Colegio de Postgraduados

Physicochemical characterization of exoskeleton-based shrimp waste meal obtained by dehydration processes

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ABSTRACT

Objective: To characterize the physicochemical and nutritional compounds of meal made from shrimp (*Farfantepenaeus aztecus* L.) exoskeleton, obtained through hot air dehydration processes, in order to value new products and applications, according to their nutritional components.

Design/Methodology/Approach: Shrimp producers from Alvarado, Veracruz, were interviewed using a quantitative approach with a descriptive scope. Likewise, shrimp (*Farfantepenaeus aztecus* L.) shells were dehydrated and powdered to transform them into meal. The proximate chemical composition was analyzed to determine its nutritional composition and its macro and micronutrients, as well as to identify the deficiencies or excesses of certain nutrients. The general public and local ranchers were surveyed and interviewed to establish the opinions, preferences, and behaviors of consumers regarding meal by-products, in order to evaluate their market acceptance.

Results: In Alvarado, Veracruz, 2.5 tons of shrimp shell are wasted. The meal obtained from these shells has a high protein (45.40%) and mineral content, which includes Ca (11.17%), Na (6.86%), Fe (237 mg/Kg^{-1}), and Zn (77 mg/Kg^{-1}). Therefore, this nutrient content guarantees the quality of the protein input that is acquired and the food that is provided.

Study Limitations/Implications: Access to outdated statistical information, resulting from the COVID-19 pandemic, hindered the collection of relevant data. Likewise, the lack of interest of the producers in monitoring the project and the limited participation and knowledge of the workers represented a significant challenge to the progress of the study.

Findings/Conclusions: The meal under study contained nutritional elements, making it a product with high nutritional quality that could add value to shrimp waste and that has potential applications in the food industry, in the production of fertilizers, and in the formulation of balanced feed for animals. Consequently, it would contribute to the reduction of pollution in the Alvarado lagoon system.

Keywords: Shrimp, aquaculture residue, hot air drying, nutritional value.

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INTRODUCTION

The United Nations Food and Agriculture Organization (FAO) considers Mexico as the second-best shrimp fishing and aquaculture producer in Latin America (CONAPESCA, 2024). According to the Comisión Nacional de Acuacultura y Pesca (CONAPESCA,

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2024), the preliminary national statistical information for 2023 (obtained from the harvest notifications of the shrimp aquaculture sector) indicates that a >192,600 t production was achieved, resulting in an economic value of >$19,800 million Mexican pesos.

Shrimp holds the third place in fishing production in Mexico in terms of volume; however, its value puts it in first place, with a mean annual growth rate of 4.56% during the last 10 years. Likewise, Mexico is ranked fourth in terms of fishing species, behind the United States of America, China, and Japan (CONAPESCA, 2021).

Freshwater shrimp production reached more than 30,200 tons, equivalent to more than $2.2 billion Mexican pesos. Preliminary official statistics indicate that Sinaloa recorded more than 8,400 t of deep-sea shrimp and more than 14,300 t of shrimp caught by small boats (CONAPESCA, 2024). Regarding the use large and small boats, other states with great producing potential include: Campeche, >1,040 t and >800 t; Veracruz, >400 t and 700 t; Oaxaca, >370 t and 400 t; Nayarit, >48 and >1,900 t; and Chiapas, with >212 t and 500 t (CONAPESCA, 2024).

Sequential shrimping in the state of Veracruz takes advantage of the biological cycle of the shrimp (4-6 months). This system allows fishers to catch both juveniles in coastal lagoons (artisanal fishing) and adults in the deep-sea (industrial fishing) (IMIPAS, 2018). In particular, freshwater fishermen carry out estuary shrimping in the main lagoons of Veracruz (*e.g.*, Sistema Lagunar de Alvarado, Pueblo Viejo, La Costa, Tamiahua, and Chila) and deep-sea shrimping in the northern and southern areas of the Veracruz coast, where the predominant species is the brown shrimp (*Farfantepenaeus aztecus* L.) (IMIPAS, 2018).

