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Influence of pre-treatment and drying process of the shrimp (*Litopenaeus vannamei*) exoskeleton for balanced feed production

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ABSTRACT

Shrimp industry wastes can be transformed and used as raw material for the development of new products. The aim of this research was to evaluate the influence of pre-treatment and drying process of the shrimp (*Litopenaeus vannamei*) exoskeleton for balanced feed production. The balanced feed was made with shrimp flour (25.74%), cotton seed cake (24.56%), rice bran (22.06%), beef tallow (16.18%), sweet potato flour (5.81%), and cassava flour (5.66%). To obtain the flour, shrimp processing waste (heads and exoskeletons) were blanched, dried, ground and sieved. Blanching was carried out using a full factorial 2^2 experimental design, where temperature and time were evaluated as independent variables. The drying kinetics of the blanched exoskeletons were performed in a tray dryer at different temperatures (40 and 50 °C) and air velocity (1, 1.5 and 2 m/s). The blanching process showed no significant effect on the protein content present in shrimp by-products. The drying kinetics showed that the greatest loss of moisture occurs in the period of decreasing velocity, dominated by mass transfer by diffusion. The Page model showed the best fit for the experimental data. From the mixture of shrimp flour with the other ingredients in the proportions indicated by the Solve software, fish food pellets were obtained. These met the nutritional requirements of fish (tarpon) in the juvenile-commercial stage.

1. Introduction

Globally, shrimp have been farmed for several decades and are produced in at least 50 countries around the world, although the industry is concentrated in two major regions: Asia and the Americas. The world shrimp production reached 5.03 million tons in 2020 and is expected to grow up to 7.28 million tons by 2025 [1].

The shrimp industry generates approximately 50–60% of solid waste as by-products (heads, viscera, and exoskeletons). Although a small quantity of this waste is used as animal feed and as an ingredient in aquaculture feed formulation [2], large quantities of this byproduct are being wasted, resulting in the loss of valuable bioactive components and increased environmental pollution [3–5].

Shrimp processing waste has been used in animal feed production owing to its nutritional and bioactive compounds (protein, carotenoid, chitin, and lipid), which could improve the growth performance and immunity of farmed fish. In aquaculture production,

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the main goal is to increase the live weight of animals in the shortest time possible, meeting the species' nutritional requirements at low production costs. This is where commercial concentrates become of great impact, making it necessary for them to have a precise amount of nutrients. Nowadays, fish production in ponds has been increasing, such is the case of shad (*Megalops atlanticus*) production. This is a species that can reproduce in saltwater or freshwater habitats [6], and it is highly voracious and fast-growing. In pond culture conditions, it can reach an average weight of 500 g or more in 7 months, or 1 kg after 10 months of culture, facilitating its commercialization [7]. The nutritional requirements of young fish are the same or greater than in adult fish [8,9].

In the preparation of fish feed, the raw materials that provide amino acids can be classified into two groups according to their origin: vegetable and animal. Within the latter, fishmeal has been the most used raw material, since it covers the amino acid requirements for most fish species [10,11]. It is used in combination with cakes of vegetable by-products, animal oils, grains, and cereals. However, the high cost of fishmeal has led researchers to look for other protein-rich animal in order to obtain balanced fish feed at low cost [12,13]. Lu and Ku [14] studied the effects of replacing fish meals with shrimp waste meals in diets fed to juvenile cobia (*Rachycentron canadum*). The weight gain and feed conversion rate showed an increasing trend as the shrimp waste meals proportion in the diet increased from 0 to 25%.

Due to its abundance, chemical composition, and the high percentage of protein, shrimp exoskeleton is an excellent source for the manufacture of balanced feed for aquaculture that helps reduce the current consumption of fishmeal [9,15,16]. This product is an important source of phosphorus and calcium, rich in phenylalanine, lysine, and leucine. It has a high content of aspartic acid and glutamic acid, which is characteristic of fish and crustaceans. It is an excellent source of cholesterol, phospholipids, fatty acids, and carotenoid pigments [2,15,17,18], such as astaxanthin, which is frequently used as a feed additive in the formulation of aquafeeds to improve the coloration of many aquatic species, resulting in better quality and acceptance of the flesh within the consumer market [19]. Shrimp exoskeleton flour is obtained from dried waste products from marketed shrimp, consisting mainly of heads and exoskeletons and, to a lesser extent, entire organisms that are rejected for marketing.

