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Correlation of water quality and parasite community in *Cyprinus carpio var. koi* in Pachuca de Soto, Hidalgo-Mexico

Correlación de la calidad del agua y la comunidad parasitaria en *Cyprinus carpio var. koi* en Pachuca de Soto, Hidalgo-México

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ABSTRACT
Ornamental fish farming represents a high economic value activity worldwide; however, various environmental stressors can affect the health of these organisms. This study analyzed the parasite profile of 18 koi carp (*Cyprinus carpio var. koi*) and its correlation with water quality. A total of 223 parasites were observed, with a prevalence of 77.7 %. The parasite community showed a higher presence of the monogenean *Gyrodactylus* spp. (16.7 %) and the trematode *Centrocestus formosanus* (66.6 %). Water quality showed high levels of nitrates (61.1 ± 20.2 mg L^{-1}), alkalinity (203.0 ± 124.0 mg L^{-1}), and carbonates (263.0 ± 89.8 mg L^{-1}), as well as a correlation between nitrogen compounds and the prevalence of monogeneans (r=0.6 and 1.0), and a correlation between *C. formosanus* and nitrates (r=0.3) and pH (r=0.4). The correlation of environmental stressors with parasite loads in ornamental carp can provide crucial information for their management and marketing.

Keywords: *Centrocestus formosanus*; ecological indices; pearson index; monogenean; zoonoses

RESUMEN
La producción de peces ornamentales representa una actividad de alto valor económico a nivel mundial; no obstante, diversos estresores ambientales pueden afectar el estado sanitario de los organismos. En este estudio se analizó el perfil parasitario de 18 carpas (*Cyprinus carpio var. koi)* y su correlación con la calidad del agua. Se observaron 223 parásitos y una prevalencia de 77.7 %, la comunidad parasitaria evidenció mayor presencia del monogeneo *Gyrodactylus* spp. (16.7 %) y el trematodo *Centrocestus formosanus* (66.6 %). La calidad del agua presentó valores elevados de nitratos (61.1 ± 20.2 mg L^{-1}), alcalinidad (203.0 ± 124.0 mg L^{-1}) y carbonatos (263.0 ± 89.8 mg L^{-1}), así como correlaciones de compuestos nitrogenados con la prevalencia de monogeneos (r=0.6 a 1.0) y de *C. formosanus* con los nitratos (r=0.3) y el pH (r=0.4). La correlación entre los estresores ambientales y las cargas parasitarias en carpas de ornato puede resultar determinante para su gestión y comercialización.

Palabras clave: *Centrocestus formosanus*; índices ecológicos; índice de Pearson; monogeneo; zoonosis

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1. INTRODUCTION

The ornamental fish industry represents an economic niche that has experienced substantial growth in recent years. Globally, it is estimated to be worth USD 5.88 billion annually, while in Mexico it represents sales of USD 2.16 million annually. Commercialization is supported by approximately 250 farms distributed across 20 states, led by Morelos, Veracruz, Yucatán, the State of Mexico, and Jalisco (Instituto Mexicano de Investigación en Pesca y Acuacultura Sustentable, 2018; Paredes-Trujillo et al., 2024). Ornamental production is associated with a high diversity of teleost fish, including widely marketed species such as goldfish (*Carassius auratus*), platy fish (*Xiphophorus maculatus*), Siamese fighting fish (*Betta splendens*), Oscar fish (*Astronotus ocellatus*), guppies (*Poecilia reticulata*), cardinal tetra (*Paracheirodon axelrodi*), serpae tetra (*Hyphessobrycon eques*), angelfish (*Pterophyllum scalare*), and discus fish (*Symphysodon discus*) (Coelho Florindo et al., 2017; Ribeiro et al., 2009; Sasanami et al., 2021; Sermwatanakul, 2019).

