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Scientific research on crustacean farming in Mexico: a scientometric scenario

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ABSTRACT

Objective: The objective of this article is to evaluate the research effort developed by Mexican scientists in relation to the study of native and exotic crustacean species, based on articles hosted in Scopus.

Design/methodology/approach: Species were selected based on documentary research and personal communication with researchers related to the subject. All scientific articles published between 1993 and 2023 related to culture, which included the species name in the title, abstract and keywords, were selected from the Scopus® database. The number of publications, publication timelines, topics addressed, institutions, sponsors and type of access were obtained.

Results: The search yielded a total of 1,240 articles published by Mexican institutions, penaeid shrimps representing 85% of the total, and *P. vannamei* represents almost 75%. In general, UNAM and CIBNOR lead scientific production followed by the IPN and the CIAD. The most common topic areas include nutrition, aquaculture, morphophysiology and genetics. The main source of financing is CONAHCYT and 46% of the publications are available in open access.

Limitations on study/implications: The study is restricted to the Scopus database, recognized for including the largest number of journals worldwide, although the omission of other data-bases could cause bias in the results. However, we consider that this limitation will not significantly affect the identified trends.

Findings/conclusions: Research has predominantly focused on the marine shrimp *P. vannamei*, reflecting significant technological development in its culture, while other species such as *C. quadricarinatus* and the genus *Macrobrachium* have received limited attention. It is crucial to encourage research and technological development in native and alternative species, secure funding and institutional support, promote equitable access policies, and improve regulation for sustainable practices.

Keywords: Aquaculture, *Macrobrachium*, marine species, *Penaeus vannamei*, social impact.

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INTRODUCTION

Mexico is a megadiverse country in terms of crustacean diversity. Alvarez *et al.* (2014), report a total of 1,775 species classified in 537 genera and 115 families of decapod crustaceans,

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which represents 11.9% of the total number of species in the world and 57.5% of the families. Of this total, only a few species have been studied as feasible for culture. According to Chong-Carrillo *et al.* (2023), research directed to these purposes by the Centros Públicos de Investigación (Public Research Centers; CIP) of the Consejo Nacional de Humanidades, Ciencias y Tecnologías (National Council of Science, Humanities and Technology; CONAHCYT) has focused, for the most part, on marine species with high added value, while freshwater species have been poorly attended to. In relation to cultured crustaceans, although Mexico has an enormous diversity, only a few species have been studied with the purpose of developing culture technologies. Penaeid shrimps have received the most scientific and technological attention, followed by far by river shrimps of the genus *Macrobrachium* (Chong-Carrillo *et al.*, 2023). Research on cultivable crustaceans in Mexico has been less than on fish and mollusks because native crustacean species that can be taken to aquaculture have been little studied. However, the commercial value of shrimp production in culture is enormous and this has led to practically only one species being of priority interest. According to the Secretaría de Agricultura y Desarrollo Rural (SADER), 192,600 tons of farmed marine shrimp were produced in 2023, with an economic value of more than 19.8 billion pesos.

Research on native crustacean species in Mexico with aquaculture potential has been relevant and large governmental funds have been allocated for this purpose. However, most of these funds have been directed to one native species, the Pacific white shrimp, *Penaeus vannamei* (Chong-Carrillo *et al.* 2023) with a high economic value, especially in international markets. The study also mentions the Australian lobster, *Cherax quadricarinatus*, which is a proven exotic species with a great invasive capacity (Rodríguez-Cruz *et al.*, 2023), which has not been an impediment to public funding for its research for aquaculture purposes.

The objective of this article is to evaluate the research effort developed by Mexican scientists in relation to the study of native and exotic crustacean species, based on articles published in international and regional journals hosted in Scopus. This is done to identify the strengths, weaknesses and areas of opportunity in the study of these aquatic organisms, whose ecological, social and economic importance is relevant for the country.

The above considering the hypothesis that the scientific research on crustacean aquaculture in Mexico is predominantly focused on the shrimp *P. vannamei*, leading to significant technological development in its cultivation, while native and alternative species have been underexplored, limiting the potential for aquaculture diversification in the country.

MATERIALS AND METODS

Crustacean species were selected based on documentary research and personal communication with researchers related to the subject. All scientific articles or reviews, published between 1993 and 2023 related to culture, which included the species name (*Penaeus*, *Litopenaeus*, *Farfantepenaeus*, *Macrobrachium*, *Cherax* and *Procambarus*) in the title, abstract and keywords, were collected from the Scopus® database (Elsevier, The Netherlands). The choice of Scopus over other databases can be justified for several key reasons, making it particularly suitable for bibliometric studies in scientific research. It

is the largest abstract and citation database of peer-reviewed literature, covering over 24,000 titles; is updated more frequently compared to other databases, ensuring that the bibliometric analysis reflects the most up-to-date information available; it tends to include more literature from developing countries and regional journals, which is critical for this study focused on the scientific output of Mexican institutions.

The database obtained was subjected to a filtering process that focused on studies carried out by Mexican institutions. Subsequently, those articles that did not comply with the parameters established for the genus and species of the crustacean under study were eliminated. The complete records were transferred to Excel® (Microsoft, USA) data sheets for subsequent analysis. The filtered database was organized to obtain, by species and in general, the number of publications, publication timelines, topics addressed, institutions, sponsors and type of access (open or paid). The results were graphed using Excel®.

RESULTS ANS DISCUSSION

The SCOPUS search yielded a total of 1,240 articles published by Mexican institutions on native and exotic crustaceans that are being studied in Mexico for culture purposes. The study focused on 11 species, which are mentioned individually below.