Drying is a complex process characterized by interactions of simultaneous heat and mass transfer. Food product behavior during drying is determined from the drying kinetics analyses. Knowledge of the drying kinetics of biological materials is essential to the design, optimization and control of the drying processes. Different mathematical models have been used to characterize and optimize the drying process [20–23]. The Newton, Page, and Henderson and Pabis are among the most used. Thus, the purpose of this research is to evaluate the influence of pre-treatment and drying process of the shrimp (*Litopenaeus vannamei*) exoskeleton for balanced feed production, that meets the nutritional requirements of juvenile fish and allows the revaluation of the by-products of the fishing industry.

2. Materials and methods

2.1. Materials

Fresh shrimp exoskeletons were purchased at commercial stores and local seafood restaurants in Montería, Córdoba (Colombia). They were washed with water at room temperature to remove impurities. The remaining raw materials such as cassava flour, rice bran, sweet potato flour, and beef tallow, were purchased from the local market in Montería, Córdoba (Colombia).

2.2. Blanching process

The blanching process was carried out to inactivate microbial growth and thus reduce shrimp deterioration [24]. In each experimental batch, 500 g of shrimp by-products were treated with 2 L of distilled water. The blanching process was carried out in a thermostatic bath (Thermo Scientific Precision GP 20, Massachusetts, United States), evaluating different temperatures (80 and 95 °C) and times (5 and 15 min). The samples were removed from the water and placed on a metal mesh to remove excess moisture, and stored at −18 °C until analysis of crude protein. This analysis was performed in duplicate.

2.3. Experimental design of blanching process

The influence of the temperature (80 and 95 °C) and time (5 and 15 min) on the protein content was evaluated using a 2^2 factorial design with four central-points (87.5 °C for 10 min) for estimating the experimental error. The experiments were repeated two times, and mean values were used. The data was analyzed using the JMP 9.0 software, with multifactor analysis of variance (ANOVA) and Tukey's test at a 5% significance level.

2.4. Drying process

The drying experiments on shrimp exoskeleton were performed in a laboratory model tray dryer (TD/EV manual, Italy). The dryer contains a number of accessories to control and carry out an effective drying operation (setting the velocity and temperature of the air). The average drying air conditions were 25 ± 2 °C temperature and 60 ± 5% relative humidity. The hot air dryer was run for 30 min before starting each experiment to achieve the desired temperature and air velocity. 500 g of shrimp by-products (blanched by immersion in water at 80 °C for 5 min) were uniformly spread in rectangular perforated aluminum trays (size: 290 mm, 395 mm and 7 mm) and the air flowed parallel to the trays. The samples dried under the conditions to be evaluated. Moisture loss was recorded at 10 min intervals by a digital balance of 0.1 g accuracy (Kern KB 10000-1, Germany). The drying process was carried out until the samples reached constant weight. The dried samples were packed in polyethylene bags. The kinetics were adjusted by three empirical models widely used in foods: the Newton's model (Eq. (1)), Page model (Eq. (2)) and Henderson and Pabis model (Eq. (3)).

$$MR = \exp(-kt) \tag{1}$$

$$MR = \exp(-kt^n) \tag{2}$$

$$MR = a\exp(-kt) \tag{3}$$

Where MR is moisture ratio (non-dimensional), calculated from the ratio of moisture over time and initial humidity, t is time, k is a drying rate constant, and a and n are adjustment coefficients.

