production in live weight reached 290 thousand tons in 2022. However, FAO projections estimate that by 2032, this will be reduced to 284 thousand tons, implying a decrease of 1.8% (FAO, 2024).

The aquaculture industry in México employs few personnel compared to fishing or the seafood restaurant industry, but paid personnel represent 54% of the total employed personnel. While fishing reaches 38% and the total for the sector reaches 48% (**Table 1**) (Instituto Nacional de Estadística y Geografía, 2019). Therefore, aquaculture is an important economic activity for the country because it generates paid employment and socioeconomic impact (Cuéllar-Lugo et al., 2018) (**Table 1**).

**Table 1.** Aquaculture production units and employed personnel.

| Economic activity | Economic units total | Total employed personnel | Paid personnel |
|---|---|---|---|
| Subtotal. Fishing, aquaculture and related activities | 56,629 | 369,500 | 17,789 |
| Aquaculture | 3666 | 33,768 | 18,249 |
| Fishing | 19,627 | 179,478 | 68,763 |
| Preparation and packaging of fish and seafood | 216 | 16,043 | 9211 |
| Wholesale trade of fish and seafood | 618 | 6731 | 4760 |
| Retail trade of fish and seafood | 10,280 | 25,540 | 9592 |
| Restaurants with fish and seafood preparation service | 22,222 | 107,940 | 67,317 |

Source: Own elaboration based on the 2019 economic census (Instituto Nacional de Estadística y Geografía, 2019).

In México, fish production through aquaculture is closely related to small-scale aqua culturists in rural areas. It is focused on species of low commercial value requiring little technology, such as the wild mojarra (Oreochromis niloticus), a species of the tilapia family. This species is mainly sold gutted at the time of purchase. Its flavor is like soil, but consumers accept it due to its low cost (Conapesca, 2008). However, its importance lies in its impact on food security and poverty reduction (Vázquez-Vera and Chávez Carreño, 2022) and in the possibility of contributing to some sustainable development objectives, like the number 14 (FAO, 2024).