Cherax quadricarinatus (Australian red claw crayfish)

Commonly known as Australian freshwater lobster or red claw crayfish (*Cherax quadricarinatus*, von Martens 1868), it is a decapod crustacean of the family Parastacidae, native to Australia and Papua New Guinea. It inhabits freshwater bodies such as rivers, streams and lakes (Ghanawi *et al.*, 2012). It prefers warm, well-oxygenated waters and refugia such as rocks, logs and aquatic vegetation. It is one of the most cultivated freshwater species worldwide (Ghanawi *et al.*, 2012) so it can be found in the Americas, including Mexico (Bortolini *et al.*, 2007). It is in high demand in the international market for its flavor and nutritional value, which has led to a significant increase in aquaculture production in recent decades and also as an ornamental species in aquariums (Jones *et al.*, 1994; FAO, 2022). In Mexico, it is cultured in intensive and semi-intensive systems. The states of Baja California, Veracruz and Tamaulipas stand out as the main producers of this species (IMIPAS, 2018). Research, in Mexico, directed to this crustacean has focused on aspects of aquaculture and nutrition, mainly. The Centro de Investigaciones Biológicas del Noroeste (Northwest Biological Research Center; CIBNOR) is the CPI of CONAHCYT that has dedicated more studies to this exotic species (Figure 1) and CONAHCYT has granted most of the resources for its financing.

Macrobrachium acanthurus (Cinnamon river shrimp)

The cinnamon river shrimp (*Macrobrachium acanthurus*) is a freshwater prawn endemic to the Americas that is distributed in rivers, lagoons and estuarine areas along the Atlantic coast, from North Carolina in the United States to southern Brazil (Torati *et al.*, 2011). It has a high economic value due to its flavor, high protein content and visual attractiveness (Kent, 1995; García-Guerrero *et al.*, 2013). In Mexico, *M. acanthurus* is consumed regionally and represents a source of income for fishers in the states of Veracruz and Tabasco (Hernández-

Abad *et al.*, 2018). Due to its demand in the regional market, fishing volumes of this species have been reduced, and in some parts of Mexico have evidenced the disappearance of natural populations such as in the rivers of the Papaloapan and Coatzacoalcos Basins (García-Guerrero *et al.*, 2013). More studies aimed at the development of its culture are required, as there are still gaps in knowledge that prevent the successful achievement of its complete culture technology (García-Guerrero *et al.*, 2013; Villafuerte Mojica *et al.*, 2016). Research, in Mexico, directed to this crustacean has focused mainly on aquaculture and nutrition aspects. The Universidad Nacional Autónoma de México (UNAM) is the university that has dedicated the most studies to this native species and also has provided most of the resources for its financing.

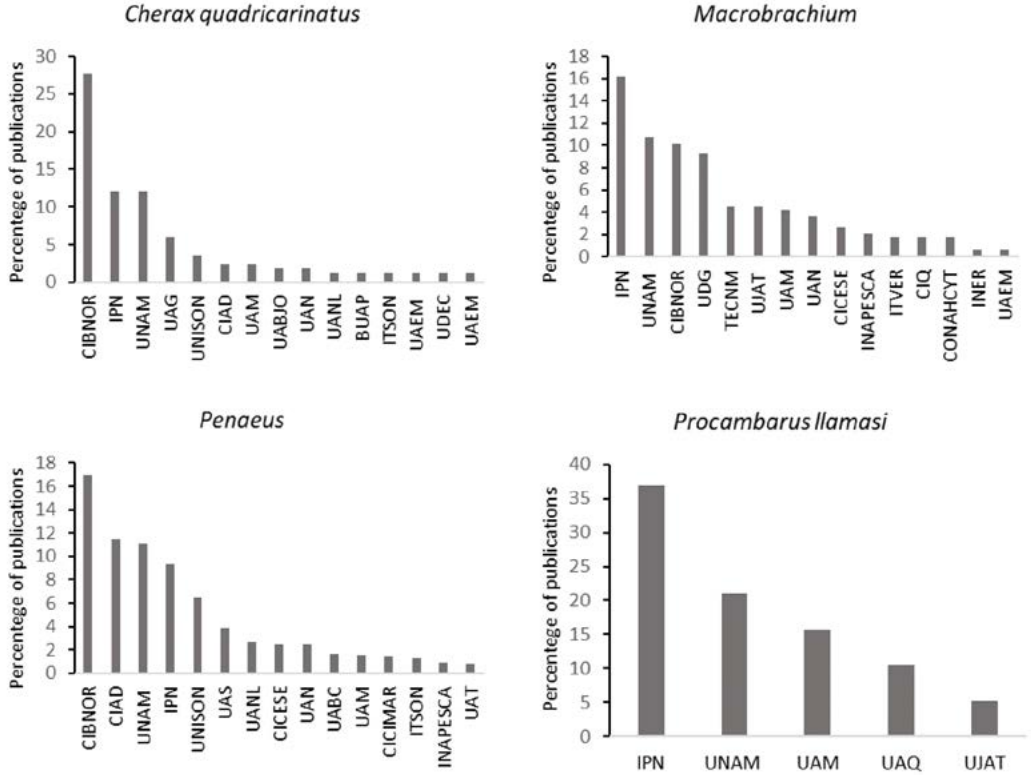

Figure 1. Mexican institutions that conducted studies of crustaceans with culture technology developed, under development or with culture potential in Mexico according to Scopus. The graphs show the 15 institutions with the most studies for each genus. Nomenclature of institutions in alphabetical order: BUAP=Benemérita Universidad Autónoma de Puebla, CIAD=Centro de Investigación en Alimentación y Desarrollo, CIBNOR=Centro de Investigaciones Biológicas Del Noroeste, CICESE=Centro de Investigación Científica y de Educación Superior de Ensenada, CICIMAR=Centro Interdisciplinario de Ciencias Marinas, CIQ=Centro de Investigaciones Químicas, CONAHCYT=Consejo Nacional de Humanidades, Ciencias y Tecnologías, INAPESCA=Instituto Nacional de Pesca y Acuacultura, INER=Instituto Nacional de Enfermedades Respiratorias, IPN=Instituto Politécnico Nacional, ITSON=Instituto Tecnológico de Sonora, ITVER=Instituto Tecnológico de Veracruz, TECNM=Tecnológico Nacional de México, UABC=Universidad Autónoma de Baja California, UABJO=Universidad Autónoma Benito Juárez de Oaxaca, UAEM=Universidad Autónoma del Estado de México, UAG=Universidad Autónoma de Guadalajara, UAM=Universidad Autónoma Metropolitana, UAN=Universidad Autónoma de Nayarit, UANL=Universidad Autónoma de Nuevo León, UAQ=Universidad Autónoma de Querétaro, UAS=Universidad Autónoma de Sinaloa, UAT=Universidad Autónoma de Tamaulipas, UDEC=Universidad de Colima, UDG=Universidad de Guadalajara, UJAT=Universidad Juárez Autónoma de Tabasco, Universidad Nacional Autónoma de México, UNISON=Universidad de Sonora.