2.5. Experimental design of drying process

An experimental design 2*3 was used, corresponding to 2 levels of temperature (40 and 50 °C) and 3 levels of air velocity (1, 1.5 and 2 m/s). The experiments were repeated three times, and mean values were used. To evaluate the effect of these factors on the critical moisture (M_{cr}) content and time (t_{cr}) and equilibrium moisture (M_{eq}) content and time (t_{eq}), a variance analysis (ANOVA) was carried out at 5% significance level. Experimental data were fitted to the drying kinetics models using the OriginPro 9.0 software. The evaluation and selection criteria of the best model to describe the drying kinetics of shrimp by-products were the coefficient of determination (R^2) and Chi-Square (X^2).

2.6. Preparation of a balanced feed for fish

For the elaboration of the shrimp by-products flour, a manual mill (Corona, Colombia) was used in which the size of the dried husks was reduced and the flour obtained was screened. For the formulation of balanced food, the concentration of shrimp flour is kept constant at 25% for every 1000 g of feed, based on studies reported by Hardy [25]. To obtain 1400 g of the balanced feed, the amounts of the other ingredients were calculated using the Microsoft Excel software solver extension (Table 1). Before forming the pellets, the ingredients (shrimp flour, cotton seed cake, rice bran, beef tallow, sweet potato flour and cassava flour) were sieved with a 0.84 mm mesh sieve.

All ingredients were mixed in the industrial mixer (JAVAR, Model MZ-50, Colombia) and animal fat was added in order to achieve better consistency and compaction for the pelletizing process. The pellet formation was performed using a pelletizer (GEMCO, Model ZLSP230B, China), where the mixture was forced to pass through a mesh with holes of 4 mm in diameter at 120 °C. The pellets were dried in a dryer oven (WTC Binder, Germany) at 90 °C for 12 h to remove water added during the pelletizing process. The process was carried out until constant weight.

2.7. Bromatological analysis

The moisture (#950.46), crude protein (#940.25), ethereal extract (#996.06), and ash (#938.08) contents of the balanced feed were determined using the AOAC methods (AOAC, 2011).

3. Results and discussion

3.1. Blanching process

The results obtained for the protein content in the samples of shrimp by-products subjected to blanching are shown in Table 2. The analysis of variance showed that none of the factors had a significant effect ($p > 0.05$) on the protein content. This means that the protein content in the shrimp by-product was maintained regardless of the temperature and time applied in the blanching process. Similar results were reported in a study by Andrade et al. [31], where shrimp heads were blanched at temperatures of 85 and 95 °C and times of 10 and 20 min. This behavior can be attributed to the compact structure of the shrimp waste (exoskeleton and heads), which could avoid leaching protein into the cooking water. According to the results, the treatment at 80 °C and 5 min was selected, this is the

Table 1
Feed formulation of the reference diet.

Raw material	Content (%*w/w*)	Composition				Reference
		Protein	Ethereal extract	Ash	Carbohydrate	
Shrimp flour	25.74	42.9	9.4	23.0	24.7	
Cotton seed cake	24.56	38.44	6.66	5.55	49.35	[26]
Rice bran	22.06	13.66	18.80	10.65	53.11	[27]
Beef tallow	16.18	0.0	100.0	0.0	0.0	[28]
Sweet potato flour	5.81	6.6	1.0	1.0	90.5	[29]
Cassava flour	5.66	2.11	0.44	1.30	96.15	[30]

Table 2
Effects of blanching on the protein content (% dry weight) of shrimp by-products.

Temperature (°C)	Time (min)	Protein, %
80.0	5	42.9 ± 0.38
80.0	15	44.2 ± 0.02
95.0	5	45.3 ± 0.42
95.0	15	45.2 ± 0.84
87.5	10	44.0 ± 0.02
87.5	10	45.4 ± 0.20
87.5	10	45.4 ± 0.41
87.5	10	46.0 ± 0.63

condition that presents the lowest level of the factors, which translates into economy for the process.

3.2. Drying process

Shrimp by-product samples blanched at 80 °C and 5 min had an initial moisture content (M_0) of 60.8% (1.55 kg H_2O/kg dry base). At the end of the drying process, the moisture content was approximately 10.3% (0.115 kg H_2O/kg dry base). According to the results, the temperature and air velocity did not show a significant effect ($p > 0.05$) on the final moisture content and drying time. From the kinetics obtained for each experimental assay, the critical moisture (Mcr) and the time in which it is reached in each condition was determined (Table 3).