Within this diverse market, cyprinids hold a prominent position due to their long-standing cultivation tradition. They represent the most widely produced fish family worldwide and include species used in both food production and ornamental aquaculture (Henrique et al., 2019). This taxonomic group includes species such as *Cyprinus carpio var. koi*, a carp highly valued for its pigmentation patterns in shades of green, black, gray, blue, gold, orange, and red. These colorations, in addition to their ornamental value, are indicators of the reproductive quality of the specimens (Pietsch & Hirsch, 2015; Rodríguez-Gutiérrez et al., 2025). However, cyprinid production is characterized by a sanitary profile that reveals challenges posed by a high diversity of parasitic agents, and factors such as high stocking density may increase the risk of parasitic infestation (Elisafitri et al., 2021).

In this context, the culture and maintenance of koi carp (*Cyprinus carpio var. koi*) have reported infections by the zoonotic trematode *Centrocestus formosanus*, with a prevalence of 5.5% (Zamora-Roa et al., 2025), as well as the presence of the protozoan *Myxobolus koi* in gills, intestine, and liver (Maftuch et al., 2018), and the crustacean *Argulus japonicus*, identified in an artificial lake in Brazil with a prevalence of 100.0% (Silva et al., 2024). Additionally, specimens of *C. carpio var. koi* have been reported as hosts of various ectoparasites such as *Trichodina* sp., *Gyrodactylus* sp., *Dactylogyrus* sp., *Glossatella* sp., and *Ichthyophthirius multifiliis*, which are commonly found in the gills and on the body surface of fish (Elisafitri et al., 2021).

The presence of parasites associated with environmental stressors, such as water quality, may lead to parasitosis (Adamba et al., 2020), a condition that can compromise production and the quality of life of ornamental organisms. Therefore, the objective of this study was to provide information on the parasite–host relationship by characterizing the parasitic community and water quality parameters associated with the commercialization of *C. carpio var. koi* specimens in the central area of Pachuca de Soto, Hidalgo.

2. MATERIALS AND METHODS

Study Area

The study area comprised the central zone of the municipality of Pachuca de Soto, Hidalgo, Mexico (**Figure 1**), This municipality is the capital of the State of Hidalgo and is geographically located at coordinates 20°07’21” N latitude and 98°44’09” W longitude, at an altitude ranging from 2400 to 2800 m above sea level. It has a temperate, semi-cold climate with summer rainfall, with an average annual precipitation of 400-800 mm. Winds predominantly originate from the northeast and are present in the city for nine months of the year, with a maximum speed of 65 km/h. The city has an average temperature of 24 °C (Cruz García et al., 2015; Rebollar-Zamorano et al., 2020). It is noteworthy that Pachuca de Soto is located approximately 100 km from Mexico City (CDMX) and represents the most populated municipality in the State of Hidalgo, with 314,331 inhabitants (Instituto Nacional de Estadística y Geografía (INEGI), 2010).

