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Physicochemical and Microbiological Assessment of Fishmeal

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ABSTRACT

Objective: To evaluate the quality of fishmeal obtained from two fish species (trout and carp) through its physicochemical and microbiological characterization, and to verify its compliance with established regulatory standards and its potential use in animal feed.

Design/methodology/approach: The fish samples consisted of rainbow trout (*Oncorhynchus mykiss*) and carp (*Cyprinus carpio communis* L). The freshness of the raw material was determined, and it was processed to obtain a fishmeal-type product for subsequent physicochemical and microbiological assessment.

Results: The trout and carp used as raw materials for fishmeal production scored 96 and 93.2 respectively, classifying them as top-quality fresh fish. Physicochemical analysis indicated that the moisture and protein content for trout fishmeal was 4.53% and 60.3%, respectively, while for carp fishmeal the moisture and protein content was 6.4% and 53%, respectively. In addition, the microbiological analysis indicated that *Salmonella* spp. and coliforms were not found in either fishmeal sample, and only low counts of aerobic mesophiles, fungi, and yeasts were present.

Limitations on study/implications: According to the results obtained, the species of fish and processing conditions in the production of fishmeal influence the physicochemical and microbiological properties, which suggests consideration in future research.

Findings/conclusions: The fishmeal obtained from trout and carp complied with the regulatory framework in terms of microbiological and physicochemical profile, with potential use in animal feed.

Keywords: Fishmeal production, feed, carp, trout, microbiological quality.

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INTRODUCTION

Fish is a highly perishable food product due to various intrinsic factors (high water activity, nutrients, and a near-neutral pH); its shelf life is limited by factors such as enzymatic, chemical, and microbiological deterioration (de Paiva Soares & Gonçalves, 2012; García *et al.*, 2022). Fish consumption is considered important for human nutrition and health due to its contribution of nutrients such as lipids (omega-3 fatty acids), proteins (high biological

value and digestibility), vitamins, and minerals, with a weekly recommended consumption of three to four servings per week (de Paiva Soares & Gonçalves, 2012; Fuertes Vicente *et al.*, 2014; Restrepo-Betancurt *et al.*, 2016; Cortés-Sánchez *et al.*, 2024). According to FAO, the world production of fish through fishing and aquaculture activities in 2024 was 184.5 million tons, which 164.6 million tons were destined for direct human consumption, with a *per capita* consumption of 20.7 kg; meanwhile, the remaining 20.8 million tons of production were directed to non-food uses such as the production of fishmeal and oil (FAO, 2024). Among the species of importance in aquaculture activities are the common carp and the rainbow trout, which at the global level in continental aquaculture were reported for the year 2020 an estimated production of 4236.3 million tons and 739.5 million tons respectively (FAO, 2022). Fishing and aquaculture activities represent a globally important production chain, which often generates large quantities of fish that may consist of different species of small fish, unwanted catch products or by-products of the process (heads, skins, scales, skeletons and viscera), with significant economic, health and negative environmental impacts caused by rejects and accumulation (Hleap & Gutierrez, 2017; Jiménez *et al.*, 2022). The use of whole fish or by-products from different species can lead to the generation of products with high nutritional value, such as fishmeal (Hleap & Gutierrez, 2017; Chonta, 2022; FAO, 2022). It is estimated that in 2020, 27% of global fishmeal production came from the use of by-products and 73% from whole fish (FAO, 2022).

Fishmeal is produced worldwide using different technologies and is the main form of cleansing of non-edible fishing and residues of the fillet and preservation industries (Silva Ortiz, 2003).