The constant velocity period for all treatments was short, with time values between 9.85 and 14.80 min, with a minimum loss of moisture, meaning the greatest loss of water content happened in the decreasing velocity period. According to Verma and Tomar [32], the behavior of shrimp by-products against the drying process can be explained as an effect of their structural characteristics, because the structure of these by-products consists of superimposed layers, forming thick surfaces of low porosity. At constant drying velocity, only the superficial water would be removed, while the water inside the product would be detached by diffusion processes, where mass transfer is slower, characteristic of this type of materials.

The ANOVA showed that temperature and air velocity, as well as their interaction had a significant effect on equilibrium moisture content (M_{eq}) and equilibrium time (t_{eq}). At an air temperature of 40 °C, an increase in air velocity (1 to 2 m/s) causes a decrease in M_{eq} of 67.6%, while at a temperature of 50 °C, this same increase in air velocity produces only a decrease in M_{eq} of 17%. On the other hand, at an air velocity of 1 m/s, an increase in air temperature (40–50 °C) produces a decrease in equilibration time of 35.1%, while at a temperature of 50 °C this increase in air velocity only causes a decrease in t_{eq} of 4%. According to the results, the drying conditions employed to obtain the shrimp exoskeleton flour used in the balanced feed formulation were 50 °C and an air velocity of 2.0 m/s, because under these conditions the lowest equilibrium humidity and drying time were obtained.

The results summarized in Table 4 indicate that the experimental drying data was better adjusted to the Page model (Fig. 1 a, b), since the value obtained for R^2 was the closest to 1, while the statistic X^2 was the closest to 0. The ANOVA showed that none of the factors had a significant effect ($p > 0.05$) on the parameter n of Page model; however, temperature ($p = 0.0047$) and temperature-air velocity interaction ($p = 0.0163$) had a significant effect on parameter k. An increase in temperature causes an increase in the parameter k, which is seen mainly at low air velocity. This agrees with what was reported by Simal et al. [33], Demiray and Tulek [34], and Mwithiga and Olwal [35].

3.3. Proximal composition of balanced feed

The result of the proximal composition of the balanced feed (Table 5) demonstrates that the content of protein complies with the diet that was formulated by linear programming in Solver. This indicates that the processing steps in the elaboration of the balanced feed did not affect the composition of the ingredients used.

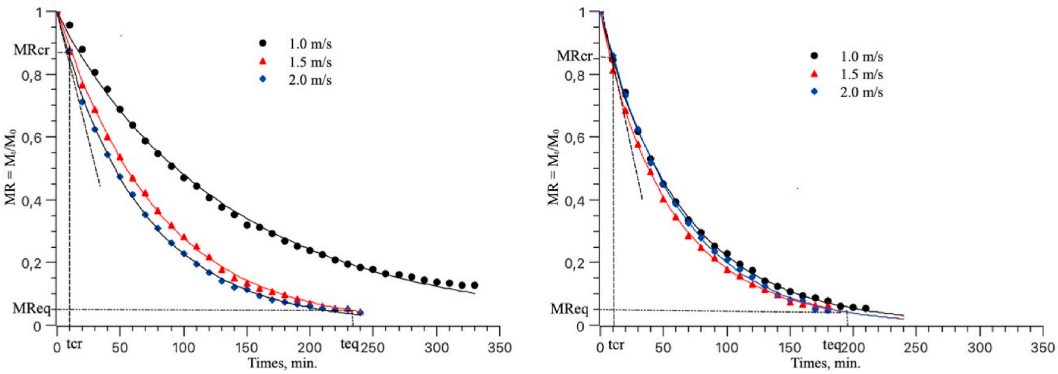
The nutrient found at the highest proportions was protein, which represented 26.60% of the material. This is because the main ingredient in the formulation is shrimp flour (25.74%), which has a high protein content (42.9%). The result of ethereal extract (16.12%) was greater than that reported by Salas et al. [36] of 11.05% and Oliveira et al. [18] of 12.5%, for a diet based on shrimp flour. This increase can be attributed to the beef tallow used for compaction of the feed. The content of ashes was 10.23%, this value can be attributed to the high content of shrimp minerals such as calcium and phosphorus, in addition to the chitin and chitosan

Table 3
Critical moisture (M_{cr}) content and time (t_{cr}) and equilibrium moisture (M_{eq}) content and time (t_{eq}) for each treatment.