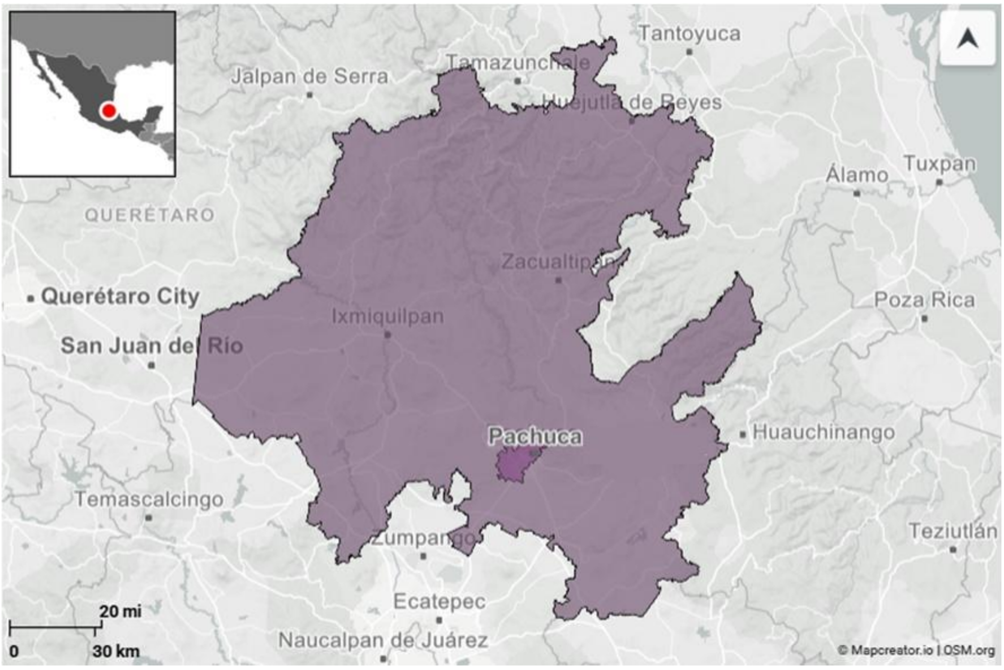

Figure 1. *Study area. The upper-left map shows the location of the State of Hidalgo in central Mexico, marked with a red point. The enlarged view displays the boundaries of the State of Hidalgo, with the municipality of Pachuca de Soto highlighted in dark purple.*

Sample Collection

A total of six ornamental fish retail establishments (“aquariums”) were identified in the central area of Pachuca de Soto. From each establishment, juvenile ornamental carp specimens of the species *Cyprinus carpio var. koi* were collected in triplicate. Fish were transported in plastic bags containing a 30% water:70 % air ratio, with oxygen injected to achieve a saturation level >5 mg L^{-1} (Bocek, 1991; Muthiah, 2014). From each sampling point, 200 mL of water was collected from the aquaria where *C. carpio var. koi* specimens were displayed. Both fish and water samples were transported to the Parasitology Laboratory of the Institute of Basic Sciences and Engineering for further processing.

Necropsy and Parasitological Determination

A total of 18 fish were processed for parasitological examination. Standard length and weight were recorded for each individual. Subsequently, fish were euthanized using a two-step method consisting of an ice bath at temperatures below 4 °C, followed by cranial puncture for physical brain destruction, as described by Lavalle et al. (2025). Each specimen was then positioned in dorsal recumbency with the head oriented toward the operator's left hand. Parasitological examination included the collection of mucus samples by cranio-caudal scraping onto microscope slides. A second mucus sample was obtained by pooling scrapings from the dorsal, lateral, anal, pelvic, and caudal fins on the left lateral side of the fish. The left gill arch was dissected, and the four gill lamellae were separated for transfer and preparation as independent squash mounts. Each organism was further examined for endoparasites through dissection of the thoracic cavity, performed by a longitudinal incision from the anus to the lower jaw and a second incision from the anus to the upper region of the operculum. Subsequently, target organs of the thoracic cavity—including the esophagus, stomach, intestine, liver, spleen, gallbladder, gonads, swim bladder, kidney, and heart—were exposed, isolated, and prepared as independent squash mounts for observation (HIPRA, 2024; Sepulveda & Kinsella, 2013), finally, the muscle tissue from the left lateral fillet region of each fish was dissected for the detection of endoparasite cysts through transillumination (Secretaría de Salud, 2010). Observations were carried out using bright-field microscopy with an attached camera on a Zeigen WF10x microscope (nopCommerceCopyright© 2022 Zeigen Microscopios, CDMX, Mexico).

Water Quality Determination

Each water sample was processed to determine nitrite (mg L^{-1} NO_2^-), nitrate (mg L^{-1} NO_3^-), alkalinity (mg L^{-1} $CaCO_3$), hardness (mg L^{-1} $CaCO_3$), and pH values using HANNA® colorimetric kit reagents. Measurements were obtained following the manufacturer's protocols according to the following product codes: HI3874 (nitrates), HI3873 (nitrites), HI3811 (alkalinity), HI3812 (hardness), and HI98107 (pH) (Acosta-Pérez et al., 2022). Carbonate (mg L^{-1}) and chlorine (mg L^{-1}) values were determined using aquarium-specific reactive test strips from LOMAS®.