Fishing and aquaculture significantly contribute to the volume of agri-food waste generated by society; therefore, communities must participate in the change towards a circular economy (Veronesi-Burch, Rigaud, Binet, and Barthélemy, 2019; CONAHCYT, 2020). Although shrimp is a widely consumed crustacean, not all its parts are edible and the head, tail, and exoskeleton (body shell) —which account for 45-60% of its total weight— are usually discarded (Pattanaik, 2020). Based on consumer demand, inadequate waste management in the shrimp industry is a problem that affects not only the Alvarado region, but also many other coastal regions around the world (FAO 2022).

Shrimp waste contains large amounts of proteins, lipids, chitin, and carotenoids, such as astaxanthin (Pattanaik, 2020). Shrimp shell meal is a by-product of this waste, which, as it is a rich source of protein and minerals, can be used as an ingredient in animal feed and, due to its content of nitrogen and other nutrients that are beneficial for plants, can be used as an organic fertilizer (Universidad Autónoma del Estado de México, 2018). Processing meal from dehydrated shrimp shells is an interesting initiative that seeks to take advantage of a resource that would otherwise be wasted. Shrimp waste (shell) is transformed into high value-added products, such as chitin, chitosan, amino, sugars, proteins, and pigments, which are used in the cosmetic, food, agricultural, and pharmaceutical industries (Salas-Ovilla, Gálvez-López, and Rosas-Quijano, 2017).

Shrimp is a source of waste for the Alvarado area, due to the high concentration fishmongers dedicated to the retail sale and national trade of shrimp pulp. Hundreds of kilos of shrimp are cooked daily and the exoskeleton is discarded; therefore, the objective of this study was to characterize the chemical and nutritional compounds of shrimp shell meal, valuing new products and applications, according to their nutritional components.

MATERIALS AND METHODS

This research used a quantitative approach with a descriptive scope. Documentary and field information sources were used to determine the amount of waste generated and the final destination of the shrimp shell, through direct interviews with the 12 shrimp producers in the Alvarado area. The waste was transformed into shrimp shell meal and its proximate chemical composition and micronutrients were analyzed. Structured surveys were applied to a sample of 600 people and 5 local ranchers were interviewed to describe and explore the opinions, preferences, and behaviors of consumers in relation to shrimp meal and its various uses. A detailed understanding was achieved, from beginning to end, of the acceptance of the product in the market. The research team proposes that this organic product that can be used as fertilizer, seasoning, or the basis for a balanced diet for livestock, therefore reusing a resource that was considered waste.

Figure 1 shows the amount of shrimp processed weekly. The results were obtained from the interviews carried out with the producers. The smallest producer processes less than 500 kg (Pesqueros de La Trocha) and the largest national distributor and seller in the entire area handles 3,000 kg of processed shrimp (Productos Majo).

The production of shrimp pulp in the municipality of Alvarado is concentrated in 12 establishments that, in average, process approximately 9,640 kg per week, which means that around 2,410 kg of shrimp exoskeletons could be used to produce meal. These quantities were recorded during the mid-season (May-June) and increase by up to 20% in the high season (November-December and March-April). However, the said supply will depend on various factors, such as availability, increased demand, and market prices.

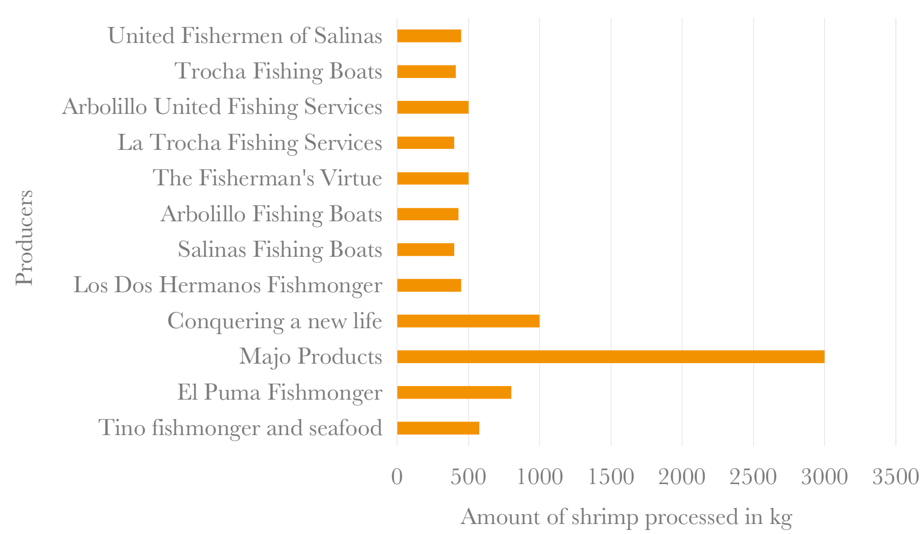

Figure 1. Kilograms of processed shrimp (cooked and peeled) per producer.