Fishmeal is considered the product of whole fish or by-products from processing such as filleting, which may or may not include oil extraction, and treatment with antioxidants (Cabello *et al.*, 2013; Quijije-Mero *et al.*, 2019). The general production process initially involves chopping or grinding the fish, cooking it at 100 °C for 20 minutes, pressing and/or centrifuging the product to extract some of the oil, and finally drying it to a maximum moisture content of 10% (Crispín-Sánchez *et al.*, 2019; FAO, 2022). Fishmeal can be used for various purposes, such as plant nutrition, acting as an organic fertilizer due to its high nitrogen and ash content (Monares-Gallardo *et al.*, 2012), and as a basic ingredient in the production of feed for livestock and companion animals (ruminants, rabbits, fish, crustaceans, pigs, and poultry) due to its high nutritional value in protein and omega-3 fatty acids (Cabello *et al.*, 2013; Quijije-Mero *et al.*, 2019; Chonta, 2022; FAO, 2022). It benefits animal production by reducing costs due to faster growth, improving nutrition and fertility, and decreasing the risk of disease (Chonta, 2022). In Mexico, fishing and aquaculture are economically important. In 2023, a total live weight production of 2,150,294 tons was recorded, with the main species produced being sardines, tuna, shrimp, carp, trout, among others. 1,511,332 tons were primarily destined for direct human consumption, with a *per capita* consumption of 14.68 kg and an additional 634,752 tons were used indirectly, meaning the fish was used to obtain fishmeal for animal feed (CONAPESCA, 2023). Carp and trout are important species in Mexico's aquaculture and fisheries production. Both activities are sources of employment and contribute to social subsistence and economic development. In 2023, carp production reached a peak of 14,816 tons for both capture fisheries and aquaculture, with the state of Hidalgo being the main producer; while total trout production was 2,748 tons, with the state of Veracruz contributing the most nationally. (CONAPESCA, 2023).

Thus, various species of fish inhabit the coasts, inland waters and are produced in various aquaculture systems in Mexico. It is estimated that 60% of a fish's contents are used for food production, while the remaining 40%, consisting of fins, scales, skeleton, and head, is discarded. However, in various regions of Mexico, fishmeal and fish oil are obtained and used in livestock farming (Jiménez *et al.*, 2022).

Therefore, the objective of this research was to evaluate the quality of fishmeal obtained from two fish species (trout and carp) through its physicochemical and microbiological characterization, in order to verify its compliance with established regulatory standards and potential use in animal feed.

MATERIALS AND METHODS

Sample Collection

The samples consisted of three batches of rainbow trout (*Oncorhynchus mykiss*) weighing 813±34 g, from aquaculture centers in the Lerma region and surrounding areas in the State of Mexico, and three batches of common carp (*Cyprinus carpio communis* L.) weighing 1292.6±326 g, caught in Lake Chignahuapan, located in the municipality of Almoloya del Río, State of Mexico. The samples obtained were immediately transported under aseptic and refrigerated conditions to the laboratory for freshness analysis, processing into fishmeal under good hygiene practices, and subsequent physicochemical and microbiological assessment of the product.

Methodology

Samples of fresh whole carp and trout were evaluated for their sensory attributes to determine their quality grade according to Mexican standard (NMX-FF-002-SCFI-2011). This indicates that the product rating is based on a point deduction system starting from a base of 100. The final product rating is obtained by adding up all the applied deductions and subtracting the sum from the base score (Table 1). Subsequently, the fish were gutted, washed, and processed to obtain fishmeal according to Ayala-Pérez *et al.*, 2015, with modifications such as cooking at 90 °C for 20 minutes and drying at a controlled temperature of 90 °C in an oven (Memmert Model 30-1060) until reaching a final moisture content of less than 10%, followed by grinding (using a manual iron mill). The yield of fishmeal obtained was calculated using the following formula:

$$yield\,\% = \left(weight\ of\ fishmeal\ produced\ /\ weight\ of\ fresh\ fish\right) \times 100$$

The product obtained was subjected to the corresponding physicochemical analysis of pH (NOM-F-317-S-1978), moisture (NOM-116-SSA1-1994), proteins (NOM-F-68-S-1980), lipids (NMX-F-545-1992), ash (NMX-F-066-S-1978), carbohydrates (by difference), granulometry: 5% retained on #2 sieve with nominal opening of 2 mm (NMX-Y-013-1998-SCFI; COVENIN (1979) 1482-79), rancidity (Cabello *et al.*, 2013) microbiological assessment was carried out using traditional methods with nutrient, differential and/or selective culture media by pour plate count, enrichment and selective isolation corresponding to total aerobic mesophilic bacteria (NOM-092-SSA1-1994), total coliforms (NOM-113-SSA1-1994), fungi and yeasts (NOM-111-SSA1-1994) and *Salmonella* spp. (NOM-114-SSA1-1994) respectively. Physicochemical and microbiological studies were performed in triplicate on independent batches of fishmeal obtained.