Data Analysis

Counts and prevalence values with confidence intervals were calculated using the formula: Prev = (number of fish presenting the condition / number of fish sampled) × 100. In addition, abundance (Abu = number of parasites / number of fish sampled) and intensity (Int = number of parasites / number of infected fish) were estimated for each observed parasite genus, following Aragón-Pech et al. (2018). Furthermore, biodiversity indices were calculated, including Simpson's index, Berger–Parker dominance index, Shannon–Wiener diversity index, and Pielou's evenness index (Moreno, 2001). Water quality parameters were expressed as mean ± standard deviation based on 18 measurements. Finally, prevalence values and water quality parameters were correlated using Pearson's correlation coefficient (Formula 1). Analyses were conducted in an open-source computational environment using RStudio© version 2025.09.01 and the statistical package "corrplot." Interpretation allowed the identification of negative correlations (values close to −1), positive correlations (values close to 1), and weak correlations (values close to 0)(Berman, 2018).

Formule 1.- $$r = \frac{\sum_{i=1}^{n}(x_i - \tilde{x})(y_i - \tilde{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \tilde{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \tilde{y})^2}}$$

3. RESULTS AND DISCUSSION

Parasitic Community

Ornamental fishkeeping is one of the most popular hobbies worldwide. The industry is continuously growing while facing biosecurity challenges (Hoshino et al., 2018), mainly associated with the high movement of organisms, where fish may contribute to the co-introduction and spread of pathogens, including parasitic agents (Wilson, 2019). This highlights the importance of continuous evaluation of parasitic communities in ornamental fish. In this study, a total of 18 juvenile ornamental fish of the species *C. carpio var. koi* were analyzed, with a mean length of 11.3 ± 2.04 cm and an average weight of 16.4 ± 6.96 g. Parasitological examination revealed a total of 223 parasites in 14 of the 18 analyzed fish, yielding an overall prevalence of 77.7% for the parasitic community. This value is considerably higher than that reported by Paredes-Trujillo et al. (2024) in Morelos, Mexico, who described 12 parasitic species associated with ornamental fish with prevalences ranging from 0.2% to 4.5%. In the analyzed specimens of *C. carpio var. koi*, five parasites were identified (**Figure 2**). Four of them were identified at the genus level, where the monogeneans *Dactylogyrus* spp., *Dawestrema* spp., and *Gyrodactylus* spp. presented eight, four, and three observations, with prevalences of 5.6%, 11.1%, and 16.7%, respectively. These parasites have been previously reported in koi carp populations in Indonesia, where *Dactylogyrus* spp. and *Gyrodactylus* spp. showed prevalences of 80.0% and 40.0%, respectively (Elisafitri et al., 2021). Meanwhile, *Dawestrema* spp. has been reported in tilapia populations in the State of Hidalgo with a prevalence of 11.0% (Acosta-Pérez et al., 2022), although there are no previous reports of this genus in koi carp populations in the region. Monogenean infestations in *C. carpio var. koi* occur at the level of the dermis and gills, where these ectoparasites feed on mucus, causing lethargy, anorexia, and irritation. These clinical signs may be exacerbated by stressors such as overcrowding and poor water quality (Steckler, 2016). On the other hand, the genus *Trichodina* showed a single observation (5.6%). Trichodinids are widely reported in aquatic environments and are recognized as facultative fish parasites. They firmly attach to the host's skin, fins, and gills, generating a suction movement through the aboral membrane, causing localized irritation that may lead to secondary infections by fungi, viruses, or bacteria (Rivera Pérez & Hernández Saavedra, 2021). In koi carp, prevalences of up to 80.0% have been reported during early developmental stages (Elisafitri et al., 2021). These findings were complemented by the presence of the trematode *C. formosanus*, which accounted for 207 observations and represented the parasite with the highest abundance (11.50), intensity (17.25), and prevalence (66.6%) in this study. This trematode has been reported in Mexico as a parasite of 39 fish species, including cyprinids, across 11 states, such as Colima, Guanajuato, Jalisco, Michoacán, Morelos, San Luis Potosí, Sonora, Tabasco, Tamaulipas, Veracruz, and Hidalgo. In the latter, the first report of metacercariae was documented in the municipality of Tezontepec de Aldama (Scholz, 2009). In populations of *C. carpio var. koi*, *C.*