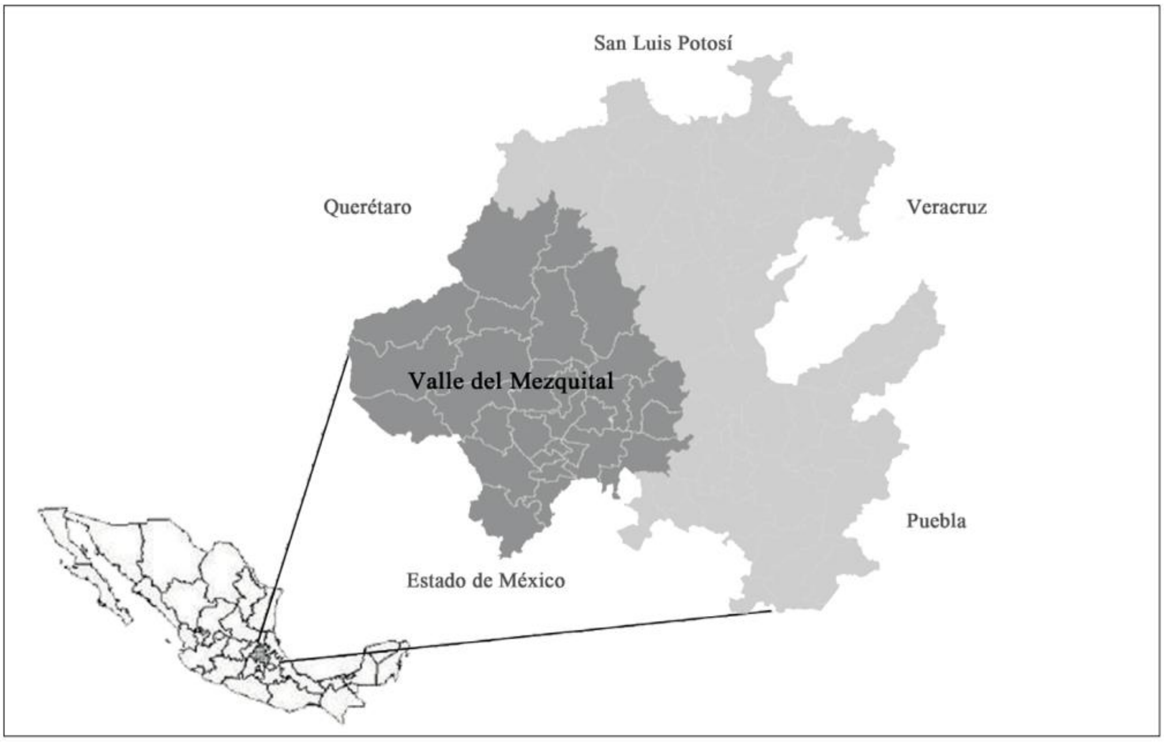


**Figure 1.** Location of the Mezquital Valley region.
Source: Contreras Román (2021).

The largest of the ten regions in the State of Hidalgo is the Mezquital Valley. Its surroundings are typically desert-like, and its economic development has been linked to farming activities that have benefited from wastewater collection from Mexico City since the late 19th century (Román, 2019). The Mezquital Valley is the largest region in Hidalgo, covering 9685 $km^2$, representing approximately 46% of the territory. It is located in the southwest of the state (**Figure 1**). Aquaculture activity is one of the main ones in the region–Other activities are agriculture and livestock- standing out for hosting the most significant number of farms in the state, 273 of 765 units; the main species produced are tilapia, catfish, and carp (Secretaría de Agricultura, 2021).

## 3. Theoretical framework

Organizational capabilities are the habitual and ingrained behavioral activities companies develop to streamline and optimize their day-to-day operations. As these capabilities become more deeply rooted, they effectively serve as the organizational memory (Nelson and Winter, 1982), shaping the company's identity in terms of specialized knowledge and expertise. That means that as long as the company consistently refines its operational routines and maximizes its resources, it can effectively gain and maintain competitive advantages (Zambrano and Yepes, 2006). However, true uniqueness emerges when the company is compelled to adapt and evolve in response to the dynamic conditions of its external environment through the renewal, integration, and reconfiguration of its resources and capabilities (Zapata and Mirabal, 2018).

In globalization, competencies are developed based on the Theory of Resources and Capabilities (TRC) to navigate the challenges and opportunities in global markets effectively. These competencies differentiate a company's distinct resources from its capacity to leverage them (Barney et al., 2011). Additionally, the dynamics capabilities are the regular actions of creating, expanding and modifying an organizational resource base and can be viewed as an expansion of these concepts (Kurtmollaiev, 2020).

According to Sánchez et al. (2022), Teece and his collaborators developed the theoretical perspective of competencies, a paradigm that attributes companies the ability to obtain advantages not only due to the tangible or intangible resources they possess or the capabilities they master but also considering the changes and requirements of their environment.

Originally, competencies were defined as the company is highly skilled in effectively integrating, constructing, and adapting internal and external competencies to proficiently address rapidly changing environments (Teece et al., 1997). It is essential to understand that competencies are the ability to detect opportunities and threats, to make timely decisions, and to implement strategic decisions and changes efficiently, thus ensuring direction results in the creation of new resources and improving their competitive advantage (Ferreira et al., 2020).

According to Teece, Pisano, and Shuen (Teece et al., 1997), competencies are ways of integrating existing conceptual and empirical knowledge that facilitate the acquisition of competitive advantages. The term "dynamic" refers to the renewal of competencies at the same speed as the business environment changes. Competencies are considered dynamic since they affect organizational and administrative capacities in different areas (Díaz et al., 2023).

It is interesting to know the relationship between this work and innovation. It is true that Teece (2020) currently projects a relational vision between his theory of capabilities and innovation. On the other hand, Teece (2007) stated that organizations with diverse competencies can adapt to dynamic business ecosystems and shape them through a combination of innovation and collaboration with other companies, entities, and institutions.

