Ciência Rural, Santa Maria, v.52:1, e20200801, 2022
http://doi.org/10.1590/0103-8478cr20200801
ISSNe 1678-4596
ANIMAL PRODUCTION

Pterygoplichthys spp. (Siluriformes: Loricariidae) meal is suitable for the culture of Nile tilapia *Oreochromis niloticus* (Cichlidae) juveniles

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ABSTRACT: *We search for positive utility impact on the invasive species Pterygoplichthys spp. The optimal level of replacement of sardine meal (SM) by Pterygoplichthys spp. meal (PLM) in practical feeds for fry of Nile tilapia (Oreochromis niloticus) was evaluated. We evaluated six experimental diets: 50% PLM–50% SM, 60% PLM–40% SM, 70% PLM–30% SM, 80% PLM–20% SM, 90% PLM–10% SM and 100% PLM–0% SM. In a recirculation system, 270 sex-reversed tilapia fry were used (0.7 ± 0.1 g). Diets were administered in triplicate and the experiment lasted 56 days with sampling every 14 days. There were no statistical differences in growth. At the end of the experiment, the SGR, ADG, CF, WG, DFI, FCR and PER were determined without significant differences (P > 0.05) between treatments, but there was a tendency that could indicated higher WG and PER in the 90% PLM–10% SM treatment (93.56 ± 0.43% and 8.44 ± 1.18 g, respectively). All survival rates were higher than 90% with no significant differences. Additionally, there were no statistical differences in the chemical composition of the whole fish, while apparent digestibility coefficients of protein (81–90%) and lipids (87–93%) also showed no significant differences. We concluded that 100% PLM can replace 100% SM in feeding fry of O. niloticus without affecting their survival, growth or chemical composition or the apparent digestibility of nutrients.*
Key words: *apparent digestibility coefficient, growth parameters, protein, pterygoplichthys meal, replacement.*

Farinha de *Pterygoplichthys* spp. (Siluriformes: Loricariidae) é adequado para a cultura da tilápia juvenil do Nilo *Oreochromis niloticus* (Cichlidae)

RESUMO: *Buscamos por um impacto positivo de utilidade nas espécies invasoras como Pterygoplichthys spp. Foi avaliado o nível ótimo de substituição da farinha de sardinha (SM) pela farinha de Pterygoplichthys spp. (PML) em dietas práticas para tilápia do Nilo (Oreochromis niloticus). Foram utilizadas seis dietas experimentais; 50% PLM–50% SM, 60% PLM–40% SM, 70% PLM–30% SM, 80% PLM–20% SM, 90% PLM–10% SM e 100% PLM–0% SM. Em sistema de recirculação foram colocados 270 filhotes de tilápia machos (0.7 ± 0.1 g). As dietas foram triplicadas, o experimento durou 56 dias com amostragem a cada 14 dias, não houve diferença estatística para o crescimento. No final do experimento, foram determinados SGR, ADG, CF, WG, DFI, FCR e PER, não encontrando diferenças significativas (P> 0,05), embora tenha havido uma tendência indicando maior WG e PER na dieta 90% PLM–10% SM (93,56 ± 0,43% e 8,44 ± 1,18 g). A sobrevida foi superior a 90%, sem diferenças significativas. Além disso, não houve diferenças significativas na composição proximal de todo o peixe, enquanto o aparente coeficiente de digestibilidade de proteínas (81–90%) e lipídios (87–93%) também não mostrou diferenças significativas. Podemos concluir que o uso de 100% de farinha de Pterygoplichthys spp. pode substituir 100% de farinha de sardinha na alimentação de jovens O. niloticus sem afetar a sobrevivência, o crescimento, a composição química e a digestibilidade aparente dos nutrientes.*
Palavras-chave: *coeficiente de digestibilidade aparente, parâmetros de crescimento, proteína, farinha de Pterygoplichthys, substituição.*

INTRODUCTION

There is a fish group from the Loricaridae family and genus *Pterygoplichthys* present in southeast Mexico. These fish are an invasive species introduced as ornamental fish from different parts of the world and have presented very serious environmental problems, such as damage to local fisheries, species displacement, orographic impact and as vectors of non-native parasites (MENDOZA et al., 2009; ORFINGER et al., 2018). In Mexico, these species do not represent any economic value to fishermen and are not accepted as food by the general population, so research has been focused on obtaining