formosanus has been previously reported with a prevalence of 5.5% in Tulancingo de Bravo (Zamora-Roa et al., 2025). Its infestation is associated with the development of metacercariae in the gills, and infection intensity may lead to respiratory impairment, morbidity, and mortality in fish (B. G. D. Sumuduni et al., 2020). Furthermore, this parasite is of public health concern, as it has been associated with intestinal infections in humans following the consumption of raw or undercooked contaminated fish (Paopun et al., 2024; Pinto et al., 2014). The parasitic community in this study presented a Simpson index of 0.13. Additionally, the Berger–Parker dominance index reached 0.92, with *C. formosanus* as the most abundant parasite. In contrast, the Shannon and Pielou indices were low at 0.34 and 0.21, respectively. These indices serve as important indicators of the parasitic community structure and complement parasitological findings in *C. carpio var. koi* (Moreno, 2001). The low values of the Simpson and Shannon indices indicate low parasitic diversity associated with the analyzed carp (Acosta-Pérez et al., 2022), while the low Pielou index suggests low evenness in parasite abundance. This pattern is reinforced by the high Berger–Parker index for C. formosanus, highlighting the strong influence of this trematode on the structure of the parasitic community in C. carpio var. koi (Acosta-Pérez et al., 2022; Morris et al., 2019).

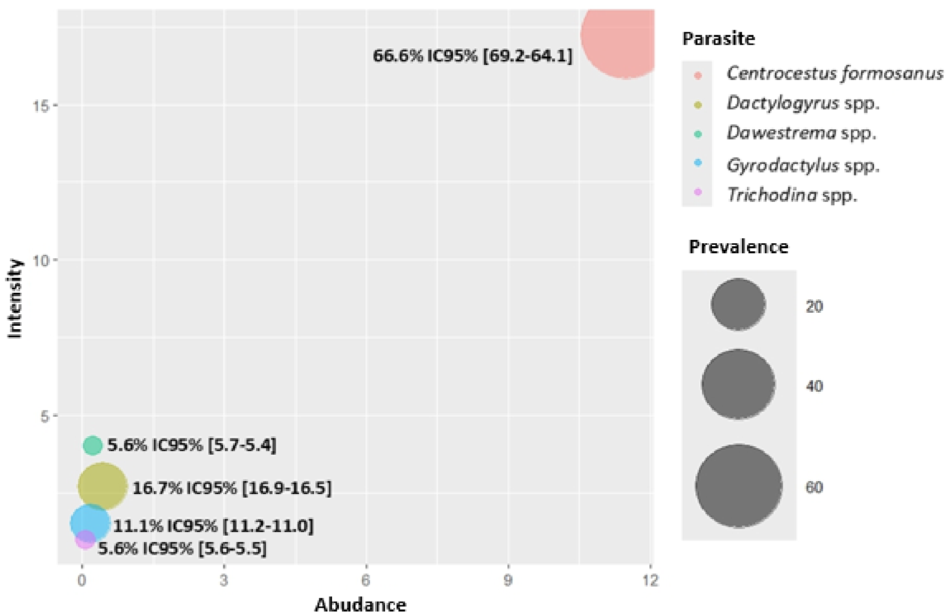

Figure 2. *Characterization of the parasitic community. Y-axis: parasite abundance values; X-axis: parasite intensity values; prevalence values of the observed parasites with 95% confidence intervals*

The observed parasites (**Figure 3**) corresponded to adult stages of the monogeneans *Dactylogyrus* spp., *Dawestrema* spp., and *Gyrodactylus* spp. In Figures 3a, 3b, and 3c, their fluke-like morphology can be observed. These parasites exhibit direct life cycles, with *Dactylogyrus* spp. most commonly reported in gills and on the skin of *Gyrodactylus* spp. (Steckler, 2016). This is consistent with the findings of the present study, as all three monogenean genera were observed as ectoparasites on the gill filaments. In the case of *Trichodina* spp., Figure 3d shows an adult specimen identified on the mucosal surface of the left lateral plane of the fish. This protozoan is characterized by its discoidal shape and the presence of an aboral region used for attachment to the host, as well as proteinaceous denticles and a macronucleus (Pietsch & Hirsch, 2015). On the other hand, Figures 4a and 4 b show cysts of the trematode *C. formosanus*. This stage corresponds to metacercariae that lodge in the gills of *C. carpio var. koi* through cyst formation (B. Sumuduni et al., 2017; Vélez-Hernández et al., 1998).