Analysis of data

Data analysis was performed using a one-way analysis of variance (ANOVA), following normality tests (Kolmogorov-Smirnov, $\alpha=0.05$) and Bartlett's test for homoscedasticity ($\alpha=0.05$). Significant differences ($p<0.05$) were determined using Tukey's multiple comparisons test ($p<0.05$). Data expressed as percentages were subjected to arcsine square root transformation (Zar, 2010). All tests were performed using SigmaStat V3.1 statistical software (2004).

RESULTS AND DISCUSSION

Quality grade of raw materials intended for fishmeal production

For trout and carp used as raw materials in the production of fishmeal, the total freshness scores were 96±5.4 and 93.2±4.4, respectively, indicating, according to the Mexican standard (NMX-FF-002-SCFI-2011), that they are first-quality fresh fish (Table 1), the

Table 1. Sensory evaluation attributes to determine the quality grade of fish (NMX-FF-002-SCFI-2011).

Factor	Variation	Deduction
Smell of meat	Fermented grass (light), moisture.	0
	Fermented (penetrating), sweetish herb.	4
	Fecal-ammoniacal, rotten fruit (light).	8
	Ammoniacal rotten fruit (penetrating).	16
Meat Consistency	Resistance to digital and elastic pressure.	0
	The fingerprint pressure print disappears slowly, elastically.	2
	With little elasticity, fingerprints persist for extended periods.	8
	When the skin is flaccid, fingerprints do not disappear.	16
General appearance of the skin	Shiny, lifelike appearance, transparent mucus, attached scales.	0
	Loss of shine, slightly dark mucus, with detachment of some scales.	2
	Slight loss of color, sticky mucus, loss of scales.	4
	Dull, ashy, dull, milky or greenish mucus, without scales.	8
Eyes	Convex pupil, shiny black or slightly diminished.	0
	Flat pupil, slightly opaque cornea.	2
	Flat pupil and opaque cornea.	6
	Pupil totally reduced, cornea milky.	8
Gills	Bright pink, blood red or brick red color, well differentiated gill lamellae.	0
	Purple, blood red, brick red, some flakes stick together, smell of the sea.	2
	Purple, blood red, brick red, slightly discolored, loss of sea smell.	6
	Yellowish, dark brown, discolored, sour smell.	8

standard indicates that any product with less than 85 points is out of specification. Fish freshness is defined as the combination of multiple nutritional and sensory attributes that deteriorate rapidly in stages following capture or harvesting (processing, storage, transport, distribution, and marketing). The rate of spoilage is affected by factors such as fish type, capture conditions, temperature, water activity, pH, among others (Fuertes Vicente *et al.*, 2014; García *et al.*, 2022). Fish freshness is a key characteristic in the food industry and influences consumers' willingness to purchase the product. Sensory analysis is the oldest and most reliable method for assessing fish freshness and it is considered a tool that allows the evaluation of freshness-related attributes (color, odor, appearance, among others) (de Paiva Soares & Gonçalves, 2012; García *et al.*, 2022). Among the characteristics of sensory evaluation is its frequent use in the fishing industry, facilitating the assessment of batches of raw materials or finished products, as well as for sanitary evaluations (de Paiva Soares & Gonçalves, 2012; Prado-Toledo *et al.*, 2022). These tests are minimally invasive, easy to perform, do not involve the destruction of the sample, allow for the estimation of shelf life, are low-cost, and offer a comprehensive evaluation of fresh fish (de Paiva Soares & Gonçalves, 2012; García *et al.*, 2022).