Received 08.27.20 Approved 04.14.21 Returned by the author 06.01.21
CR-2020-0801.R2
Editors: Rudi Weiblen Levy Carvalho Gomes

various by-products for use as fertilizers, for human consumption and as fishmeal for feed; such utilization could control their invasion (GUERRA, 2008). Fishmeal is the by-product with a wider perspective because it is a product with high protein content (56–60%) and has an adequate amino acid profile (ESCALERA et al., 2006).

Nile tilapia, *Oreochromis niloticus*, Linnaeus, 1758, are highly resistant to changes in environmental conditions and shows rapid growth, high productivity and good adaptation to captivity. Is well known that tilapia is an omnivorous species (MORALES, 1991), which allows a wide range of feed to be used for their growth. Tilapia is the most widely produced fish (ZHOU, 2019) and Mexico is one of the largest producers of tilapia in the Americas (FITZSIMMONS, 2000). However, as tilapia culture has increased, the demand for feed has also increased, raising the production costs by almost 50% (EL-SAYED, 1999). The production of fish feed has traditionally been based on the use of fishmeal (sardine, anchovies, etc.), this being the main source of protein, with a suitable amino acid profile and a source of essential fatty acids, digestible energy, vitamins and minerals (TACON, 1993; ABDELGHANY, 2003), all of which makes fishmeal the most expensive ingredient in animal feed (PETERS et al., 2004). In this sense, several studies have been undertaken to achieve reductions in this ingredient through the use of alternative sources of protein. Worldwide efforts have been developed to assess the partial or total replacement of fishmeal by other ingredients, either from terrestrial animals or plant sources. Several alternative ingredients, such as terrestrial animal by-products, have been tested: feather meal, chicken viscera, cattle blood (PETERS et al., 2004), aquatic animals such as shrimp-head meal, squid meal (ÁLVAREZ et al., 2001, OLIVEIRA et al., 2007), as well as those of plant origin, such as legume and cereal meals (BORGESON et al., 2006; GARDUÑO-LUGO et al., 2008), and the use of probiotics (LARA-FLORES et al., 2002) because of the omnivorous habit. However, their use depends largely on the nutritional value, quality, inclusion levels, availability and cost of each ingredient.

Aquaculture efforts should be focused on the use of local, non-human-food ingredients in order to reduce imported feed ingredients and so to ensure a sustainable aquaculture industry (TACON, 2020). Thus, the objective of this study was to evaluate six experimental diets, using as protein source the nonfood *Pterygoplichthys* spp. meal, on apparent digestibility and the growth, survival and chemical composition of juvenile Nile tilapia *Oreochromis niloticus*.

MATERIALS AND METHODS

Fry collection

Sex-reversed tilapia larvae were obtained from the Tropical Aquaculture Laboratory UJAT-DACBIOL, Villahermosa, Tabasco, Mexico.

Preparation of the Pterygoplichthys spp. meal (PLM)

For meal preparation, 715 adults of *Pterygoplichthys spp.* (500–700 g) were collected from the El Chimal and El Susil lakes, Balancan, Tabasco, Mexico. Muscle was cut near the tail fin, then dried in an oven (Coriat, HC-35-D, Zapopan, Jalisco, Mexico) for 24 h. Once dried, it was passed through a Wiley-type mill (AHT Co, Philadelphia, PA, USA) and a 2-mm sieve to produce *Pterygoplichthys spp.* meal (PLM, 54% protein). Samples were stored in plastic bottles and refrigerated for proximal chemical analysis.

Formulation and manufacture of experimental diets

Six experimental diets were formulated and manufactured. The Mixit-Win® 5.0 software was used, considering the nutritional requirements of the species and the proximate composition of different ingredients, including PLM (AOAC, 1995).