The Innovations are heavily influenced by competencies, which are not just about owning difficult-to-collect or imitate resources but also unique skills (Froehlich et al., 2017; Teece, 2007). Competencies are crucial drivers of innovation and play a significant role in absorbing knowledge and turning it into an advantage (Alves et al., 2017; Teece et al., 1997). The ability to innovate is directly linked to organizational performance, and organizations can acquire knowledge through various means, such as experience, experimentation, and acquisition. In order to achieve innovation, the capacity to absorb knowledge is crucial (Tidd and Bessant, 2020). Absorptive capacity, introduced by Cohen and Levinthal (1990), is defined as the ability to recognize the value of new information and assimilate and apply it (Castaneda and Cuellar, 2020). Absorption capacities have been widely accepted (Bastanchury-López et al., 2023).

Cohen and Levinthal (1990) explain the concept of absorptive capacities, which emphasizes organizations' ability to leverage external knowledge for innovation. Studies support knowledge sharing, supported by absorptive capacity and dynamic skills, which help capitalize on open innovation through knowledge management skills (Chatterjee et al., 2022). Also, the relationship between knowledge sharing and innovation continues to grow (Castaneda and Cuellar, 2020).

Knowledge it is considered an essential ingredient that can significantly impact the success of innovation initiatives (Lin et al., 2016). Several researchers have pointed out the interaction between absorptive capacity and innovation. Darwish et al. (2020) explain that the leader can convert external knowledge into strategic innovations compared to other actors in the company. If the managers have absorption capacity and are flexible to adapt to dynamic environments, they will use the available resources and capabilities to take advantage of emerging opportunities (Castrilló, 2016). Then, managers possess crucial competencies for successful management (Teece, 2019). Managers play a vital role in identifying and exploiting opportunities and developing strategies for business management (Augier and Teece, 2009). They build competence through decisions, intuition, and perception (Zapata and Mirabal, 2018). This capacity allows the company to acquire external knowledge, incorporate it, and thereby improve its organizational processes and strategies, as demonstrated by the research of Bastanchury-López et al. (2023).

Based on the above, absorptive capacity is conceptualized as the ability of a company to absorb external knowledge and represents an essential element for innovation and the creation of competitive advantages. The learning process allows the company to adapt to its environment. Derived from the above, we have the following hypothesis.

Hypothesis 1. The absorption capacity of external knowledge has a positive influence on the innovations of aquaculture companies.

Therefore, this work focused on the capacity of managers or owners of aquaculture companies to absorb internal or external knowledge, defined as the ability to use the knowledge acquired through experience, experimentation, or acquisition to innovate (Tidd and Bessant, 2020).

## 4. Materials and methods

This research applies a quantitative, cross-sectional approach, using a questionnaire to collect data among aquaculture producers—farmers. The survey technique was used to collect the information. A structured instrument (See Appendix) was built, developed from two interviews with two expert researchers and a representative of the producers. The questionnaire was applied in person to producers from August 2022 to September 2023.

The study encompassed aquaculture enterprises situated within the municipalities of operation or organizational structure. The majority of the surveyed producers, predominantly male, operate as sole proprietors engaged in the direct sale of unprocessed products to end consumers without intermediaries.

Responses were collected from 40 producers chosen through Snowball Sampling Techniques covering the most representative municipalities of the geo region. Prior to testing the hypothesis, the correlation of the variables was carried out in the SPSS program. Data analysis for hypothesis testing was performed by modeling structural equations by partial least squares in Smart PLS (Partial Least Square) version 4 software.

Correlation is a statistical measure that expresses the extent to which two variables are linearly related. It is proposed to establish the dependency between the variable's dynamic capacities for knowledge absorption and innovation. All items of each variable were considered in the correlation, yielding a Cronbach's Alpha of 0.856. It describes simple relationships without making claims about cause and effect. For this work, the correlations of variables were chosen to find similarities in the results using partial least squares. With this method, it was not possible to consider all the constructs of the variables, while with the correlation, it was possible to correlate all the variables described in **Table 2**.

The questionnaire used was composed of 21 closed questions structured in three parts. The first part includes sociodemographic variables, the second part captures innovation, and the last includes knowledge absorption capacity. The questionnaire was structured based on the literature review (Cohen and Levinthal, 1990; Lin et al., 2016; Tidd and Bessant, 2020). The first questions were closed with a five-dimensional Likert scale where 1 = nothing and 5 = too much. For the latter, the scale had five dimensions, where 1 = never and 5 = always. The data collection method was face-to-face interviews.