It has been noted that the quality, yield, and nutritional value of fishmeal depend on factors such as the type of fish used, fish freshness, cooking temperature, drying, and storage conditions (Silva Ortiz, 2003; Ionita, 2022; FEDNA, 2025). Fish freshness can be affected by temperature and storage time conditions both after capture and before processing. From the moment of capture, fish are susceptible to autolytic and microbiological changes due to the activity of enzymes and microorganisms present on their surfaces and in their digestive system, leading to spoilage (Cruz *et al.*, 2000; Silva Ortiz, 2003). Therefore, spoiled fish can generate various undesirable compounds, including biogenic amines, which can affect the safety, nutritional value, digestibility, and sensory characteristics of a final product such as fishmeal (Cruz *et al.*, 2000; FEDNA, 2025).

Physicochemical assessment of fishmeal

In fishmeal production, the yield obtained from trout was 20±0.6% and 23±0.9% for carp. These values match with those reported by various studies on the yield of fishmeal production, estimated at around 20% (Tornes & George, 1970), 21% (Osorio, 2014), and 22% (Sandbol, 1993). The physicochemical analysis of the fishmeal obtained from trout and carp indicated a moisture content of 4.53% and 6.4%, respectively, which is lower than the maximum specification established by Mexican standard NMX-Y-013-1998-SCFI (animal feed-fish meal-specifications), Ecuadorian standard INEN 472. 1988-04 (fish meal-for animal consumption-Requirements) and Venezuelan standard COVENIN (1979) 1482-79 (Requirements for fishmeal), which specify a maximum of 10%. Fishmeal is primarily valued for its protein content. For the fishmeal obtained from trout and carp, the protein content was 60.3% and 53%, respectively, which was lower than the minimum content specified by Mexican standard NMX-Y-013-1998-SCFI of 62% (which will be used in this study as the main standard of comparative reference). However, according to Venezuelan standard COVENIN (1979) 1482-79, which specifies a protein content of 55 to 65% in fishmeal, only trout meal, with 60.3% protein, met this standard and was therefore classified as Class B. Similarly, according to Ecuadorian standard (INEN 472. 1988-04), which indicates a protein content of 60% in fishmeal, only trout meal also met this specification with 60.3% (Table 2). Likewise, the quality specifications for fishmeal according to the Animal Health Service of the Republic of Argentina indicate a classification based on protein content, with first quality being those with a minimum of 60% protein and second quality those with a minimum of 40% protein (Flores, 2012). Considering the above, the trout and carp meal obtained is considered to be of first and second quality, respectively, according to the Animal Health Service of the Argentine Republic. It should be noted that standards applied to fishmeal are diverse and may not always have homology in quality specifications. This would require harmonization by the different regulatory entities for this type of product in terms of quality criteria, methods of analysis, units used, certification systems, among others.

The lipid content in trout and carp meal was 12.4% and 21%, respectively, exceeding the maximum specifications of the standards (NMX-Y-013-1998-SCFI), (INEN 472. 1988-04), and COVENIN (1979) 1482-79 (Table 1). Likewise, the lipid values obtained in the trout and carp meals are higher than the quality specifications for fishmeal according to the lipid content guidelines of the Animal Health Service of the Republic of Argentina, which indicate a maximum of 8% for first-quality meals and a maximum of 10% for second-quality meals (Flores, 2012). The differences in lipid content of the meals may be due to the production process and the type of raw material used. It has been established that fat and moisture content influence the shelf life of these products and if these are not controlled, spoilage due to rancidity and/or microbial growth can occur (Cabello *et al.*, 2013). Furthermore, the importance of fish lipids lies in their high nutritional value due to their omega-3 fatty acid content (eicosapentaenoic acid (EPA), docosapentaenoic acid, and docosahexaenoic acid (DHA), in addition to their prophylactic and therapeutic properties under certain nutritional conditions and diseases. Species such as trout have been reported to contain 4.5 g of EPA and 8.6 g of DHA per 100 g of lipids, respectively (Valenzuela *et al.*, 2012).

Table 2. Physicochemical assessment of fishmeal trout (*Oncorhynchus mykiss*) and carp (*Cyprinus carpio*).