Treatments	Temp (°C)	Air velocity (m/s)	M_{cr} (kg H_2O/kg dry base)	t_{cr} (min)	M_{eq} (kg H_2O/kg dry base)	t_{eq} (min)
T1	40	1.0	1.47 ± 0.03	10.0 ± 0.3	0.120 ± 0.02	320 ± 5
T2	40	1.5	1.27 ± 0.02	14.8 ± 0.5	0.085 ± 0.008	235 ± 4
T3	40	2.0	1.36 ± 0.05	10.0 ± 0.4	0.078 ± 0.007	220 ± 5
T4	50	1.0	1.32 ± 0.02	10.2 ± 0.4	0.085 ± 0.005	200 ± 5
T5	50	1.5	1.26 ± 0.03	10.0 ± 0.3	0.085 ± 0.003	190 ± 5
T6	50	2.0	1.33 ± 0.04	9.85 ± 0.2	0.070 ± 0.007	180 ± 3

Table 4
Parameters of the kinetic models applied to the drying process of shrimp exoskeleton at different treatment conditions.

Treat	Equation model	Coefficients			R^2	X^2
		k, min^{-1}	n	a		
T1	Newton	0.0072 ± 0.0002	0.951 ± 0.020	0.995 ± 0.025	0.996	2.45E-04
	Page	0.0092 ± 0.0004			0.997	1.74E-04
	Henderson/Pabis	0.0072 ± 0.0003			0.996	2.49E-04
T2	Newton	0.0128 ± 0.0004	1.022 ± 0.040	1.003 ± 0.052	0.999	6.21E-05
	Page	0.0116 0.0005 ±			0.999	5.11E-05
	Henderson/Pabis	0.0129 ± 0.0004			0.999	6.40E-05
T3	Newton	0.0149 ± 0.0006	0.963 ± 0.040	0.990 ± 0.018	0.999	1.03E-04
	Page	0.0175 ± 0.0003			0.999	7.11E-05
	Henderson/Pabis	0.0147 ± 0.0002			0.999	9.81E-05
T4	Newton	0.0152 ± 0.0002	0.952 ± 0.024	0.986 ± 0.032	0.999	1.01E-04
	Page	0.0188 ± 0.0004			0.999	3.83E-05
	Henderson/Pabis	0.0150 ± 0.0004			0.979	8.60E-05
T5	Newton	0.0176 ± 0.0004	0.931 ± 0.025	0.977 ± 0.025	0.998	1.59E-04
	Page	0.0235 ± 0.0008			0.999	2.83E-05
	Henderson/Pabis	0.0172 ± 0.0004			0.999	1.07E-04
T6	Newton	0.0160 ± 0.0004	1.015 ± 0.031	1.005 ± 0.038	0.999	4.31E-05
	Page	0.0150 ± 0.0005			0.999	3.86E-05
	Henderson/Pabis	0.0161 ± 0.0004			0.999	4.24E-05



(a) (b)

Fig. 1. Drying kinetics for experimental data and values predicted by Page model: (a) 40 °C; (b) 50 °C.

Table 5
Proximal composition of balanced feed for fish (tarpon) in the juvenile-commercial stage.

Component	Content (%*w/w*)
Dry matter	95.30 ± 0.10
Protein	26.60 ± 0.35
Ethereal extract	16.10 ± 0.26
Ash	10.23 ± 0.15
Total carbohydrate	47.02 ± 0.52

characteristic of the shrimp exoskeleton [18,37]. The supplements of chitin in the diet improve the growth and feed efficiency of various fish [14]. Taking into account the nutritional requirements of the tarpon in the juvenile-commercial stage, an optimal food for the species was obtained, since it must provide 25% of protein.