***Macrobrachium americanum* (Cauque river prawn)**

Macrobrachium americanum, colloquially known as cauque, has good potential for culture because it reaches a large size and currently has a well-established local market in Mexico as an edible product (García-Guerrero and Apun-Molina, 2008). This river shrimp is distributed along the Pacific slope of the Americas from Baja California in Mexico to Peru, as well as in the Cocos and Galapagos Islands (Holthius, 1980). Pressure from local fisheries has severely depleted natural populations, but there is a lack of studies that can provide a better scenario of the current status of their populations. The Instituto Politécnico Nacional (IPN) is the institution most mentioned in published studies on the species, followed by CIBNOR. Funding sources have come mainly from CONAHCYT and the IPN.

***Macrobrachium carcinus* (Bigclaw river shrimp)**

The bigclaw shrimp is one of the largest river shrimp in the world, measuring up to 300 mm in length. It is distributed from Florida in the United States to southern Brazil (Lima *et al*., 2014). This species is an important local source of protein for human consumption in the Atlantic Ocean slope in Latin America (Benítez-Mandujano and Ponce-Palafox, 2014), in addition to having high commercial value (Valenti, 2007). Although adult specimens of *M. carcinus* live and breed in freshwater, larval development occurs strictly in brackish water (Benítez-Mandujano and Ponce-Palafox, 2014). However, due to intensive overexploitation by artisanal fisheries, pollution and destruction of natural environments, it is listed as a vulnerable species in several countries (Coelho-Filho *et al*., 2018). Domestication attempts have been made to keep it in culture, with partial success, generating management handbooks as results (García-Guerrero *et al*., 2013). The Universidad Juárez Autónoma de Tabasco (UJAT) is the institution that demonstrates the greatest production in publications and the financing has been provided by CONAHCYT and UNAM.

***Macrobrachium tenellum* (Longarm river prawn)**

The longarm river prawn inhabits fresh and brackish waters, and can be found in estuaries, rivers, and coastal lagoons throughout its range from the Baja California Peninsula to the Chira River in northern Peru and Galapagos Island (Holthuis, 1952). *Macrobrachium tenellum* is an amphidromous species with great commercial value and is the subject of artisanal fisheries by rural communities in Mexico for direct consumption and for sale. It plays an important role in food chains, contributing to the flow of energy and nutrients in limnetic environments (García-Guerrero *et al*., 2013). It has been considered a good candidate for aquaculture, mainly because of its tolerance to environmental factors and its low aggressiveness compared to its congeners *M. americanum* and *M. carcinus* (López-Uriarte *et al*., 2020; De los Santos-Romero *et al*., 2021). Cultures of this species have been developed at experimental and pilot levels in rustic, semi-rustic ponds, circular pools, earthen ponds and in pond cage systems (Ponce-Palafox *et al*., 2006; Vega-Villasante *et al*., 2011; Ponce-Palafox *et al*., 2013; López-Uriostegui *et al*., 2014) with yields ranging from 560 to 2013 kg h^{-1} (Vargas-Ceballos *et al*., 2021). However, the scarcity of studies on the larval stages of this species has not allowed it to be cultivated for commercial purposes

(Vargas-Ceballos *et al.*, 2020). The Universidad de Guadalajara (UDG) appears as the most productive institution in articles, followed by IPN and CIBNOR. Most of the funding for the study of this species has been provided by CONAHCYT.

***Macrobrachium rosenbergii* (Giant River Prawn)**

The Malayan prawn is native to the tropical Indo-Pacific region, but its distribution has spread significantly through introduction and culture in different parts of the world (New and Valenti, 2009). The natural habitat of *M. rosenbergii* is characterized by warm, tropical rivers and streams. In its natural distribution, it is found in areas with moderate currents and depths ranging from 0.5 to 5 meters. The species can adapt to different water conditions, including temperatures between 20 and 30 °C and pH between 6.5 and 8.5 (New, 2002). Modern cultivation of this species originated in the 1960s in Malaysia, where it was found that larvae required brackish conditions to survive (FAO, 2009). The institution with the highest number of publications is UNAM and funding has been granted by CONAHCYT.

***Penaeus californiensis* (Yellowleg shrimp)**

The yellowleg shrimp *P. californiensis* (Holmes 1900, subgenus *Farfantepenaeus*) is a native species of the Gulf of California in Mexico, with populations from San Francisco Bay, California, USA, to the coast of Paita in Peru (Peña-Rodríguez *et al.*, 2017); with marine habits, but with larval development in estuaries (Villareal *et al.*, 2003). It is able to reproduce in different salinity gradients and develop at winter temperatures (around 20 °C), with high fishery value and aquaculture potential (Martínez-Córdoba *et al.*, 1998). It has been fished since 1930 in Mexico and its catch represents around 40% of the total shrimp fishery in the Mexican Pacific, with a catch similar to *P. stylirostris* and higher than *P. vannamei* (Barbosa-Saldaña *et al.*, 2012).

Aquaculture of *P. californiensis* has been under development in Mexico since the end of the last century, although it has been overshadowed by the adaptability and technological development of *P. vannamei* (Villareal *et al.*, 2003). Its monoculture has been carried out in ponds with aeration (Martínez-Córdova *et al.*, 1998), although since 2011 its culture efforts in the Pacific have been focused more on co-culture with the alga *Ulva clathrata* (Peña-Rodríguez *et al.*, 2017), the same alga that has been reported to have a positive effect on the growth of penaeid shrimp (Portillo-Clark *et al.*, 2013). CIBNOR is the CPI with the highest production of scientific articles, while funding has been obtained from CONAHCYT, for the most part.