For the manufacture of each diet the macro-ingredients were mixed in a rotary mixer (BATHAMMEX^{MR} 178716, Mexico) for 10 min. Subsequently, the micro-ingredients were added and mixed for another 10 min. Then, in a plastic container, liquid ingredients were mixed for 10 min to form an emulsion, which was added to the mixture of dry ingredients and mixing for 10 min. Finally, 400 mL of water was added slowly to produce a paste, which was passed through a meat grinder (TORREY^{MR} M-22R1, N.L., Mexico) to form pellets with a die of 0.45 mm in diameter, which were then were dried in an oven (CORIAT, HC-35-D, Zapopan, Jalisco, Mexico) for 12 h at 60 ºC. The pellets were ground and stored in refrigeration at –20 ºC until use.

Experimental design

Sardine meal (SM) was taken as the base for partial replacement of protein with PLM, from 50% to 60, 70, 80, 90 and 100%, also varying the amount of sorghum meal and fish oil in order to obtain iso-lipidic and iso-proteinic diets (Table 1). The experiment was carried out in a recirculation system with 270 tilapia juveniles (0.7 g ± 0.1)

Table 1 - Formulation and proximate analysis of the experimental diets.
1 Balanced Feeds Galmez, Villahermosa, Tabasco, Mexico; 2 Proteínas marinas y agropecuarias, S. A de C.V. Guadalajara, Jalisco, Mexico, 3 Lagunas Susil y el Chinal, Balancán, Tabasco, Mexico, 4 Sigma-Aldrich, Cat. 8020, 5 Pronat Ultra. Mérida, Yucatán, Mexico, 6 Almacenes Chedraui, Mexico, 7 Jalmek, Cat. 5260-05, 8 Vitamin premix (g/kg of premix): Vitamin A Acetate (Retinol), 0.086; Vitamin D3 (Cholecalciferol), 0.006; Vitamin E (Tocoferol), 5; Vitamin K Menadiona, 1; Thiamine (B1), 0.1; Riboflavin (B2), 0.4; Pyridoxine (B6), 0.3; DL-Pantothenic Acid, 2; Niacin (acid nicotinamide), 1; Biotin, 0.016; Inositol, 30; Cyanocobalamin (B12), 0.002; Folic Acid, 0.1; Vehicle (cellulose), 960, 9 Mineral premix (g/kg of premix): $CaCl_2.2H_2O$, 257.5; $MgSO_4.7H_2O$, 149.14; $ZnSO_4.7H_2O$, 2.76; $MnCl_2.4H_2O$, 0.96; $CuSO_4.5H_2O$, 0.25; KI, 0.00003; Na_2SeO_3, 0.0042; Na_2HPO_4, 571.58; $FeSO_4.7H_2O$, 17.88, 10 Rovimix ® C-EC (Roche) active agent 35%.

Ingredients (g/100 g diet)	50% PLM– 50% SM	60% PLM– 40% SM	70% PLM– 30% SM	80% PLM– 20% SM	90% PLM– 10% SM	100% PLM– 0% SM
Sardine meal	15.80	12.90	9.49	6.29	3.17	0.00
Sorghum meal	35.04	34.10	33.04	32.10	31.20	30.31
Pterygoplichthys meal	20.66	23.90	27.89	31.88	35.87	39.99
Soybean meal	20.00	20.64	21.17	21.38	21.49	21.50
Sardine oil	2.00	2.00	2.00	2.00	2.00	2.00
Soybean lecithin	1.92	1.88	1.83	1.76	1.70	1.62
Grenetin	2.00	2.00	2.00	2.00	2.00	2.00
Chromic oxide	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin premix	1.00	1.00	1.00	1.00	1.00	1.00
Mineral premix	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin C	0.08	0.08	0.08	0.08	0.08	0.08
----------Proximal composition (g/100 g dry matter) except nitrogen-free extract (NFE)----------						
Moisture	3.07 ± 0.20	3.09 ± 0.24	3.48 ± 0.18	3.72 ± 0.05	3.22 ± 0.07	3.29 ± 0.08
Ash	9.71 ± 0.09	9.82 ± 0.04	9.87 ± 0.04	10.06 ± 0.24	9.82 ± 0.06	9.88 ± 0.04
Protein	38.68 ± 0.29	39.52 ± 0.22	40.57 ± 0.28	41.39 ± 0.19	42.48 ± 0.03	42.52 ± 0.15b
Ether extract	7.90 ± 0.39	7.62 ± 0.09	6.99 ± 0.05	6.90 ± 0.02	6.13 ± 0.20	5.72 ± 0.14 a
Fiber	0.80 ± 0.08	0.68 ± 0.06	0.67 ± 0.08	0.77 ± 0.21	0.55 ± 0.03	0.69 ± 0.05ab
Nitrogen-free extract	42.82 ± 0.11	42.36 ± 0.24	41.90 ± 0.26	40.88 ± 0.38	41.02 ± 0.28	41.19 ± 0.26
Energy (Kcal/g)	4.53 ± 0.32	4.57 ± 0.40	4.38 ± 0.13	4.64 ± 0.37	4.23 ± 0.14	4.85 ± 0.16