### 4.1. Data analysis

The Pearson correlation test was used as a first step to analyze variables. This technique determines the correlation coefficient that the variables maintain with each other or their independence. It is important to mention that the correlation coefficient is not interpreted as a cause-and-effect relationship; rather, it expresses an association between facts (Vallejo, 2012). A reliability analysis was also performed and measured with a Cronbach alpha value.

As a second step, partial least squares structural equation modeling (PLS-SEM) was used to test the hypotheses. It emerged as a technique to analyze the relationships between latent variables and allows for analyzing relevant elements in research, especially in the social sciences and behavior (Martínez and Fierro, 2018). The objective is prediction, and it is supported by least squares estimation. For this, the measurement model was evaluated, consisting of the construct's reliability and convergent and discriminant validity (Benitez et al., 2020).

The reliability of the construct, internal consistency, was evaluated through Werts' composite reliability (rho_c), Cronbach's alpha, and the Dijikstra and Henseler value (rho_a) with values between 0.6 and 0.95 (Hair et al., 2019). Convergent validity is the high significance and correlation of the items intended to measure a construct (Cepeda-Carrión and Roldán Salgueiro, 2004). The assessment of convergent validity is carried out through the average variance extracted (AVE), which must be at least 0.5 (Benitez et al., 2020; Hair et al., 2019). The Heterotrait-Monotrait Ratio (HTMT) was used to evaluate discriminant validity. To guarantee discriminant validity, the values must be less than 0.85 so that the constructs are conceptually different (Hair et al., 2017, 2019). In addition, the evaluation of the structural model was carried out for hypothesis testing. This evaluation consisted of determining the path coefficients, the determination coefficients ($R^2$), and the effect sizes ($f^2$) (Benitez et al., 2020).

## 4.2. Measures

Innovation is the dependent variable of the research. It was defined as a complex concept that includes significant changes in the company's product, process, marketing, and organization. According to the Oslo Manual, the changes imply applying new knowledge, technology, and financial and human resources (Organization for Economic Co-operation and Development, 2007). Its operational definition for this research is the quantity in agreement with the producer with the introduction of value to the product, production process, service, way of selling, and administrative process. Because it is the rural sector, innovation is also integrated into the traditional knowledge of the producer; that is, it only sometimes has to do with the use of technology (Leyva et al., 2021; Llorente and Luna, 2014).

For this research, the capacity to absorb knowledge is the independent variable and is conceptualized as the one that best contributes to creating skills for innovation (Castrilló, 2016; Lin et al., 2016; Tidd and Bessant, 2020). Knowledge absorption was subdivided into acquisition, assimilation, and transformation. The operational definition of the three knowledge absorption capacity constructs is the producer's agreement or disagreement about his performance with each of them. **Table 2** presents the indicators used to prepare the questionnaire in data collection and indicates which indicators were validated in the analyses. The same indicators are the items (to know the instrument, see the complements of this document).

**Table 2.** Variables and the research questions.

| **Construct** | **Key** | **Indicator** |
|---|---|---|
| Innovation development | INN1 | Modified or added something new to your product * |
| | INN2 | Modified or added something new to your production process* |
| | INN3 | Modified to added something new to your service |
| | INN4 | Modified or added something new to your way of selling (marketing) |
| | INN5 | Modified or added something to your administrative process |
| Knowledge Absorption capacity | CON1 | Search for solutions to the problems presented |
| | CON2 | Leadership based on values/respect, responsibility, etc. |
| | CON3 | Establishment of links between leaders, producers, or organizations |
| | CON4 | Offering personal and professional capacity to support other producers |
| | CON5 | Recognition of new knowledge* |
| | CON6 | Promotion of cooperation with academia, research centers, etc. |
| | CON7 | Cooperation with consultants, forums, fairs and events |
| | CON8 | Detect possible innovations in the product, process, or service * |
| | CON9 | Monitoring changes in the market/price, market, etc. |
| | CON10 | Promoting training for employees and yourself |
| | CON11 | Implementation of newly acquired knowledge/product, process, or service innovation |

Source: Own elaboration, adapted from (Castrilló, 2016; Leyva et al., 2021; Lin et al., 2016; Tidd and Bessant, 2020). * Valid items.