***Penaeus setiferus* (Northern white shrimp)**

The northern white shrimp *P. setiferus* (Linnaeus 1767), is a crustacean native to the northern Atlantic distributed mainly from the coasts of New Jersey in the USA to Campeche in Mexico, caught mainly in the Gulf of Mexico and the coasts of North Carolina and Florida (Valenzuela-Jiménez *et al.*, 2020). It is a euryhaline organism, with marine life, but develops to adulthood in estuarine waters (Baker *et al.*, 2014). In the last century, the fishing potential of the species was extensively studied (Gracia *et al.*, 1999), while at the

same time, its nutrition was developed by the National Autonomous University of Mexico (UNAM) (Guzmán *et al.*, 2001; Gallardo *et al.*, 2002; Arena *et al.*, 2007).

Research on its overfishing, reproduction, nutrition and behavior developed interest in its cultivation in the 1990s, and due to its high commercial value (Valenzuela-Jiménez *et al.*, 2020). However, there are still no intensive productions of the species. (Valenzuela-Jiménez *et al.*, 2020). UNAM has developed the greatest research efforts regarding its culture. It is also UNAM that has provided funding for studies on this species, followed by CONAHCYT.

***Penaeus stylirostris* (blue shrimp)**

The blue shrimp *P. stylirostris* (Stimpson 1874) is a crustacean native to Mexico, distributed from the upper Gulf of California in the USA to the coasts of Peru, with the greatest presence (and importance) in the Gulf of California, being caught mainly in the states of Sonora, Sinaloa, Baja California and Nayarit in Mexico (Ramírez-Rojo and Aragón-Noriega, 2006). Together with *P. californienses*, it is the native shrimp with the largest catch in Mexican fisheries, representing together with *P. vannamei* 90% of the total catch in the Pacific (Barbosa-Saldaña *et al.*, 2012); in addition to having a high commercial value and being more in demand because it is larger than other penaeids in capture zones (Leyva-Vázquez *et al.*, 2021). It has a life cycle similar to other penaeids, with larval stages that develop in estuarine systems throughout the Mexican Pacific (Aragón-Noriega *et al.*, 2016).

Its culture has been developed since 1975 in the Gulf of California, and the main research efforts have been carried out by CIBNOR, addressing since 1985 topics such as: nutrition, physiology, genetics, environmental impact, health and management (Pérez-Enríquez *et al.*, 2016). Its technology is highly developed thanks to research on its reproduction in captivity (Alfaro-Montoya, 2010), and the genetics of captive populations (Aubert & Lightner, 2000). The Universidad de Sonora (UNISON) and CIBNOR are the institutions most represented in the articles published. Most of the funding has been provided by CONAHCYT.

***Penaeus vannamei* (Whiteleg shrimp)**

The white shrimp (*Penaeus vannamei*) is a marine crustacean that is widely distributed in warm and subtropical waters of the Pacific. Native to the eastern coast of the Pacific Ocean from Sonora, Mexico to Peru and introduced to the coasts of the Gulf of Mexico by aquaculture activity (IMIPAS, 2018). It is distributed in coastal areas and estuaries, where it feeds on small invertebrates and plants. It is a popular edible species and is cultured on a large scale in many countries, including Ecuador, Mexico and other Latin American countries (FAO, 2009). It is grown in all systems: extensive, semi-intensive, intensive and hyper-intensive. Its biotechnology is fully developed and standardized (IMIPAS, 2018). The topics addressed by the articles identified in Scopus, show a balance in the different lines of research with a preponderance of genetics, immunology and nutrition, followed by cultivation, biochemical aspects and morphophysiology. This indicates a research process that aimed to fill the gaps in knowledge in order to achieve the integral biological

management of the species and, with this, improve the capacity for efficient culture. CIBNOR is emerging as the most relevant institution in the study of this crustacean and CONAHCYT as the sponsoring organization that has granted the most funding.

***Procambarus llamasi* (Yucatecan crayfish)**

It is a species distributed in the Yucatan Peninsula and Tabasco. It inhabits rivers, lakes, seasonally flooded areas, jagüeyes, coastal marshes, streams, water holes, canals in agricultural fields (Rodríguez-Serna,1999; Grajeda-Zabaleta *et al*., 2024). This species is part of the biocultural heritage of communities in its area of distribution and has aquaculture potential. It has been studied in various aspects such as feeding in captivity (Rodríguez-Serna *et al*., 2010), in recirculation systems and also biofloc (Grajeda-Zabaleta *et al*., 2024). This species has received attention from the IPN and UNAM, as they are the institutions that appear most often in published articles. CONAHCYT has provided most of the funding for its study.

General scenario

Table 1 lists the crustacean species that have been identified as those that have been studied for culture and have generated scientific publications. Only two species are exotic species (*C. quadricarinatus* and *M. rosenbergii*), while most are native or endemic to Mexico.

The number of publications that were selected was 1,240 in total. Of these, penaeid shrimps account for 1057 publications, representing 85% of the total, and the species *P. vannamei* alone represents almost 75%. *Macrobrachium* shrimps are the second most productive genus with 107 articles (8.6% of the total), distributed among five species, with *M. tenellum* being the most studied with 43. However, individually, *C. quadricarinatus* is the species with the second highest number of publications, 68 (5.4%), even though it is considered an exotic and invasive species. Of the crayfish of the genus *Procambarus*, only *P. llamasi* (an endemic species) recorded publications related to culture, but only marginally (eight articles).

Table 1. Crustacean species with culture technology developed, under development or with culture potential in Mexico. The scientific name, common name, status (exotic/native) and number of publications found in Scopus are shown.