In Figure 4b, cyst formation and its fusion with the primary gill filaments can be observed. Additionally, the digestive vesicle, which exhibits a characteristic "X" shape, is visible; this structure displayed circular movements during the observations (Arguedas Cortés et al., 2009; Zamora-Roa et al., 2025).

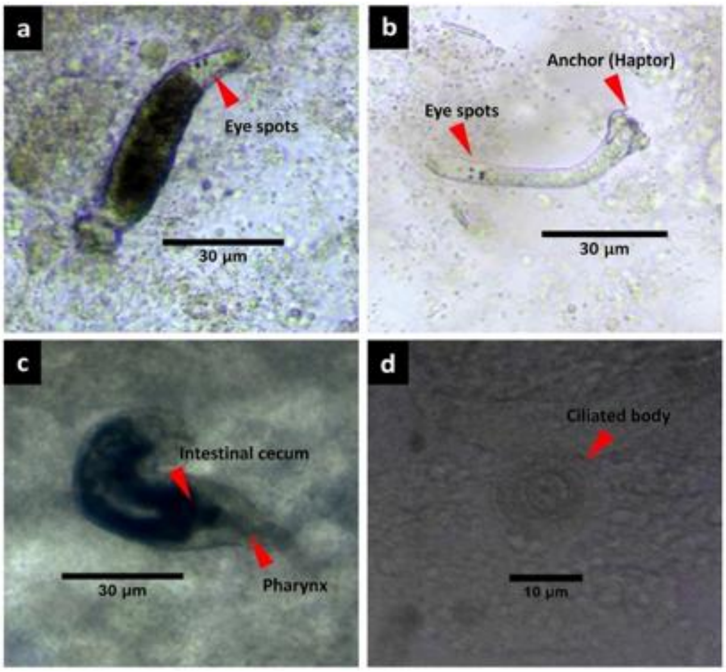

Figure 3. *Micrographs of C. carpio var. koi: (a) Dactylogyrus spp., (b) Dawestrema spp., and (c) Gyrodactylus spp., corresponding to monogeneans (observed at 10×); (d) the ciliated protozoan Trichodina spp. (observed at 40×)*

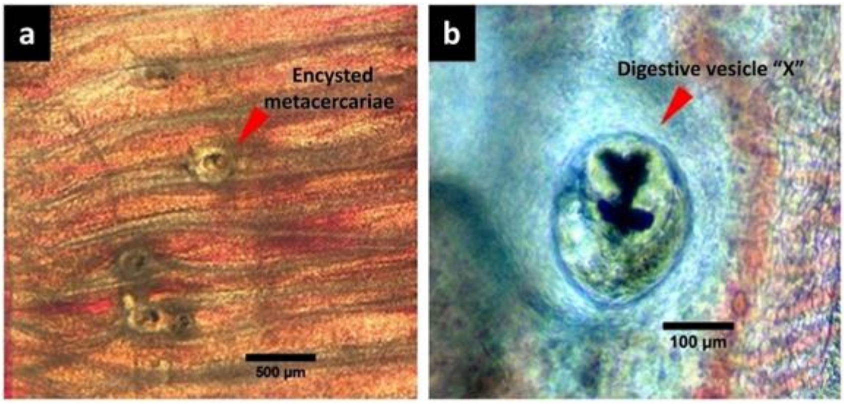

Figure 4. *Metacercariae of C. formosanus: (a) presence of multiple cysts at the gill level (4× magnification); (b) magnified view of a metacercaria of C. formosanus (10×) showing its characteristic "X"-shaped digestive vesicle*