## 4.3. Sample

The partial least squares structural equation modeling ensures efficiency when performing data analysis with a small sample size (Rigdon et al., 2017). This statistical analysis is flexible in the sense that it does not make assumptions regarding measurement levels, data distributions, and sample size; "minimum recommendations are between 30 and 100 cases" (Cepeda-Carrión and Roldán Salgueiro, 2004, p. 10).

The sample selection was based on three criteria: the location of the farms in the Mezquital Valley region, that they are in operation, and that they have ever been registered with the Aquaculture Directorate of the Secretariat of Agricultural Development of the State of Hidalgo. Such conditions are established because there is no updated database on the number of farms.

The total number of Economic Units registered in the National Statistical Directory of Economic Units in the Mezquital Valley is 73 (Instituto Nacional de Estadística y Geografía, 2019). In the report on Aquaculture Production Units in Hidalgo from the Aquaculture Directorate of the Secretariat of Agricultural Development, the bulk of aquaculture companies is 273 distributed in 13 municipalities. The selection of farms corresponded to 40 units located in the municipalities of Arenal, Actopan, Alfajayucan, Chilcuautla, Ixmiquilpan, Progreso de Obregón, San Salvador, Tezontepec and Tecozautla.

65% of the farms are legally constituted as individuals, while 35% are cooperatives. 80% are microenterprises, 7.5% are small companies and 12.5% are medium-sized. 55% are dedicated to producing and selling to the final customer in raw form. While 25%, in addition to some producers producing fish, offer it prepared to clients, 5% sell it to spas or eco-tourism parks. Another 5% is dedicated to the sale of fingerlings. 80% of the decisions and management of the farms are carried out by the owner (**Table 3**).

**Table 3.** Sociodemographic characteristics of the sample.

| Sociodemographic variable | Number | Percentage |
|---|---|---|
| **Municipality** | | |
| El Arenal | 2 | 5.0% |
| Actopan | 2 | 5.0% |
| Alfajayucan | 3 | 7.5% |
| Chilcuautla | 5 | 12.5% |
| Ixmiquilpan | 7 | 17.5% |
| Progreso | 2 | 5.0% |
| San Salvador | 5 | 12.5% |
| Tecozautla | 6 | 15.0% |
| Tezontepec | 8 | 20.0% |
| **Total** | 40 | 100.0% |
| **Legally Constitution** | | |
| Physical person | 26 | 65.0% |
| Cooperative | 14 | 35.0% |
| **Size** | | |
| Microenterprise (0-10) | 32 | 80.0% |
| Small (11-50) | 3 | 7.5% |
| Median (51-250) | 5 | 12.5% |
| **Decision making** | | |
| Owner | 32 | 80.0% |
| Others (committees) | 8 | 20.0% |
| **Specialization** | | |
| Breeding for sale to other companies (fingerlings) | 2 | 5.0% |
| Breeding for sale to the end customer (raw) | 22 | 55.0% |
| Breeding and preparation for consumption by the end customer (has a restaurant) | 10 | 25.0% |
| Breeding for self-consumption | 1 | 2.5% |
| All of the above | 3 | 7.5% |
| Others (spas, ecotourism parks) | 2 | 5.0% |

# 5. Results

## 5.1. Correlation of variable

We begin by conducting a correlation analysis in SPSS to observe whether the dependent variable, in this case, dynamic knowledge absorption capacities, is significant for aquaculture producers' adoption of innovations. A 95% confidence level is used.

Positive correlations mean that producers with high values in the knowledge variable will tend to show high values in the innovation variable. In contrast, a negative correlation will indicate that the variables are inversely proportional. The data obtained from the survey revealed that the correlation between knowledge absorption and innovation is 0.637 for a $P$ value of 0.00001, which is less than 0.05, so it is statistically significant. This relationship is direct; the more dynamic the producer's knowledge absorption capacity, the greater its capacity to innovate. Furthermore, given that Pearson's *r* value is 0.637, it is considered a medium to high positive correlation. The *R*-squared value of the simple linear regression model analysis shows the fit quality achieved with the regression. Thus, the capacity to absorb knowledge explains the innovation of producers by 40.5%.