Cientific name	Common name (Spanish)	Common name (English)	Status	Number of publications
Cherax quadricarinatus	Langosta australiana	Australian red claw crayfish	Exotic	68
Macrobrachium acanthurus	Langostino prieto	Cinnamon river shrimp	Native	10
Macrobrachium americanum	Langostino cauque	Cauque river prawn	Native	31
Macrobrachium carcinus	Acamaya	Bigclaw river shrimp	Native	7
Macrobrachium rosenbergii	Langostino Malayo	Giant river prawn	Exotic	16
Macrobrachium tenellum	Langostino chacal	Longarm river prawn	Native	43
Penaeus californiensis	Camarón amarillo	Yellowleg shrimp	Native	45
Penaeus setiferus	Camarón blanco del Golfo	Northern white shrimp	Native	38
Penaeus stylirostris	Camarón azul	Blue shrimp	Native	53
Penaeus vannamei	Camarón blanco del Pacífico	Whiteleg shrimp	Native	921
Procambarus llamasi	Acocil yucateco	Yucatecan crayfish	Native	8

The above results should not come as a surprise, since the development of research on crustacean culture in Mexico has been directed, almost entirely, to marine shrimp. Chong-Carrillo *et al.* (2023) analyze the number of projects directed to scientific research on aquatic culture and their financing in the CPI of CONAHCYT, based on information provided by the CPI themselves. The CIBNOR is the one that has directed more projects (44) to research on crustaceans, with a clear dedication to marine shrimp and *P. vannamei*, although projects have also been carried out with shrimp of the genus *Macrobrachium*, specifically *M. americanum* (but in very low numbers). The funding that CIBNOR has received for the development of these projects (from CONAHCYT) was 53,484 million pesos in approximately 25 years. With fewer scientific projects on crustacean culture (mainly *P. vannamei*), Centro de Investigación en Alimentación y Desarrollo (Research Center in Food and Development; CIAD) was detected with eleven projects, also financed by CONAHCYT, with 15.705 million pesos. Finally, the Centro de Investigación Científica y de Educación Superior de Ensenada (Ensenada Scientific Research and Higher Education Center; CICESE) reported six projects, with funding of 2.090 million pesos. This clearly demonstrates that CONAHCYT's CPIs have directed their greatest research effort in crustacean culture toward one species. The possibility of increasing the production of Pacific white shrimp, which is a high value-added species with high demand in international markets, has been, almost without a doubt, the origin of the scientific policies that have directed research toward this species. Marginally, research has been carried out with other native species that would require more studies to complete the biotechnology that would make them competitive.

The only species that has shown an almost constant upward trend since 1996 is *Penaeus vannamei*, which on average has produced 30 articles per year in three decades (Figure 2C). The rest of the penaeid species have remained with a low number of publications in the same period. *Cherax quadricarinatus* records publications since 2002, with a maximum of ten in 2003 to subsequently show few, if any, annually (Figure 2A). Of the prawns of the genus *Macrobrachium*, two species stand out from the end of the first decade of the 21st century, *M. americanum* and *M. tenellum*, and it is evident that interest in the study of both has restarted after a long unproductive period, which has continued to date, although with decreases (Figure 2B). Two peaks of article production, very similar, are observed in 2012 and 2018 with these two species. The exotic species, *M. rosenbergii*, has also been of scientific interest with some publications in the period studied, but with totally unproductive years. The same is observed for the other native species of *Macrobrachium*, which have barely maintained a discrete production of articles over the course of three decades. In the case of *P. llamasi* there was a period of only ten years in which it was of scientific interest, related to its culture (Figure 2D). From 2010, the year in which the largest number of articles was produced (3), to date, there is no record of publications.

Analysis of the timelines also suggests that there is some decline in the number of articles published from the time the COVID-19 pandemic occurred in late 2019 and early 2020. Although, for some species there is an increase and decrease in publications over the years, the decrease from 2020 onwards is notable especially in the publication of the genera *Penaeus* and *Macrobrachium*, which suffered declines after notable increases in