Water Quality Parameters

Water quality in aquaculture systems is a determining factor for the maintenance and development of aquatic species. Proper management and identification of optimal parameters enhance the cultivation of different aquaculture species (Karal Marx et al., 2020). The maintenance of *C. carpio var. koi* specimens requires water quality parameters reported within the following ranges: nitrates 0.4–0.8 mg L^{-1} NO_3^-, nitrites 0.1–3.5 mg L^{-1} NO_2^-, chlorine 0 mg L^{-1}, hardness 100–250 mg L^{-1} $CaCO_3$, alkalinity 100–140 mg L^{-1} $CaCO_3$, carbonates 100–200 mg L^{-1}, and pH 6.5–8.0 (Instituto Mexicano de

Investigación en Pesca y Acuacultura Sustentable, 2018; Saint-Erne, 2019; Yanuhar et al., 2022). Values outside these ranges lead to deterioration in water quality and pose risks to fish health and quality of life (Ojwala et al., 2018). The results of this study showed that nitrite (0.1 ± 0.4 mg L^{-1} NO_2^-), hardness (121.0 ± 0 mg L^{-1} $CaCO_3$), and pH (7.98 ± 0.1) values were within the suggested optimal range. However, nitrate (61.1 ± 20.2 mg L^{-1} NO_3^-), chlorine (0.1 ± 0.3 mg L^{-1}), alkalinity (203.0 ± 124.0 mg L^{-1} $CaCO_3$), and carbonate (263.0 ± 89.8 mg L^{-1}) values were outside the recommended range for the maintenance of *C. carpio var. koi*, highlighting areas for improvement within the commercialization chain of these ornamental fish.

Correlation Between Parasitic Loads and Water Quality

The parasite–host relationship, as well as the development of parasitic diseases, is influenced by multiple factors, including parasite pathogenicity and virulence, as well as the physiological state of the host fish, which may be negatively affected by external stressors such as water quality (Saengsitthisak et al., 2020). Additionally, the structure of parasitic communities may vary with environmental conditions, making the evaluation of water-quality effects on parasitic loads relevant across different aquaculture production systems (Adamba et al., 2020). The results of this study revealed several notable correlations between water quality parameters and parasite prevalence (**Figure 5**). Correlation indices showed that the prevalence of *Dactylogyrus* spp. and *Gyrodactylus* spp. was positively correlated with nitrate levels (mg L^{-1} NO_3^-), with Pearson coefficients of 0.6 and 0.9, respectively. Similarly, the prevalence of *Dawestrema* spp. was positively correlated with nitrite levels (mg L^{-1} NO_2^-) (r =1.0). These findings suggest that the presence of nitrogenous compounds may influence the abundance of monogenean ectoparasites in *C. carpio var. koi*. Previous studies in *Oreochromis niloticus* have reported correlation coefficients of −1.0 and 0.9 for nitrites and nitrates, respectively, with to the occurrence of *Dactylogyrus* spp. (Ageng'o et al., 2024). Likewise, our results are consistent with findings from the Mezquital Valley in Hidalgo, where monogeneans (*Dactylogyrus* spp., *Dawestrema* spp., *Cichlidogyrus* spp., and *Gyrodactylus* spp.) showed positive correlations with nitrite and ammonium levels (Pearson index between 0.06 and 0.55) (Acosta-Pérez et al., 2022). However, no previous reports exist on the correlation between water quality and koi carp populations in the study region. In contrast, the presence of *Trichodina* spp. showed a weak positive correlation with carbonate levels and pH (Pearson coefficient = 0.2 in both cases), whereas alkalinity exhibited a strong negative correlation (−0.7). This pattern is similar to that reported in Hidalgo, where *Trichodina* spp. in cichlids showed weak correlations with hardness (−0.1) and pH (0.28), and a negative correlation with alkalinity (−0.11). This suggests that lower alkalinity levels may favor the population increase of *Trichodina* spp. Furthermore, this protozoan has been associated with dissolved oxygen, pH, and temperature in African cichlids (Ojwala et al., 2018). Finally, the prevalence of *C. formosanus* showed a positive correlation with nitrate levels (0.3) and pH (0.4). However, it generally exhibited negative correlations with other water quality parameters, including nitrites (−0.4), chlorine (−0.4), hardness (−0.2), alkalinity (−0.2), and carbonates (−0.4), indicating no clear correlation pattern. Despite variations in water quality, the presence of *C. formosanus* remained consistent in the analyzed carp. Moreover, the high abundance of *C. formosanus* suggests that additional factors may influence its presence, such as the availability of intermediate hosts in fish farms, particularly the invasive snail *Melanoides tuberculata*, reported as its primary host (Pinto et al., 2018), as well as the presence of piscivorous birds or mammals that facilitate the continuation of the trematode life cycle within the trophic network (Scholz, 2009). Under this scenario, an integrated biosecurity management approach is essential for the cultivation and transport of ornamental fish and other aquaculture organisms (Opiyo et al., 2020).