### 5.2. Evaluation of the measurement model

Due to its reflective nature, the PLS algorithm was used to evaluate the measurement model (Cheah et al., 2018). The construct's reliability, convergent validity, and discriminant validity were also evaluated (Benitez et al., 2020). It was considered that at least each item had a factor loading of 0.708, as Benitez et al. (2020) recommended, so nine items were eliminated for the dynamic absorption capabilities construct and three items in the case of innovation. The reliability values of both variables were found between these values, so they have internal consistency, as shown in **Table 4**. A criterion for convergent validity was met by the two variables of the model (AVE values). The results met the value for guaranteed discriminant validity.

**Table 4.** Construct reliability, convergent and discriminant validity.

| Construct | Item | Outer loading | Cronbach's alpha | Composite reliability (rho_a) | Composite reliability (rho_c) | Average variance extracted (AVE) | HTMT |
|---|---|---|---|---|---|---|---|
| Knowledge absorption capacity | CON5 | 0.717 | 0.748 | 0.760 | 0.752 | 0.604 | 0.781 |
| | CON8 | 0.834 | | | | | |
| Innovation | INN1 | 0.759 | 0.784 | 0.791 | 0.786 | 0.649 | |
| | INN2 | 0.849 | | | | | |

Source: Own elaboration in the Smart-PLS version 4 program.

### 5.3. Hypothesis testing and structural model evaluation

The structural model was evaluated to test the research hypothesis. According to the results, the level of explanatory power is moderate, given that the $R^2$ value (0.595) is more significant than 0.5 but less than 0.75 (Hair et al., 2011). At the same time, the effect size is large (1.532) since this value is more significant than 0.35 (Cohen, 1992). According to the path coefficient, hypothesis 1 is tested (see **Figure 2**). The absorption capacity of external knowledge positively influences aquaculture companies' innovations ($\beta$ = 0.778, $p$ = 0.000).

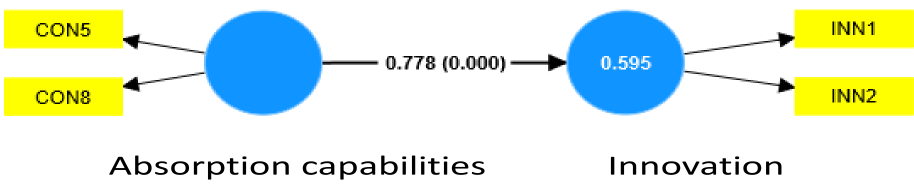


**Figure 2.** Absorption and innovation capabilities model.

Note: Con: absorption capabilities and INN: Innovation.

In this study, the active role of the producers in the absorption of knowledge is highly evident. Their ability to search for information, willingness to learn, and need to solve immediate problems are key factors that shape their knowledge absorption capacities. This is best illustrated by some of the comments of the producers during the application of the questionnaire (**Table 5**).

**Table 5.** Comment of the producers about knowledge absorption.

| Date | Comments | Knowledge absorption |
|---|---|---|
| 11/7/2022 | *I am stubborn! I had already seen the bio floc system on the internet. I had even asked biologists* | |
| 1/14/2022 | *We have here the Polytechnic Institute that is installed in Pachuca, and we have the Technological University of Valle del Mezquital, these two institutions supported with research aimed at the professionalization of producers* | Links |
| 1/11/2023 | *They see which farm they bring it from, and they learn through experience; they themselves try it* | |
| 2/18/2023 | *We have been learning and training all of these things… what I do is check the internet for aquaculture in Chiapas and Sonora because they use more sophisticated techniques* | Search of information |
| 9/28/2022 | *We searched on YouTube, and the blogger saw the geomembrane installation on other farms* | |