Figure 2 shows the amount of shrimp shells that each producer discards per week. The wasted volume ranges from 100 kg to more than 700 kg, which constitutes a source of contamination.

According to the data collected through the survey, 100% of shrimp producers throw all their shrimp waste into the Alvarado lagoon. They process over 9,640 kg every week, 25% of which is made of exoskeletons. Only the exoskeleton was considered for this study, because local fishmongers usually receive headless shrimps. In conclusion, more than 2.5 tons of exoskeleton are discarded into the lagoon system each week (Figure 3).

Production of shrimp shell meal

For this research, 6,500 kg of shrimp exoskeleton were collected from the same producers that had been interviewed. In order to determine the capacity of the production process and the result of the final product, the Majo fishmonger, located on Francisco I. Madero,

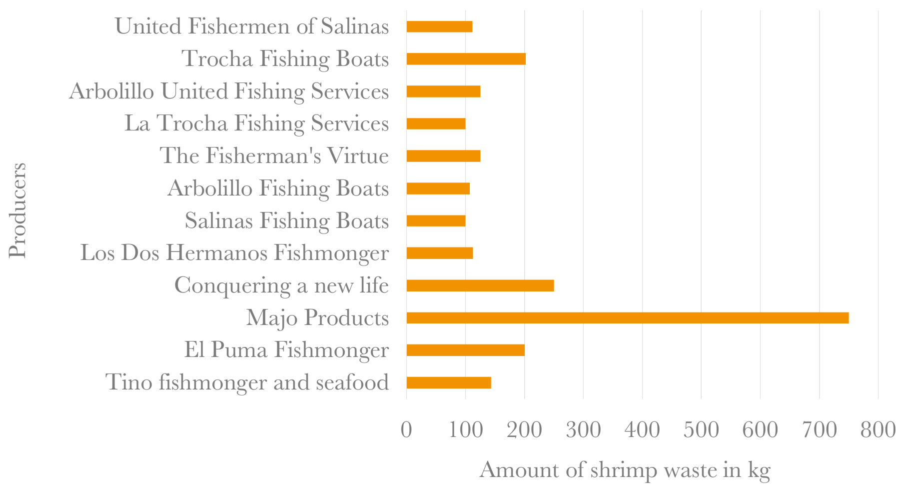

Figure 2. Kilograms of shrimp exoskeleton that producers discard per week.

Figure 3. Shrimp exoskeletons.

Colonia Centro, Alvarado, Veracruz was chosen as the supplier of the raw materials for this study. The shrimp shells were directly collected from the waste containers of the shrimp marketing companies, inspected to eliminate any residues or impurities, cooked at 90 °C for 10 minutes, and processed in a MIGSA FD-1 hot air electric dehydrator, at 65 °C for 5 hours, following a similar procedure to that described by Moncada-Guamán (2011). The abovementioned parameters were analyzed with a 2k factorial design, studying four factors with two levels, resulting in a total of 16 tests with three replications. The shells were subsequently pulverized in a Yf3-1 grain mill and sieved with a YC200 stainless steel electric vibrating sieve. Figure 4 shows the flow diagram of the production process used to obtain meal.