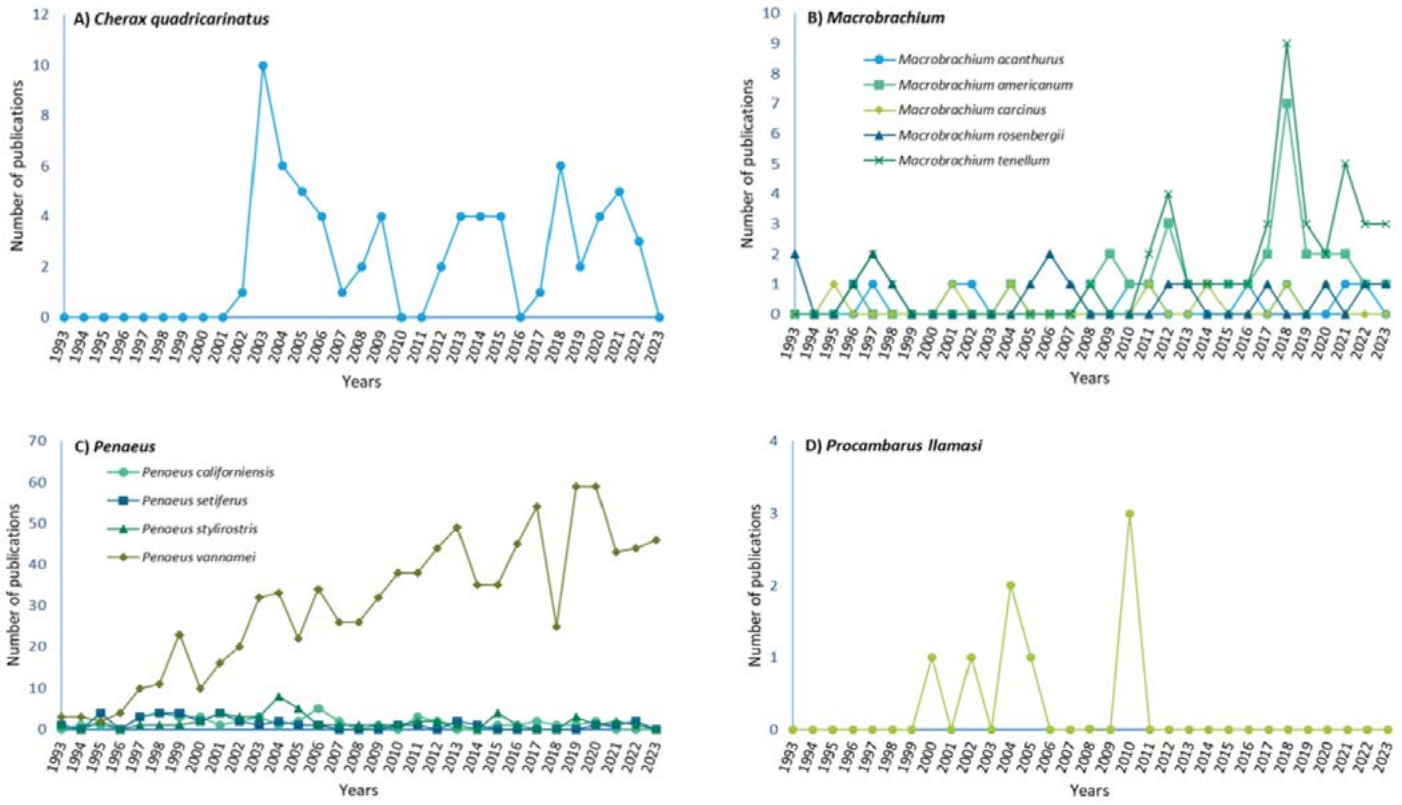

Figure 2. Timeline of publications of crustacean species with culture technology developed, under development or with culture potential in Mexico according to Scopus. A) *Cherax quadricarinatus*, B) Species of the *Macrobrachium* genus, C) Species of the *Penaeus* genus, D) *Procambarus llamasi*.

previous years and the recovery has been slow. This phenomenon is not the product of a light interpretation but has been studied by other authors. Gao *et al.* (2021) mention that the pandemic had important, long-term effects on the creation of new projects and on the performance of scientists, especially women and men with young children. Riccaboni and Verginer (2022) study the number of publications generated in the first years of the pandemic and mention that there was a general decrease, except for those related to health issues and the pandemic itself. Jamali *et al.* (2023), comment that the closure of laboratories and the impossibility of carrying out field work had a severe impact on the development of young scientists in training and on their productivity, an important sector in population science since it is the main workforce of research groups. The consequences of the COVID pandemic on scientific productivity in Mexico should be further studied and is part of our future studies in aquaculture research.

The 20 institutions that have conducted the most research on crustacean culture are presented in Table 2, considering the total number of articles generated by each one and the respective percentage per institution. CIBNOR leads the percentage of publications, together with UNAM (20% both). The participation of CIBNOR is remarkable in studies directed to aquatic cultures in Mexico. This has already been mentioned in previous reports (Chong-Carrillo *et al.*, 2023; Nieves-Rodríguez *et al.*, 2024; Chong-Carrillo *et al.*, 2024).

The participation of the other two CPIs with a vocation in aquaculture research (CIAD and CICESE) is also relevant in this case. However, the contribution of public universities is also preponderant.

UNAM, IPN, UNISON and Universidad Autónoma de Sinaloa (UAS), among others, show that these institutions have consolidated research groups in crustacean culture. As part of a study on crustacean research for farming purposes, it was found that the lines of research directed to *Penaeus vannamei* are diversified. The results show that the greatest effort for this species is directed to aquaculture and nutrition, representing 18% of the publications for each of these topics. However, areas such as biochemistry, genetics and morphophysiology also stand out. For the blue lobster (*Cherax quadricarinatus*), a similar situation occurs, where the dominant topics belong to aquaculture (30%) and

Table 2. Institutions most mentioned in articles on crustacean published by Mexican institutions and hosted in SCOPUS (as a percentage of total articles).

Institutions	% of published articles
CIBNOR	20
UNAM	20
IPN	15
CIAD	11.2
UNISON	6.2
UAS	3.8
CICESE	3
UAN	2.8
UANL	2.7
UAM	2.5
CICIMAR	2
UABC	2
INAPESCA	1.9
UAT	1.5
UDG	1.4
ITSON	1.2
UABCS	0.7
UAEM	0.4
ECOSUR	0.4
BUAP	0.2

Nomenclature of institutions in alphabetical order: BUAP=Benemérita Universidad Autónoma de Puebla, CIAD=Centro de Investigación en Alimentación y Desarrollo, CIBNOR=Centro de Investigaciones Biológicas Del Noroeste, CICESE =Centro de Investigación Científica y de Educación Superior de Ensenada, CICIMAR=Centro Interdisciplinario de Ciencias Marinas, ECOSUR=El Colegio de la Frontera Sur, INAPESCA=Instituto Nacional de Pesca y Acuacultura, IPN=Instituto Politécnico Nacional, ITSON=Instituto Tecnológico de Sonora, UABC=Universidad Autónoma de Baja California, UABCS=Universidad Autónoma de Baja California Sur, UAEM=Universidad Autónoma del Estado de Morelos, UAM=Universidad Autónoma Metropolitana, UAN=Universidad Autónoma de Nayarit, UANL=Universidad Autónoma de Nuevo León, UAS=Universidad Autónoma de Sinaloa, UAT=Universidad Autónoma de Tamaulipas, UDG=Universidad de Guadalajara, UNAM =Universidad Nacional Autónoma de México, UNISON=Universidad de Sonora.

nutrition (19%), while other areas such as morphophysiology and parasitology appear in a lower percentage. For species of the genus *Macrobrachium*, interest in technological development is also demonstrated, since aquaculture is among the main research topics (Figure 3). The aquaculture interest in research on crustacean species with culture potential is evident, since the studies directed at these species are mainly focused on that direction. This situation differs from research in Mexico oriented to native fish species, where although there is an interest in laying the foundations for aquaculture technological development, a large proportion of research indirectly affects aquaculture topics, with high percentages of studies focused on Ecology or Parasitology (Nieves-Rodriguez *et al.*, 2024).