## 6. Discussion

This study confirms that the knowledge absorption capabilities of the manager or owner of the aquaculture companies in the Mezquital Valley in Hidalgo directly affect the adoption of innovations. The correlation test resulted in a strong positive correlation between both constructs, and the test of partial least squares resulted in a high percentage of explanation. In the literature, there needs to be more evidence of empirical work that seeks to demonstrate knowledge absorption capacities' role in innovation in the aquaculture sector. However, Carrazco et al. (2016) demonstrated the relationship between knowledge acquisition capabilities and the competitiveness of shrimp companies in Sinaloa. The method in the cited work was the Pearson correlation coefficient. Their data showed a low or moderate correlation. However, in their case, the independent variable was competitiveness measured from profitability, market participation, growth in the number of employees, product quality, exports, and cost-benefit. Therefore, their numerical data cannot be directly compared with those collected in this work.

The results of this study allow us to argue that the recognition of new knowledge and the ability to detect possible innovations along the production chain allows producers in the Mezquital Valley-Mexico to modify their products and processes. Likewise, other studies corroborate the influence of knowledge absorption capacity on innovation in different sectors as diverse as those most developed in technology

(Tseng et al., 2011; Xie et al., 2018), as well as in cultural and creative industries (Santoro et al., 2020). In addition, other studies confirm the effect of the recognition of new knowledge, such as that obtained through the Internet, in increasing innovation in aquaculture producers in Chile (Salazar et al., 2018). Blythe et al. (2017) also highlight the role of the ability to communicate principles and knowledge as a key element for innovation in aquaculture; it is necessary to detect possible changes to innovate.

Although, in the region of this study, the innovation of micro, small, and medium-sized enterprises could be more satisfactory, this study showed that knowledge absorption capacities modify the adoption of innovations. Mexico lacks innovation due to the need for long-term planning and little interest in research and development activities (Meza, 2017). In the aquaculture sector, the situation is the same. Empirical studies have shown that some of the main factors for the adoption of innovations are the interaction of the producer with universities, committees, and research centers, among others (González, 2011). However, the results of this study go further because it considers the ability to assimilate the knowledge of such interactions and apply it to innovation. In the sheep sector, something similar occurs since the absorption capacity is related to acquiring new technologies and external knowledge to improve processes (Bastanchury-López et al., 2023).

According to the above, this empirical work shows that absorption capacities influence aquaculture producers' capacity to innovate, which contributes to literature unlike other studies presented in **Table 6**. Similar studies have been carried out in Mexico, but in particular sectoral or multi-case areas, it is not possible to reveal a region's particular panorama (Carrazco et al., 2016; Mata, 2011; Oriana et al., 2021). Similar studies have also been carried out in other countries, but they differ due to the degree of development the aquaculture sector has compared to Mexico (Cruz et al., 2010; Pache et al., 2022).

**Table 6.** Advantages and disadvantages of related studies.

| Region (country) | Advantages | Disadvantages | References |
|---|---|---|---|
| Mexico: Sinaloa | Correlation analysis of the acquisition, assimilation, transformation and exploitation of knowledge with the competitiveness of shrimp companies. | Limited size of the sample of companies, as well as being focused on very specific geographic and sectoral areas. | (Carrazco Escalante et al., 2016) |
| Mexico: Colima, Jalisco, Michoacán and Nayarit | Study of innovation in rural farms in western Mexico. | It is a multi-case study so it is not possible to assume any scope towards the generalization of the findings. | (Mata, 2011) |
| Mexico: Sinaloa | Exploratory-explanatory study, through the survey. Measures the perception towards the relevance of sustainable management of innovation in the owners and managers of six shrimp producing farms. | Limited sample size. There may be a bias in the information because it measures perception and no other specific factors about innovation. | (Oriana et al., 2021) |
| Brazil | Evaluation of the influence of interactive learning processes with innovation. | It is a case study so it is not possible to assume any scope towards the generalization of the findings. | (Pache et al., 2022) |
| Spain | Explanatory model of competitiveness through the contrast of endogenous factors of the theory of resources and capabilities. Result a positive relationship between competitiveness and value generation, productivity, size, innovation and the degree of specialization. | Aquaculture in Spain is a consolidated activity, unlike in Mexico. | (Cruz González et al., 2010) |

## 7. Conclusion

The firms in the aquaculture sector of the Mezquital Valley in the state of Hidalgo are an engine of development in the regional economy because, in addition to generating employment, they provide high-quality food, representing social well-being for families and rural communities.