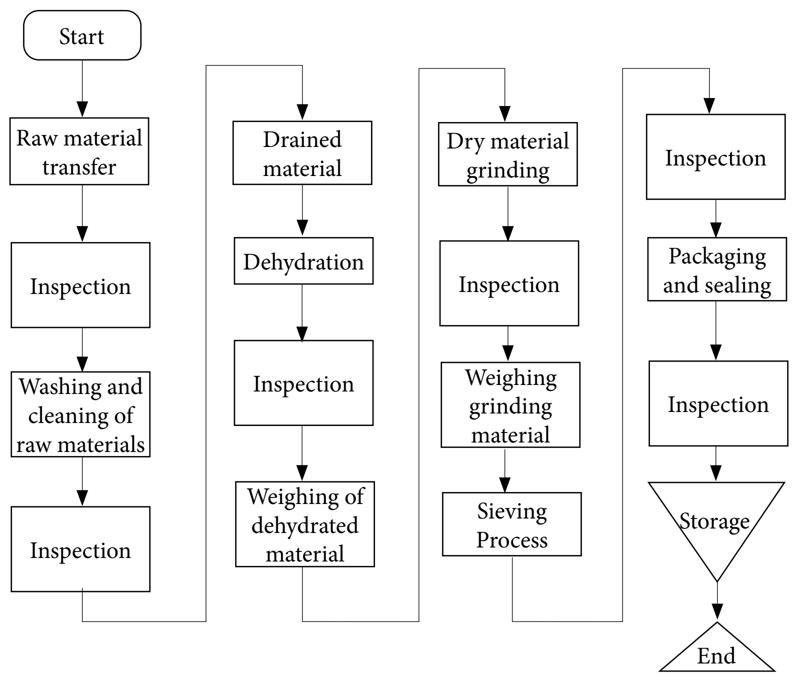

Figure 4. Operation Flow Diagram.

Figure 5. Shrimp shell meal.

Proximate chemical analysis

A proximate chemical analysis of the shrimp shell meal was carried out according to the methods developed by AOAC: AOAC 925.10 (moisture), AOAC 923.03 (ash), AOAC 920.39 (ether extract), AOAC 920.87 (proteins), and AOAC 878.10 (fiber). The purpose of this procedure was to obtain relevant information about the nutritional composition of meal, as well as its potential applications in the production of fertilizers, balanced animal feed, or in the food industry. This analysis can also help to identify possible contaminants or impurities in shrimp shell meal (AOAC, 2019).

Analysis of micronutrients in shrimp shell meal

Macro and micronutrients were analyzed to obtain the concentrations of potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), sulfur (S), boron (B), and phosphorus (P), through wet digestion with HNO_3-$HClO_4$ (Sauceda, 2013) and quantification by a plasma optical emission spectroscopy (ICP-OES) in a Perkin Elmer spectrophotometer. Micronutrient analysis can help to identify deficiencies or excesses of certain nutrients. This procedure can help to adjust the formulation of balanced feeds or to improve the nutritional quality of foods made with meal.

RESULTS AND DISCUSSION

Proximate chemical and micronutrient analysis

Table 1 shows the results of the proximate chemical analysis of shrimp meal used to determine the quality of the raw material. A 45.40% protein content was observed. Due to its cost, it is the most important nutrient in the diet in a commercial operation. An appropriate evaluation allows producers to control the quality of both the protein inputs that are acquired and the feed that is supplied. Additionally, this content could be compared with the protein values reported by Khan *et al.* (2013) and Liu *et al.* (2023), in similar material from the thoracic and abdominal exoskeleton of the shrimp, with 47.48% and 48.65% protein values, respectively.

Data represent the mean of three independent dimensions ±SD. However, according to Liu *et al.* (2021), the maximum value for the thorax and tail exoskeleton was 11.30%, and 8.81%, respectively, in heads for the species *Macrobrachium rosenbergii*. These results are similar to the findings of Wu *et al.* (2021), who recorded protein values of 10.32% for the species *Penaeus vannamei* in heads. The brown shrimp (*Farfantepenaeus aztecus* L.) raw

Table 1. Proximate chemical analysis of shrimp meal (g/100g).

	g/100g
Humidity	6.1±0.09
Protein	45.40±0.97
Fat	10.74±0.48
Ashes	5.93±0.26
Carbohydrates + fiber	31.83

material used in this research would provide better nutritional capacities, if it were included in a food formulation, because the crude protein of the by-products consists of 70% to 80% of myogenic fibronectin and 20% to 30% of sarcoplasmic protein, which increases the nutritional value of seafood protein (Halim, Yusof, and Sarbon, 2016).

Additionally, the ether extract or amount of fat was determined; the resulting percentage (10.74%) is consistent with the feeding regimes (Yi *et al.*, 2015), since the shrimp from which the exoskeleton was extracted was grown in farms. Nevertheless, this value may be subject to seasonal variations or physiological differences (Gordon and Roberts, 1977; Kinsella, 1988), as well as other physicochemical factors —*i.e.*, salinity, water temperature, and food availability (Cahú *et al.*, 2012). Likewise, this raw material had 6.1% moisture, which suggests that this meal can have a long shelf-life, depending on the type of container used for storage. Regarding the mineral content (ash), a 5.93% result was obtained, a similar percentage to that obtained by Liu *et al.* (2023) for different species, reflecting, to a certain extent, the content of inorganic compounds in biological samples, proof that the high mineral content of shrimp exoskeleton.