placed randomly in 18 tanks of 70 L for 56 days; each diet was evaluated in triplicate. Weight (g) and total length (cm) were recorded every 14 days. Survival was determined daily. An average temperature (T) between 27.2 and 30.5 °C was maintained, dissolved oxygen (DO) ranged between 6.6 and 7.5 mg/L and pH ranged from 5.2 to 7.5. These parameters were recorded daily with a YSI 85 handheld meter (for T and DO) (YSI, Ohio, USA) and a pH meter (HANNA HI 991001, Romania). Fish were fed three times per day (9:00, 13:00, and 17:00 h) starting with 10% of the biomass in each tank and then adjusting the ratio in terms of feed consumption.

Proximal analysis

At the end of the experiment, five fish per replicate were sampled for proximal chemical analysis of the whole fish. All samples were frozen at –20 ºC and then lyophilized. Analyses were carried out in the Institutional Laboratory of the Colegio de la Frontera Sur, San Cristobal de las Casas Unit, Chiapas, according to the AOAC (1995).

Apparent digestibility coefficient

To determine the apparent digestibility of nutrients (protein and lipids), feces were collected three times a day, 1 h after each feeding, by siphoning. After collection, feces were frozen at –20 °C for lyophilization. The lyophilized feces were analyzed to determine the concentration of proteins, lipids, dry matter and chromic oxide (Cr_2O_3). For the determination of protein content, the micro Kjeldhal method was used according AOAC (1995) and for lipids the Bligh, Dyer (1959) technique using a Soxlet-Avanti FOSS TECATOR (AB, BOX 70, S-26321, Höganäs, Sweden). To determine the chromic oxide, the FURUKAWA et al. (1966) technique was used. The analyses were carried out in the Aquaculture Nutrition Laboratory of the Center of Biological Research of the Northwest, S.C. La Paz B. C. S., Mexico.

Statistical analysis

To determine significant differences among the treatments and growth variables (total length and weight) and survival, a test for normality (Kruskal–Wallis test) and Levene's test for homogeneity of variance were first applied and, if these postulates were met, a one-way ANOVA was used, and finally the Tukey test was applied to determine the differences among treatments. Growth rates, feed quality, proximal chemicals of the fish, and apparent digestibility (protein and lipids) of the treatments were compared by using the nonparametric test of Kruskal–Wallis and, where significant differences were found, the Nemenyi test was applied. All statistical tests were performed with a significance level of $\alpha = 0.05$ using STATISTICA v.8 software (Statsoft, Inc., Tulsa, OK, USA).

RESULTS AND DISCUSSION

Results of growth in weight and total length over 56 days showed no significant differences ($P > 0.05$) among treatments, values ranged from 9.07 ± 0.39 g in 60% PLM–40% SM treatment to 10.76 ± 1.04 g in 90% PLM–10% SM treatment for weight and 7.57 ± 0.23 cm in 70% PLM–30% SM treatment to 8.17 ± 0.32 cm in 90% PLM–10% SM treatment (Table 2).