This work explains whether knowledge absorption capacities are related to innovation capacities, which are the modification or addition of added value to the product, production process, way of selling, and company management. The results show that the capacity to absorb knowledge explains innovation in aquaculture farms. However, after the instrument was validated, some items had to be deleted; therefore, the data collection method can be improved.

A significant finding indicates that producers can acquire knowledge and know its importance. Furthermore, the linkage and association between them and the various actors are essential to generate an environment conducive to exchanging experiences, which could accelerate the absorption and transformation of knowledge and bring more innovation.

## 8. Limitations

The primary constraint of this study pertains to the sample size, which may limit the generalizability of the findings. Additionally, the geographical and sectoral restrictions further impede the ability to extrapolate the knowledge gained from this research. It is important to note, however, that the model developed and the variables examined are both reproducible and dependable, thus laying a solid foundation for more comprehensive studies in the future.

Due to its objective, the study was limited by focusing only on dynamic capacity. Additionally, the sector’s informal nature made it challenging to identify producers, resulting in a smaller sample size and limited data collection.

Another limitation of this research was the analysis of other actors involved in the production chain, so it is advisable to include the effect of pressure from these stakeholders in the analysis of innovation. Blythe et al. (2017) have suggested that Non-Governmental Organizations can promote the development and innovation of small-scale aquaculture, so it is advisable to include this type of organization, as well as the role of the government and other actors in the analysis of innovation.

### Future research

Moreover, as this is a cross-sectional study, it is crucial to underscore the importance of considering all the actors involved in future studies. Their perspectives and contributions are invaluable to the comprehensive understanding of the productive sector. It is also recommended that the variables be analyzed over time to capture the dynamic nature of the sector. Another limitation, the accessibility to primary information sources, was due to the farm owners’ initial reluctance to answer the questionnaire. Each owner had to be contacted more than once, a challenge that has been observed in other studies of the productive sector. Hence, a comparative study between productive sectors with the variables analyzed in this study is highly recommended.

Although this study proved the positive effect of knowledge absorption capacity on innovation, future research should analyze the role of the sociodemographic characteristics of aquaculture producers in their willingness to innovate, as reviewed in other studies in countries such as Chile (Salazar et al., 2018).

For future research, it is recommended to delve into other questions that explore the knowledge acquisition variable. This is particularly important as the results of this study revealed limited cooperation between producers, suggesting that the exchange of experiences could be a significant source of knowledge. This potential for knowledge exchange through cooperation should inspire researchers to analyze the interrelationship of all dynamic capabilities with innovation.

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## Appendix

**Table A1.** Complements.

| **Address:** | | | | | |
|---|---|---|---|---|---|
| Type of constitution: | | | | | |
| Size: | | | | | |
| Maker decisions: | | | | | |
| Specialization: | | | | | |
| Item | 1 | 2 | 3 | 4 | 5 |
| Innovation | Nothing | Not very regular | Regular | A lot | Too much |
| Are you modified or added something new to your product? | | | | | |
| Are you modified or added something new to your production process? | | | | | |
| Are you modified to added something new to your service? | | | | | |
| Are you modified or added something new to your way of selling (marketing)? | | | | | |
| Are you modified or added something to your administrative process? | | | | | |
| Knowledge Absorption | Never | Almost never | Sometimes | Almost always | Always |
| Are you searching for solutions to the problems presented? | | | | | |
| Your leadership is based on values/respect, responsibility, etc | | | | | |
| Are you establishing of links between leaders, producers, or organizations? | | | | | |
| Are you offering personal and professional capacity to support other producers? | | | | | |
| Are you recognizing new knowledge? | | | | | |
| Are you promoting cooperation with academia, research centers, etc.? | | | | | |
| Are you detecting possible innovations in the product, process, or service? | | | | | |
| Are you monitoring changes in the market/price, market, etc.? | | | | | |
| Are you promoting training for employees and yourself? | | | | | |
| Are you implementing newly acquired knowledge/product, process, or service innovation? | | | | | |