4. Conclusions

The protein content of shrimp by-products was maintained in the blanching process at different temperatures and time levels assayed. In the drying process, the time to reach the critical moisture average (1.29 kg H_2O/kg dry base) was not influenced by external factors such as air velocity and air temperature. The drying kinetics of shrimp by-products showed that the greatest moisture loss occurred in the decreasing velocity period. Among the three mathematical models applied to the experimental data for each drying treatment, the Page model showed the best quality in the adjustment as it presented the highest coefficient of determination and the lowest chi-square, successfully representing the drying of shrimp by-products. Finally, shrimp exoskeleton flour can replace fishmeal in the preparation of balanced feeds, since the protein content it provides meets the requirements for tarpon in the juvenile-commercial stage.

Author contribution statement

Pérez-Cervera Carmen E, Tavera-Quiroz María J: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Aleán Marlon A, Martínez-Navarro Luz K: Performed the experiments; Analyzed and interpreted the data.

Andrade-Pizarro, Ricardo D: Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] IMARC, Shrimp Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2020-2025, Shrimp Mark, 2020.
[2] E.M. Mahata, The effect of shrimp waste hydrolysate on broilers tibia weight, calcium and phosphorous content, Pakistan J. Nutr. 11 (2012) 375–378.
[3] A. Sila, Z. Ghlissi, Z. Kamoun, M. Makni, M. Nasri, A. Bougatef, Z. Sahnoun, Astaxanthin from shrimp by-products ameliorates nephropathy in diabetic rats, Eur. J. Nutr. 54 (2015) 301–307, https://doi.org/10.1007/s00394-014-0711-2.
[4] T. Senphan, S. Benjakul, Compositions and yield of lipids extracted from hepatopancreas of Pacific white shrimp (Litopenaeus vannamei) as affected by prior autolysis, Food Chem. 134 (2012) 829–835, https://doi.org/10.1016/j.foodchem.2012.02.188.
[5] N.P. Nirmal, C. Santivarangkna, M.S. Rajput, S. Benjakul, Trends in shrimp processing waste utilization: an industrial prospective, Trends Food Sci. Technol. 103 (2020) 20–35, https://doi.org/10.1016/j.tifs.2020.07.001.
[6] D.G. Smith, R.E. Crabtree, Megalopidae, in: K. Carpenter (Ed.), The Living Marine Resources of the Western Central Pacific, Food and Agriculture Organization of the United Nations, Rome, 2002.
[7] E. Argumedo-Trilleras, H. Rojas-Duarte, Manual de piscicultura con especies nativas, Asociación de Acuicultores del Caquetá-ACUICA, 2000.
[8] G.M. Mathew, D.C. Mathew, R.K. Sukumaran, R. Sindhu, C.C. Huang, P. Binod, R. Sirohi, S.H. Kim, A. Pandey, Sustainable and eco-friendly strategies for shrimp shell valorization, Environ. Pollut. 267 (2020), 115656, https://doi.org/10.1016/j.envpol.2020.115656.
[9] T.M. Fernandes, J.A. da Silva, A.H.A. da Silva, J.M.O. de Cavalheiro, e.M.L. da Conceição, Flour production from shrimp by-products and sensory evaluation of flour-based products, Pesqui. Agropecu. Bras. 48 (2013) 962–967, https://doi.org/10.1590/S0100-204X2013000800022.
[10] Z.A. Kari, M.A. Kabir, M.A.O. Dawood, M.K.A.A. Razab, N.S.N.A. Ariff, T. Sarkar, S. Pati, H.A. Edinur, K. Mat, T.A. Ismail, L.S. Wei, Effect of fish meal substitution with fermented soy pulp on growth performance, digestive enzyme, amino acid profile, and immune-related gene expression of African catfish (Clarias gariepinus), Aquaculture 546 (2022), 737418, https://doi.org/10.1016/j.aquaculture.2021.737418.