There were no significant differences ($P < 0.05$) in any of the rates of growth or feed efficiency among treatments (Table 3). Regardless of this, condition factor (CF) and weight gain (WG) in the diets with 90% PLM–10% SM and 80% PLM–20% SM both showed the highest values, of 1.97 ± 0.06 and 93.56 ± 0.43%, and 1.97 ± 0.04 and 93.04 ± 1.02%, respectively. For the feed conversion ratio (FCR) and the protein efficiency ratio (PER), despite no statistical differences being expressed among treatments, fish fed with the 90% PLM–10% SM diet showed the highest values (0.28 ± 0.04 g and 8.44 ± 1.18 g, respectively), followed by treatment 80% PLM–20% SM, of 0.31 ± 0.08 g and 7.87 ± 1.87 g, respectively (Table 3). In the case of survival, differences were not significant ($P > 0.05$), although it should be mentioned that fish fed with the 90% PLM–10% SM diet had the highest survival rate (97.7%).

In relation to the body chemical composition of tilapia fry there was no statistical significance differences ($P > 0.05$) between any of the treatments; however, the lipid content varied as did the protein content: it was similar between the treatments although there was a slight increase in the case of the 90% PLM–10% SM diet (Table 4).

For the apparent digestibility coefficients (ADCs) of protein and lipids, there were no significant differences ($P > 0.05$) between experimental diets. Apparent protein digestibility ranged between 81.4 and 89.5%, showing an increase as the inclusion level of PLM increased, while the ADCs of lipids was similar to those of protein but with higher values, ranging between 87.13 and 93.49% in relation to the increase in PLM in the diets. In this way, it was observed that the 90% PLM–10% SM treatment showed the highest ADC of lipids, of 93.49% (Table 4).

Table 2 - Weight (g) and total length (cm) of tilapia fry fed with experimental diets (mean ± SD).

Weight (g)						
Day	50% PLM–50% SM	60% PLM–40% SM	70% PLM–30% SM	80% PLM–20% SM	90% PLM–10% SM	100% PLM–0% SM
0	0.71 ± 0.00	0.69 ± 0.00	0.70 ± 0.05	0.68 ± 0.02	0.69 ± 0.03	0.74 ± 0.03
14	1.61 ± 0.03	1.50 ± 0.06	1.57 ± 0.12	1.60 ± 0.05	1.60 ± 0.03	1.54 ± 0.09
28	3.03 ± 0.09	2.90 ± 0.14	3.08 ± 0.14	3.04 ± 0.22	3.02 ± 0.17	2.96 ± 0.20
42	6.13 ± 0.44	5.95 ± 0.62	5.94 ± 0.34	6.11 ± 0.72	6.37 ± 0.38	6.08 ± 0.59
56	9.57 ± 0.80	9.07 ± 0.39	9.28 ± 0.83	10.02 ± 1.55	10.76 ± 1.04	9.96 ± 1.04
Total length (cm)						
Day	50% PLM–50% SM	60% PLM–40% SM	70% PLM–30% SM	80% PLM–20% SM	90% PLM–10% SM	100% PLM–0% SM
0	3.42 ± 0.26	3.38 ± 0.03	3.43 ± 0.04	3.38 ± 0.05	3.37 ± 0.03	3.45 ± 0.07
14	4.61 ± 0.05	4.53 ± 0.04	4.44 ± 0.22	4.65 ± 0.08	4.59 ± 0.04	4.49 ± 0.07
28	5.78 ± 0.03	5.62 ± 0.05	5.74 ± 0.10	5.72 ± 0.11	5.76 ± 0.16	5.66 ± 0.12
42	7.61 ± 1.04	6.91 ± 0.18	6.83 ± 0.10	7.00 ± 0.30	7.06 ± 0.16	6.99 ± 0.14
56	7.67 ± 0.12	7.80 ± 0.00	7.57 ± 0.23	7.97 ± 0.40	8.17 ± 0.32	7.90 ± 0.26

Table 3 - Growth variables and survival percentage of tilapia fry fed with experimental diets for 56 days (mean ± SD) and feed efficiency of tilapia fry fed with experimental diets for 56 days (mean ± SD).