Figure 4 shows the publications by species considering the access to them, either open access or paid access. Of the total number of articles published, 46% were open access through the paid access system of the respective journals, while only 54% were restricted with paid access. These percentages are similar to those reported in the analysis of fish studies carried out by Nieves-Rodríguez *et al.* (2024), which also shows that Mexican researchers use the paid access method in high-impact journals so that their research can be placed with greater visibility and "greater prestige".

According to the president of the aquaculture group of the Consejo Nacional de Fabricantes de Alimentos Balanceados y de la Nutrición Animal (CONAFAB) Jaime Almazán, aquaculture generates social benefits, such as: greater food security (access to fish and seafood at affordable prices), job creation (economic growth in aquaculture zones reduces the expulsion of labor to urban areas), among others (El Economista, 2024). Undoubtedly, the beneficial effects of aquaculture in terms of economic growth derived from job creation are indisputable. According to the Comité de Sanidad Acuícola del Estado Sonora, A.C. (COSAES), in Sonora alone, marine shrimp aquaculture is considered to generate 50,000 direct and indirect jobs, in 140 farms with 26,000 hectares of culture (personal communication with Miguel Ángel Castro Cosío). This confirms the job-generating vocation of the cultivation of this crustacean and, consequently, its economic benefits for a certain sector of the population. However, its participation in achieving food security is not so clear, at least in terms of products obtained through crustacean aquaculture. The Programa Nacional de Pesca y Acuicultura (PNPA) 2020-2024 (SADER, 2019), mentions that "the aquaculture sector will be promoted, with the purpose of contributing to food security, by virtue of the fact that, through this activity, a greater production of food of high nutritional value can be obtained". The above shows the spirit in which development policies in the fisheries and aquaculture sector should be carried out in the established period. However, in the same PNPA it is mentioned that there is low productivity in these sectors, which leads to low-income levels. The causes of this are identified as follows: 1) Low contribution of fisheries and aquaculture to food security, 2) Low levels of income and poverty in fishing and aquaculture communities, 3) Inadequate management of fishery and aquaculture resources, 4) Weak legal and institutional framework for fisheries and aquaculture. These causes, which are directly related to aquaculture, include "insufficient supply of fishery and aquaculture products at accessible and quality prices in rural communities," "deficient quality, adequate and

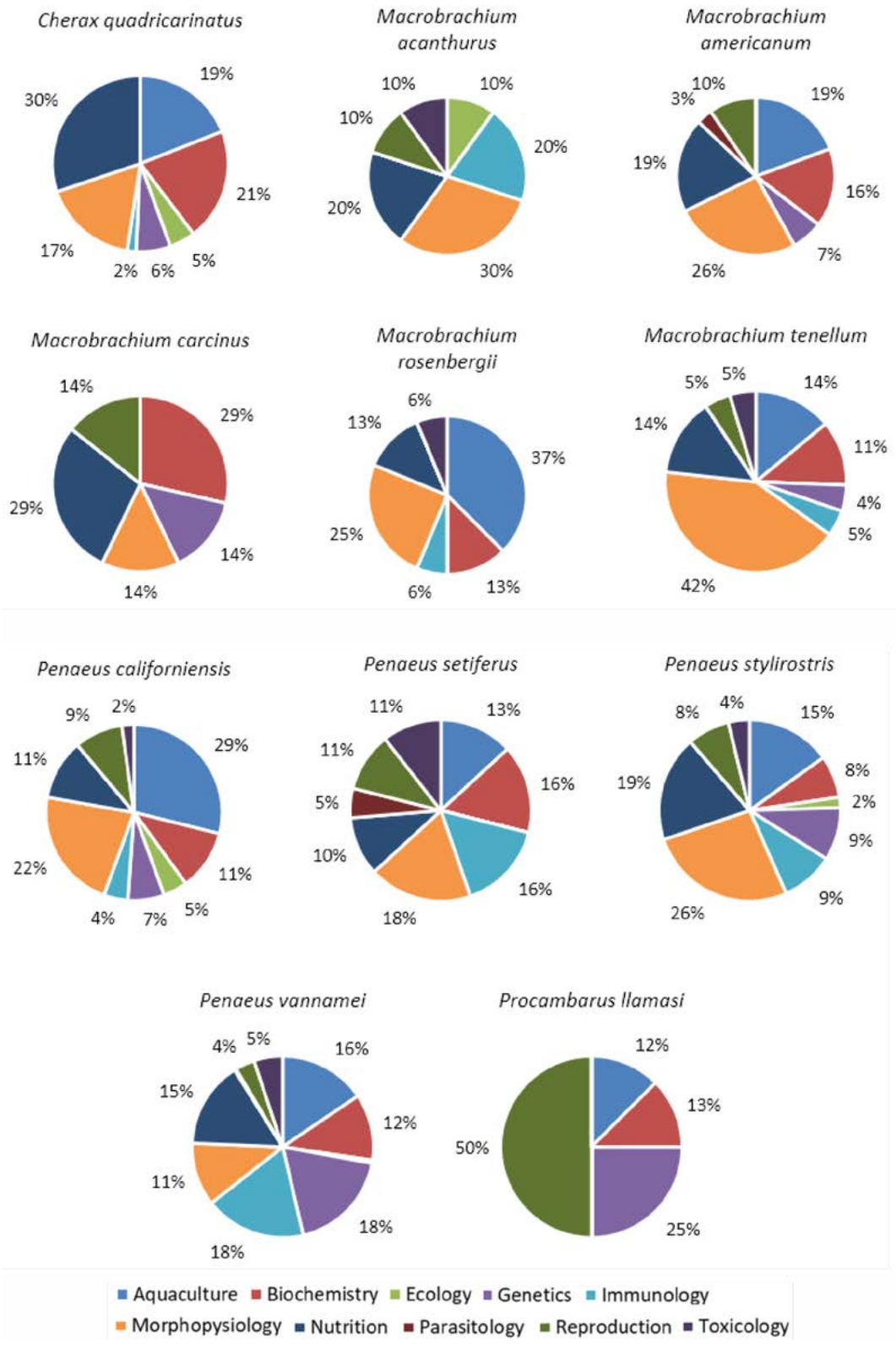

Figure 3. Percentage of publications by thematic areas of crustacean species with culture technology developed, under development or with culture potential in Mexico according to Scopus.