Parameter	Trout	Carp	Mexican Standard (NMX-Y-013-1998-SCFI)	Ecuadorian Standard (INEN 472. 1988-04)	Venezuelan Standard COVENIN (1979) 1482-79
pH	6.6±0.01a	6.61±0.02a	NS	NS	≥5
Moisture (%)	4.53±0.05b	6.4±0.4a	10%	10%	10%
Protein (%)	60.3±0.6a	53±3.8b	62%	60%	55-65%
Lipids (%)	12.4±0.12b	21±0.76a	12%	10%	10-13%
Ash (%)	8.4±0.08b	13.8±0.36a	16%	16%	18-20%
% Carbohydrates (%)	14.2±1.8a	5.8±0.7b	NS	NS	NS
Rancidity meq O_2/kg	3±0.2b	4.5±0.71a	NS	20	13
Granulometry	0.69 ± 0.02 %a	0.46 ± 0.02 %b	5% retention in 2 mm opening mesh	2% retention in 2 mm opening mesh	0% retention in 2 mm opening mesh

NS=Not Specified. The standard does not present a specific criterion.
Mean ± standard deviation. n=3. Different letters per column indicate statistical differences ($p<0.05$).

Trout and carp meal had an ash content of 8.4% and 13.8%, respectively, which is lower than the maximum specification of 16% set by the NMX-Y-013-1998-SCFI and INEN 472.1988-04 standards, as well as the COVENIN (1979) 1482-79 standard, which specifies a content of 18% to 20% (Table 2). A high ash content in fishmeal can indicate a high proportion of bones in the raw material, which affects the digestibility and quality of the meal (Cabello *et al.*, 2013). Furthermore, the ash content of fishmeal is relevant in plant nutrition, where its alternative use as an organic fertilizer and complement to inorganic fertilizers has been noted due to its nitrogen and ash content (Monares-Gallardo *et al.*, 2012). On the other hand, the presence of carbohydrates in fishmeal is due to their presence mainly in the fish muscle where they are found as glycogen and constituents of nucleotides, which are a source of ribose released due to post-mortem autolytic changes (Huss, 1999).

The pH of the trout and carp meals obtained was around 6.6 (Table 1), complying with COVENIN (1979) 1482-79 and INEN 472 (1988-04) standards. It has been noted that the pH value should not be less than 5, as it is an indicator of the degree of chemical and physical reactions occurring in the meals (Cuéllar, 2021). Storage conditions can affect fishmeal quality, triggering chemical reactions and physical changes that can contribute to product degradation and cause a decrease in pH (Cabello *et al.*, 2013). The rancidity level in trout meal was 3 meq O_2/kg and in carp meal 4.5 meq O_2/kg. These values were lower than the peroxide value specifications of 20 and 13 meq O_2/kg established by INEN 472.1988-04 and COVENIN (1979) 1482-79, respectively (Table 1). High peroxide values can occur due to packaging defects in the fishmeal, which allow oxygen or light to penetrate. Inadequate storage conditions for the raw material also contribute to lipid deterioration (Cabello *et al.*, 2013). It has also been noted that the fishmeal production and drying process influences the oxidation of lipids present (Ackman, 1996). Regarding animal feed, the quality of fishmeal and fish oil indicates that the peroxide value recommended for feeding fish such as Salmonids should be <5 meq O_2/kg (Tacon, 1989).

The particle size analysis of the trout and carp meals obtained indicated a retention percentage lower than that specified by the NMX-Y-013-1998-SCFI and INEN 472.1988-04 standards (5% and 2%, respectively), but higher than that indicated by the COVENIN (1979) 1482-79 standard, which specifies 0% retention on a 2 mm opening mesh/sieve (Table 1). It has been mentioned that particle size is a basic parameter for the food industry in the analysis of physical properties of fishmeal, especially in food standardization and formulation processes, as well as in identifying raw material requirements (Campabadal & Celis, 1996; Dussán-Sarria *et al.*, 2019). In animal husbandry, the composition and physical properties of feed, such as uniformity and particle size, have a significant influence on digestive physiology, feed conversion, and productivity (Farfán-López *et al.*, 2015), as well as in pelleting and extrusion processes for the feed production intended for livestock (Campabadal & Celis, 1996).