[11] A.R. Hodar, R. Vasava, N.H. Joshi, D.R. Mahavadiya, Fish meal and fish oil replacement for alternative sources: a review, J. Exp. Zool. India 23 (2020) 13–21.
[12] C. Fanizza, A. Trocino, V. Stejskal, M.D. Prokešová, M. Zare, H.Q. Tran, F. Brambilla, G. Xiccato, F. Bordignon, Practical low-fishmeal diets for rainbow trout (Oncorhynchus mykiss) reared in RAS: effects of protein meals on fish growth, nutrient digestibility, feed physical quality, and faecal particle size, Aqu. Rep. 28 (2023), https://doi.org/10.1016/j.aqrep.2022.101435.
[13] M. Gokulakrishnan, R. Kumar, S. Ferosekhan, G.M. Siddaiah, S. Nanda, B.R. Pillai, S.K. Swain, Bio-utilization of brewery waste (Brewer's spent yeast) in global aquafeed production and its efficiency in replacing fishmeal: from a sustainability viewpoint, Aquaculture 565 (2023), https://doi.org/10.1016/j.aquaculture.2022.739161.
[14] C.H. Lu, C.C. Ku, Effects of shrimp waste meal on growth performance and chitinase activity in juvenile cobia (Rachycentron canadum), Aquacult. Res. 44 (2013) 1190–1195, https://doi.org/10.1111/j.1365-2109.2012.03097.x.
[15] S.S. Pattanaik, P.B. Sawant, K.A.M. Xavier, K. Dube, P.P. Srivastava, V. Dhanabalan, N.K. Chadha, Characterization of carotenoprotein from different shrimp shell waste for possible use as supplementary nutritive feed ingredient in animal diets, Aquaculture 515 (2020), 734594, https://doi.org/10.1016/j.aquaculture.2019.734594.
[16] A.A. Gonçalves, J. dos Santos, Shrimp processing residue as an alternative ingredient for new product development, Int. J. Food Sci. Technol. 54 (2019) 2736–2744, https://doi.org/10.1111/ijfs.14184.
[17] M. Naczk, J. Williams, K. Brennan, C. Liyanapathirana, F. Shahidi, Compositional characteristics of green crab (Carcinus maenas), Food Chem. 88 (2004) 429–434, https://doi.org/10.1016/j.foodchem.2004.01.056.
[18] J.M. Oliveira Cavalheiro, E. Oliveira de Souza, P.S. Bora, Utilization of shrimp industry waste in the formulation of tilapia (Oreochromis niloticus Linnaeus) feed, Bioresour. Technol. 98 (2007) 602–606, https://doi.org/10.1016/j.biortech.2006.02.018.
[19] K.C. Lim, F.M. Yusoff, M. Shariff, M.S. Kamarudin, Astaxanthin as feed supplement in aquatic animals, Rev. Aquacult. 10 (2018) 738–773, https://doi.org/10.1111/raq.12200.
[20] R. Torres, E.J. Montes, R.D. Andrade, O.A. Perez, H. Toscano, Drying kinetics of two yam (Dioscorea alata) varieties, Dyna 79 (2012) 175–182.
[21] S.M. Roknul Azam, M. Zhang, C.L. Law, A.S. Mujumdar, Effects of drying methods on quality attributes of peach (Prunus persica) leather, Dry. Technol. 37 (2019) 341–351, https://doi.org/10.1080/07373937.2018.1454942.
[22] A.C. Ersan, N. Tugrul, The drying kinetics and characteristics of shrimp dried by conventional methods, Chem. Ind. Chem. Eng. Q. 27 (2021) 319–328, https://doi.org/10.2298/CICEQ201114050E.
[23] O.L. Brasileiro, J.M.O. Cavalheiro, J.P.S. de Prado, A.G. dos Anjos, T.T.B. Cavalheiri, Determination of the chemical composition and functional properties of shrimp waste protein concentrate and lyophilized flour, Cienc. E Agrotecnol 36 (2012) 189–194, https://doi.org/10.1590/s1413-70542012000200007.
[24] T.Y.N. Tran, N.L. Nguyen, T.N.A. Nguyen, D.T. Le, D.A. Phan, T.T. Tran, T.P. Dao, Effects of blanching and drying condition on the quality of small shrimp (Acetes), Genet. Res. (2022) 2022, https://doi.org/10.1155/2022/3996787.
[25] R. Hardy, Alternative protein sources, Feed Manage. 50 (1999) 25–28.