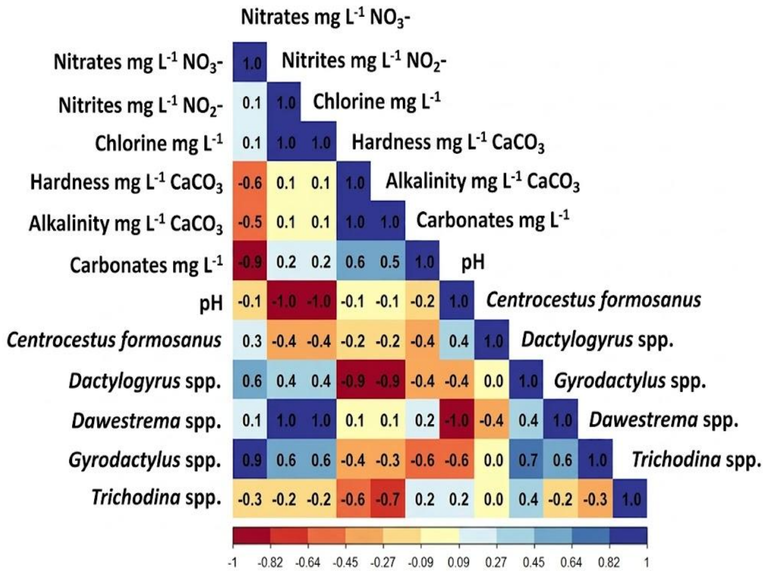

Figure 5. *Correlation matrix showing Pearson indices for the association between water quality variables and parasitic loads observed in C. carpio var. koi specimens*

CONCLUSIONS

Urban areas such as Pachuca de Soto serve as key points for the commercialization of aquatic organisms, including *C. carpio var. koi*. Therefore, the study of parasitic community structure represents a valuable source of information for understanding organism movement and the potential dispersion and co-introduction of pathogens associated with ornamental fish. In this study, the parasitic community structure revealed the presence of five parasite taxa in the analyzed carp. The obtained counts and ecological indices indicated a strong dominance of the trematode *C. formosanus*. On the other hand, water quality exhibited several deficiencies, particularly the presence of nitrogenous compounds and elevated carbonate levels, which may influence the occurrence of monogeneans, protozoa, and trematodes in the analyzed carp. The assessment of parasitic loads can help improve the epidemiological management of these pathogens. Likewise, evaluating the effects of environmental stressors, such as those associated with water quality, may enhance the understanding of the complex parasite–host relationship, ultimately supporting better aquaculture health management in high-value ornamental species such as *C. carpio var. koi*.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this work.

AUTHOR CONTRIBUTIONS

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Data collection: Villaseñor-Reyes G., Nájera-Alemán, P., Rabling-Olivera, J., González-Vázquez, J., Ubilla-Paredes, K. P. and Bell-Palacios, I. S.

Data analysis: Acosta-Pérez V. J.

Results discussion: Gómez-de-Anda F. R., Zepeda-Velázquez A.P. and Acosta-Pérez V. J.

Review and approval: Gómez-de-Anda F. R., Zepeda-Velázquez A.P. and Acosta-Pérez V. J.

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