Related research has indicated that fishmeal generally has a chemical composition of 60 to 72% protein, 5 to 12% fat, and 10 to 20% ash (Chonta, 2022). Cabello *et al.* (2013) reported, in a proximate analysis of fishmeal, a protein content of 60 to 52%, ash of 24 to 26%, lipids of 4 to 11.7%, and moisture of 4.8 to 6.7%. Quijije-Mero *et al.* (2019) indicates that fishmeal, on average, contains 60% to 72% protein, 5% to 12% fat, and a maximum moisture content of 9%. Finally, Rojas (2005) indicates that fishmeal, on average, contains a minimum of 65% protein, a maximum of 12% fat, 10% moisture, and 15% ash. On the other hand, Sancho-Hernandez and Herrera-Ramirez (1996) obtained fishmeal presenting the product with 8.9% moisture and 69.9% protein, noting that a positive aspect in the use of fish protein in animal feed is the protein content, which should be a minimum of 50%.

It is important to note that the chemical composition of fish can be influenced by various factors such as species, season, migratory behavior, sexual maturation, feeding cycles, diet, environment, size, and genetic traits, among others (Huss, 1999). Therefore, fish as a raw material for obtaining products such as fishmeal, along with processing parameters, can affect its composition and quality (Graü de Marín *et al.*, 2011; Cabello *et al.*, 2013; Quijije-Mero *et al.*, 2019).

Considering the above, it should be noted that the two different species used in this study, their origins (wild-caught carp and farmed trout), and the processing method for obtaining fishmeal, which did not involve pressing or centrifuging, are just some of the factors that may have influenced the physicochemical parameters found, such as the high lipid content in both fishmeal samples, which exceeds the levels stipulated by regulatory standards for these products. This excess of lipids, beyond the nutritional and energy value it provides, can also promote rancidity, reducing the quality and shelf life of the fishmeal for use in animal feed.

Within the fishmeal industry, quality criteria are based on chemical composition, including protein, lipids, moisture, ash, and salt. One of the main parameters is protein content, which is better the higher its value, especially when high-nutrient diets are required (Sandbol, 1993). Fishmeal production can be carried out using different raw materials, which influences the composition of the final product. It has been observed that some fishmeal made from fish by-products tend to have a lower protein content and a higher ash content compared to fishmeal obtained from whole fish (Sandbol, 1993; FAO, 2022). It has been pointed out, for example, that oily fish has a higher protein content than white fish (Ionita, 2022). Most of the fishmeal produced is used in animal feed, and its quality is primarily determined by its protein and lipid content, moisture, and the absence of pathogenic microorganisms, among other factors (Silva Ortiz, 2003). The main constituent protein in fishmeal, which is easily digestible, has a good proportion of essential amino acids such as methionine, cysteine, lysine, threonine and tryptophan with high digestibility value, in addition to having low antigenicity, making it convenient for the formulation of feeds (Graü de Marín *et al.*, 2011; Chonta, 2022; FEDNA, 2025).

Fishmeal microbiological assessment

Table 3 presents the results of the fishmeal microbiological analysis. The absence of Salmonella and total coliforms in both fishmeal is noteworthy, as is the low proportion of total aerobic mesophiles, fungi and yeasts with 135 CFU/g, and <10 CFU/g in trout meal and <10 CFU/g, and <10 CFU/g in carp meal respectively. Therefore, the fishmeal (trout and carp) meets the microbiological parameters of Mexican and international

Table 3. Microbiological assessment of fishmeal trout (*Oncorhynchus mykiss*) and carp (*Cyprinus carpio*).

Analysis	Trout	Carp	Ecuatorian standard (INEN 472. 1988-04)	Venezuelan Standard COVENIN (1979) 1482-79	Mexican Standard NMX-Y-013-1998-SCFI
Aerobic mesophiles	135±6.3 CFU/g	<10 CFU/g	10^6 CFU/g	NS	NS
Total coliforms	Absence *	Absence *	10^4 CFU/g	NS	Absence
Salmonella spp.	Absence in 25g	Absence in 25g	Absence in 25 g	Absence in 25 g	Absence in 25g
Fungi and yeasts	<10 CFU/g	<10 CFU/g	10^4 CFU/g	Absence	NS