[26] A.F. Amorim, K.F. Rodrigues, R.G.M. Vieira Vaz, D.V.G. Vieira, G.F. Da Silva, L.F. Sousa, C.F.A. Campos, C.C. Araujo, V.S. Silva, S.B. Machado, Diet metabolisability and performance of slow-growing chickens fed with cottonseed cake, Semina Ciências Agrárias 40 (2019) 379–388, https://doi.org/10.5433/1679-0359.2019v40n1p379.

[27] A. Moongngarm, N. Daomukda, S. Khumpika, Chemical compositions, phytochemicals, and antioxidant capacity of rice bran, rice bran layer, and rice germ, APCBEE Proced. 2 (2012) 73–79, https://doi.org/10.1016/j.apcbee.2012.06.014.

[28] S. Lee, F.A. Aya, S. Won, A. Hamidoghli, S.C. Bai, Effects of replacing dietary fish oil with beef tallow on growth performance, serological parameters, and fatty acid composition in juvenile olive flounder, Paralichthys olivaceus, J. World Aquacult. Soc. 51 (2020) 393–406, https://doi.org/10.1111/jwas.12654.

[29] A. Ramesh Yadav, M. Guha, R.N. Tharanathan, R.S. Ramteke, Changes in characteristics of sweet potato flour prepared by different drying techniques, LWT (Lebensm.-Wiss. & Technol.) 39 (2006) 20–26, https://doi.org/10.1016/j.lwt.2004.12.010.

[30] S.M. Chisenga, T.S. Workneh, G. Bultosa, M. Laing, Proximate composition, cyanide contents, and particle size distribution of cassava flour from cassava varieties in Zambia, AIMS Agr. Food 4 (2019) 869–891, https://doi.org/10.3934/agrfood.2019.4.869.

[31] R.D. Andrade-Pizarro, M.M. Chávez-Baldovino, V. Naar-Osorio, Evaluation of the cooking and drying procedures to obtain crop shrimp (Penaeus sp) heads flour, Dyna 74 (2007) 181–186.

[32] D. Verma, V. Tomar, An investigation into environment dependent nanomechanical properties of shallow water shrimp (Pandalus platyceros) exoskeleton, Mater. Sci. Eng. C 44 (2014) 371–379, https://doi.org/10.1016/j.msec.2014.08.033.

[33] S. Simal, A. Femenia, M.C. Garau, C. Rosselló, Use of exponential, Page's and diffusional models to simulate the drying kinetics of kiwi fruit, J. Food Eng. 66 (2005) 323–328, https://doi.org/10.1016/j.jfoodeng.2004.03.025.

[34] E. Demiray, Y. Tulek, Drying characteristics of garlic (Allium sativum L) slices in a convective hot air dryer, Heat Mass Trans./Waerme- Und Stoffuebertragung 50 (2014) 779–786, https://doi.org/10.1007/s00231-013-1286-9.

[35] G. Mwithiga, J.O. Olwal, The drying kinetics of kale (Brassica oleracea) in a convective hot air dryer, J. Food Eng. 71 (2005) 373–378, https://doi.org/10.1016/j.jfoodeng.2004.10.041.

[36] C. Salas, A. Chacon, L. Zamora, La harina de exsoesquelo de camarón en raciones para gallinas y pollos crecimiento y engorde, Agron. Mesoam. 26 (2015) 333–343.

[37] K. Kim, B. Park, Y. Cho, S. Kim, H. Cho, Quality characteristics of shrimp flour added dumpling shell, Kor. J. Food Cultur. 24 (2009) 206–211.