In another sense, the 31.83%carbohydrate content makes it the second largest compound of the meal, only after proteins. Crude shrimp fiber consists mainly of chitin, a high-molecular-weight linear polymer of N-acetyl-D-glucosamine (N acetyl-2-amino-2-deoxy-D-glucopyranose) units linked by β-D bonds (1→4), which exist mainly in the shell of shrimp and are the second most abundant natural polymer on Earth after cellulose (Younes *et al.*, 2014). However, chitin —a white, hard, inelastic substance, and a nitrogenous polysaccharide— is the main source of surface pollution in coastal areas (Gupta and Ravi Kumar, 2000). As a highly nitrogenous compound, it is mainly used as a chelate, although, as a natural polymer, it has excellent properties, such as biocompatibility, biodegradability, non-toxicity, adsorption, etc. (Muzzarelli, 1973).

Therefore, this meal can be used as raw material to obtain chitin and its derivative chitosan. This biomaterial has been used to manufacture coating films that have been successfully used to preserve seafood, extending its shelf-life and improving its quality, as a consequence of its antimicrobial and antioxidant effects (Chang, Wu, and Tsai 2018; Kontominas *et al.*, 2021). This phenomemon would represent an economic advantage by adding value to a product that, under normal conditions, would be discarded.

MINERAL ANALYSIS

Table 2 shows the results of the macro and micronutrient analysis of shrimp shell meal. The shrimp exoskeleton was found to be rich in Ca, Na, Fe, and Zn. As expected, they had a considerable concentration of P (≈3.26%), because this element is one of the main

Table 2. Analysis of the macro and micronutrients of meal made from the exoskeleton of shrimps camarón (*Farfantepenaeus aztecus* L.).

N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	B
%						mg Kg^{-1}				
6.86	3.26	0.06	11.17	0.71	0.70	13	237	17	77	9

ingredients of the structures of crustaceans. Likewise, combined with ca, P plays a major role in the formation and strengthening of the tissues of crustaceans and shellfish.

These results were contrasted with findings of Balogun and Akegbejo-Samsons (1992), who determined that *Parapenaeopsis atlántica* had a Ca>Na>P relationship, just like *Farfantepenaeus aztecus* L did in this study. In their turn, Brito *et al.* (2020) reported that Ca is the main macroelement present in shrimp meal made from heads and thorax exoskeleton.

The most abundant microelement in shrimp (*Farfantepenaeus aztecus* L.) meal was Fe (237 mg/Kg), followed by Zn and Mn with 77 mg/kg and 17 mg/kg, respectively. These results are similar to those reported by Brito *et al.* (2020) and Lee *et al.* (2017).

In general, the data about the main composition and minerals found in shrimp meal show a nutritious food biomaterial that, through a bioconversion process, can be used as the base for other materials (*e.g.*, chitin and chitosan), adding value to the shrimp waste from of the Alvarado lagoon system, in Veracruz.

CONCLUSIONS

This study highlights the importance of exploiting the shrimp exoskeleton waste and of establishing a process to obtain this product, potentially contributing to a significant degree to the reduction of pollution in the Alvarado lagoon system and to the sustainable use of marine resources. The study also points out the need to fully explore the potential applications of this meal and its acceptance in the market, potentially providing an economic benefit to local producers and benefiting the environment.

From an environmental point of view, the composition of the shrimp exoskeleton is a contamination risk. Shrimp (*Farfantepenaeus aztecus* L.) meal from the Alvarado lagoon system proved to be a product of high nutritional quality, due to its quantity of nutritional elements, as well as to its amount of high-quality and low-cost protein. In addition, the reduction of humidity prevents microbial growth and a homogeneous particle size facilitates the logistics of its handling. Some by-products had a clear potential: their nutritional contribution could be used in the food area. Shrimp meal hasa high-quality protein that could be exploited in the health care and nutrition sector or as fertilizer or feed for livestock. This added value could be an economic benefit for local producers, as well as beneficial for the environment.

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