NS: The standard does not present a specific criterion. CFU: colony-forming units. *No growth at 10^{-1} dilution.

standards. In fishmeal, microbiological quality is evaluated by counting or detecting the presence of various pathogens such as *Salmonella*, *Shigella*, *Vibrio cholerae*, coliforms like *Escherichia coli*, and fungal organisms (Silva Ortiz, 2003; Crispín-Sánchez *et al.*, 2019; Ubaqui, 2021). Given that the fishmeal production process involves cooking and drying, which inactivate microorganisms and spoilage enzymes and even when the raw material is in a highly deteriorated state, it is considered that microbiological contamination should not be present in the final product (Silva Ortiz, 2003; Chonta, 2022). However, in stages subsequent to drying, contamination can occur due to product handling by the operator, inadequate or nonexistent cleaning and disinfection procedures, as well as poor hygiene conditions during fishmeal storage (Silva Ortiz, 2003; Chonta, 2022). In this study, the processing of fish to obtain fishmeal, including handling, packaging (at room temperature), and subsequent storage, was carried out following good hygiene practices. Likewise, the microbiological analysis was performed under aseptic conditions for handlers, materials, equipment, and the work area. This contributed to the low microbial load present in the trout and carp fishmeal.

It should be noted that stages involving heat treatment in the fishmeal production process allow for the control of microbial contamination of these products, but the quality of their constituents can be affected when prolonged temperatures and times are involved. Therefore, alternatives for the microbiological control of fishmeal, such as the use of organic acids, have been proposed (Crispín-Sánchez *et al.*, 2019).

Among the zoonotic pathogens to be evaluated in fishmeal, *Salmonella* spp. is the most prominent in sanitary control due to its economic impact on human and animal health (Silva Ortiz *et al.*, 2003). *Salmonella* belongs to the Enterobacteriaceae family, inhabits the intestinal tract of humans and animals, and consists of Gram-negative, motile bacteria. It grows at pH 4-9 and temperatures of 8-45 °C, is heat-sensitive, and dies at temperatures of 70 °C or higher; it is resistant to drying and can survive for years in dust and dirt (Crispín-Sánchez *et al.*, 2019). Furthermore, this pathogen has been identified as one of the main agents responsible for cases of foodborne illness worldwide (Alerte *et al.*, 2012; Espinosa *et al.*, 2014; Soto *et al.*, 2016).

The main use of fishmeal is in the development of balanced feeds for aquaculture and livestock activities, making the control of this pathogen in feed particularly important, as its purpose is to protect the human food chain from contamination by infected animals (Crispín-Sánchez *et al.*, 2019). In fishmeal, fungal contamination can lead to the presence of fungi and mycotoxins responsible for serious human and animal health problems from the consumption of contaminated food and feed. Fishmeal with a moisture content above 10%, subjected to inadequate drying or improper storage, becomes a substrate for the growth of various fungal species such as *Aspergillus*, *Penicillium*, *Fusarium*, and *Mucor*, some of which produce mycotoxins (Graü de Marín *et al.*, 2011). Coliform bacteria are found throughout nature, including in humans and animals; coliform bacteria are Gram-negative, aerobic or facultative anaerobic bacilli that ferment lactose (Campuzano *et al.*, 2015). In food, they are considered indicators of quality and hygiene, reflecting inadequate hygiene practices in food handling, manufacturing, and preservation (NOM-113-SSA1-1994; Campuzano *et al.*, 2015). This microbial group assesses the microbiological quality of a product, the efficiency of sanitary and hygienic practices for equipment, and the sanitary quality of the water used in food processing (NOM-113-SSA1-1994).

Aerobic mesophilic bacteria are a group of microorganisms capable of growing at around 35 °C. Their count estimates the total bacterial population, reflecting the sanitary quality of a food product and the handling and hygiene conditions of the raw materials (ANMAT, 2014; Campuzano *et al.*, 2015). High counts may indicate high contamination of the raw materials, poor hygienic handling during processing, the possible presence of pathogens, and a short shelf life for the product (ANMAT, 2014). In studies related to the microbiological analysis of fishmeal, Sancho-Hernandez & Herrera-Ramirez (1996) reported that fishmeal made from bycatch of shrimp catches showed a total bacterial count of 1.4×10^5 CFU/g and a fungal and yeast count of 3×10^2 CFU/g, indicating hygienic handling in the fishmeal production process. Therefore, it was considered suitable for use in formulating chicken diets.