	1	2	3	4	5	6	7	8	9	10	11
Pay	34	10	17	2	8	11	23	19	28	526	6
Open access	34	10	14	5	8	40	22	19	25	395	2

Figure 4. Number of publications of crustacean species with culture technology developed, under development or with culture potential in Mexico according to Scopus and classified by access (open or paid access). 1. *Cherax quadricarinatus*, 2. *Macrobrachium acanthurus*, 3. *Macrobrachium americanum*, 4. *Macrobrachium carcinus*, 5. *Macrobrachium rosenbergii*, 6. *Macrobrachium tenellum*, 7. *Penaeus californiensis*, 8. *Penaeus setiferus*, 9. *Penaeus stylirostris*, 10. *Penaeus vannamei*, 11. *Procambarus llamasi*.

pertinent technical-scientific information," and "limited growth and diversification of aquaculture.

The social impact of the research carried out to develop the cultivation of the crustacean species included in this study is low. Most of the species studied and for which the complete technology is already available are of high added value. However, these crustaceans could be a valuable source of protein for human consumption, especially for sectors of the population with limited access to other sources of animal protein. The three species that are currently being cultured in Mexico (*P. vannamei*, *C. quadricarinatus* and *M. rosenbergii*) and that have been subjected to research in CPI and academic institutions, have sales value that is not accessible to a large sector of the population. According to information provided by the producers themselves, the retail price of Australian lobster (*C. quadricarinatus*) is around $250 pesos per/kg; and that of the Malaysian prawn (*M. rosenbergii*) at the farm is around $600 pesos/kg, both data obtained in Veracruz. In Mérida, Yucatán, in the Chedraui supermarket, the price of Malaysian prawn is $599 pesos/kg, while in San Pedro Pochutla, Oaxaca, it is $700 pesos in farm. In the case of head-on shrimp, prices at Walmart supermarkets (online) range from 199 pesos/kg to 299 pesos/kg, depending on size. According to Smattcom (agricultural, aquaculture and fishery products trader), the price of fresh shrimp per kg, wholesale, in May 2024, can have a minimum price of 82 to 146 pesos and a maximum of between 195 to 899 pesos (no information on size or origin). In a study currently carried out in Veracruz, Puebla and the La Viga market in Mexico City, it has been recorded that the price of *M. rosenbergii* can vary from $380 pesos per box with two pounds (wholesale), up to $450 pesos (retail) and even up to $700 pesos (for individuals and restaurants). For Australian lobster, prices have been recorded ranging

from $80 pesos to $200 per kg (depending on size and freshness) (personal communication with Gonzalo Ammiel Gómez Salgado).For the Pacific coast, in the Cajón de Peñas dam (Jalisco), the price per kg of Australian lobster varies from $40 to $50 pesos and the price of river shrimp, *M. americanum*, is $500 pesos/kg (personal communication with fishermen of the Cajón de Peñas dam). It is worth mentioning that both species are the product of fisheries (in the same dam). The Australian lobster is already fished regularly in that area and represents a profitable activity for the inhabitants, despite being an exotic species that has been distributed both in the dam and in its canals (Vega-Villasante *et al.*, 2015). It is clear that a low-income family would not be able to acquire, on a daily basis, such products that are, in an obvious way, aimed at a population sector with greater purchasing power. Therefore, at least in the case of crustaceans, the insufficient supply at accessible and quality prices for rural populations is confirmed.

The deficient scientific-technical information and the scarce diversification of aquaculture, problems identified in the PNPA 2020-2024, are consequences of the same phenomenon. According to the results of the analysis of the publications in this study, scientific-technical information has been profuse and relevant for *P. vannamei*, and to a much lesser extent for shrimp of the genus *Macrobrachium* and *C. quadricarinatus*. Decades ago, there was interest in the scientific and technological study of native and alternative species for marine shrimp culture. The production of articles over time, shown in Figure 1, demonstrates this. However, the lines of research that would allow the aforementioned diversification were not maintained and only those directed to the study of Pacific white shrimp were (apparently) preserved. At least, for the study of crustaceans with a vocation for cultivation, there do not seem to be new lines that address new or forgotten species, except for the genus *Macrobrachium* and its native species. For *M. rosenbergii*, there is also no evidence to show that studies are being carried out to improve or make culture, reproduction or nutrition techniques more efficient, even though its cultivation is growing in several regions of the country.

CONCLUSIONS

The dominance of the marine shrimp *P. vannamei* is clear, since most of the research has focused on this crustacean, reflecting a clear preference and technological development in its culture. Despite initial mentions of studies on other species such as *C. quadricarinatus* and some of the *Macrobrachium* genus, the research and technology developed are limited, suggesting a lack of exploration towards culture diversification. Shrimp aquaculture generates significant employment and economic growth in specific areas, but the products obtained are of high value, limiting their accessibility to the low-income population. The sector faces challenges such as low productivity, insufficient supply at affordable prices, and limited research on native species and alternatives to *P. vannamei*.

Therefore, it would be advisable to encourage research and technological development in native species and alternatives to *P. vannamei*, such as shrimp of the *Macrobrachium* genus, in order to reduce dependence on a single species and explore new markets. Ensure sustained funding and institutional support for aquaculture research projects, especially those directed toward less studied species and innovative technologies. Promote policies

that allow equitable access to the economic benefits of aquaculture, considering food production at affordable prices for rural and low-income communities. Improve the regulation and institutional framework to promote sustainable, efficient and ethical practices in aquaculture, ensuring responsible development of the sector. Encourage collaboration between research institutions, production centers, and international cooperation to share knowledge, technologies and best practices in aquaculture.

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