Meanwhile, Lúquez-Pérez & Hleap-Zapata (2020) in their microbiological analysis of fishmeal obtained from viscera for use in broiler chicken feed, reported that the fishmeal had microbiological values adjusted to what is allowed in the Colombian Technical Standard (NTC 685/2004) including the absence of *Salmonella*, mesophilic count $\leq10\times10^4$ CFU/g, coliforms $\leq10\times10^2$ CFU/g, fungi and yeasts $\leq10\times10^2$ CFU/g, concluding that the fishmeal obtained is an alternative for animal feed.

The fishmeal obtained from trout and carp, evaluated for its physicochemical profile, presented a moisture content of less than 10%, as stipulated by the regulatory framework (NMX-Y-013-1998-SCFI, INEN 472.1988-04 and COVENIN (1979) 1482-79) focused on physicochemical specifications for fishmeal used in animal feed. However, regarding protein content, one of the main parameters considered in the quality of fishmeal, the carp meal did not meet the established requirements for protein content; while the trout meal only failed to meet the specification of the NMX-Y-013-1998-SCFI standard, as its protein values were below the stipulated level.

The trout and carp fishmeal obtained and microbiologically evaluated met the microbiological specifications (*Salmonella*, aerobic mesophilic bacteria, and total coliforms) of the regulatory framework (NMX-Y-013-1998-SCFI, INEN 472.1988-04, and COVENIN (1979) 1482-79) focused on microbiological specifications for fishmeal used in animal feed.

The lipid content of the carp meal obtained was above the limits established by the regulatory framework NMX-Y-013-1998-SCFI, INEN 472.1988-04, and COVENIN (1979) 1482-79. While the trout meal presented levels within the established COVENIN (1979) 1482-79 standard, it exceeded the specifications of the NMX-Y-013-1998-SCFI and INEN 472.1988-04 standards.

The carp and trout fishmeal obtained showed values for ash content, rancidity index, and particle size (granulometry) in accordance with the established regulatory framework (NMX-Y-013-1998-SCFI, INEN 472.1988-04, and COVENIN (1979) 1482-79), which focuses on physicochemical and microbiological specifications for fishmeal used in animal feed.

The carp and trout used as raw materials for fishmeal production were classified as first-class or fresh according to the specifications of standard NMX-FF-002-SCFI-2011, and rancidity index values were obtained below those stipulated in the regulatory framework (INEN 472.1988-04 and COVENIN (1979) 1482-79). The freshness and quality of the raw material are important for obtaining high-quality fishmeal, since fish, due to its lipid content and greater spoilage when used for fishmeal production, may exhibit higher rancidity levels, affecting stability and shelf life.

The protein, lipid, ash, and peroxide value content of trout and carp fishmeal, and their differences, can be associated with several factors, including the species or origin of the fish, as well as the fishmeal production process. The results obtained allow us to understand the physicochemical profile and microbiological quality of value-added products derived from the use of two aquatic resources widely produced and marketed in Mexico, primarily for human consumption.

CONCLUSIONS

Fishmeal is of primary interest in animal feed. The fishmeal obtained in this study meets the microbiological specifications of the regulatory framework established for fishmeal intended for animal feed. However, the same cannot be said for compliance with physicochemical specifications regarding lipid and protein content for carp fishmeal. Thus, trout meal can be considered potentially useful in animal feed formulations, while carp meal, only partially meeting the physicochemical specifications, should be considered with caution for this purpose.

The study presents several limitations, including the species, origin, and versatility of processing conditions in obtaining fishmeal, which may be associated with the final physicochemical and microbiological characteristics of the product. Therefore, further studies are needed to obtain more information on the conditions for obtaining and optimizing fishmeal from these two species and the effect on its physicochemical and microbiological properties in order to meet specifications for use in animal feed.

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