Indexes	50% PLM– 50% SM	60% PLM– 40% SM	70% PLM– 30% SM	80% PLM– 20% SM	90% PLM– 10% SM	100% PLM– 0% SM
Specific Growth Rate (%/day)	4.64 ± 0.15	4.59 ± 0.10	4.61 ± 0.25	4.77 ± 0.27	4.90 ± 0.12	4.65 ± 0.15
Average Daily Gain (g/day)	0.16 ± 0.01	0.15 ± 0.01	0.15 ± 0.02	0.17 ± 0.03	0.18 ± 0.02	0.17 ± 0.02
Condition Factor	2.12 ± 0.10	1.91 ± 0.08	2.14 ± 0.10	1.97 ± 0.04	1.97 ± 0.06	2.02 ± 0.03
Weight Gain (%)	92.55 ± 0.62	92.32 ± 0.40	92.40 ± 1.02	93.05 ± 1.02	93.56 ± 0.43	92.57 ± 0.63
Survival (%)	86.67 ± 11.54	86.67 ± 9.43	82.22 ± 3.85	95.56 ± 7.70	97.78 ± 3.85	93.33 ± 6.67
----------Variables----------						
Daily Feed Intake	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.00	0.05 ± 0.01	0.05 ± 0.00	0.05 ± 0.01
Feed Conversion Rate	0.36 ± 0.03	0.38 ± 0.02	0.40 ± 0.05	0.31 ± 0.08	0.28 ± 0.04	0.32 ± 0.02
Protein Efficiency Ratio	7.08 ± 0.60	6.57 ± 0.47	6.23 ± 0.94	7.87 ± 1.87	8.44 ± 1.18	7.29 ± 0.51

In the absence of significant differences among treatments by replacing SM at levels above 90% PLM it was observed that the growth of tilapia was suitable, since PLM has good levels of protein (54%) although slightly less than SM (65–70%) besides having an adequate profile of amino acids and fatty acids needed for growth (ESCALERA et al.,, 2006). In this same way, OLIVEIRA et al. (2007) used waste by-products of the shrimp industry as protein sources for tilapia, showing CFs and WGs of 0.13 and 0.16 g, respectively which turned out to be lower than those obtained in our study (0.15 ± 0.02 and to 0.18 ± 0.02 g) when evaluating levels of inclusion of 0%, 33.3%, 66.6% and 100% of shrimp-head silage meal. MEJRI et al. (2019) evaluated the use of an invasive species, white sucker (*Catostomus commersonii*) as fish meal ingredient for the growth of walleye (*Sander vitreus*) finding better growth with the experimental fish meal diet, probably due to the selective incorporation of oleic acid, which was greater in juveniles fed with white sucker fish meal. The evaluation by ABARRA et al. (2017), who evaluated fishmeal replacement by processed knife fish (*Chitala ornata*) meal in diets of *O. niloticus*, finding increases in average percentage WG, SGR and feed intake up to replacement levels of 75%. However, LLANES et al. (2006) utilizing fish silage (two wet diets containing 25% raw protein) in fingerlings of red tilapia (*O. mossambicus* x *O. niloticus*) of initial weight 3.5 g reported a high survival rate (94.6%) similar to this research (97.78%), although the parameters SGR and PER (2.36%/day and 1.05 g, respectively) were lower than those found in our study (4.90%/day and 8.44 ± 1.18 g respectively), which shows that for these species the use of PLM is more efficient than silages because during its preparation the main nutrients (protein, lipids and carbohydrates) are hydrolyzed, so releasing monomers (free amino acids, fatty acids, and monosaccharides), which can saturate the uptake channels and limit the digestibly (PARIN & SUGARRAMURDI, 1977).

Also, the quality of the manufactured fish silage can be affected in some cases by the type of fermentation, decreasing enzymatic activity and the assimilation of protein by juvenile tilapia (EL-SAYED, 1999). This same happens when using poultry by-products (hydrolyzed feather meal) and mixtures of these and pig meal as alternative protein sources for tilapia, where growth rates SGR, FCR and PER were decreased (3.21%/day, 1.64 and 2.2, respectively) in comparison with our results using PLM (4.9%/day, 0.28 and 8.44 ± 1.18 g, respectively) as reported by HERNANDEZ et al. (2009).

A high inclusion of PLM in balanced feed for *O. niloticus* is considered suitable in terms of growth; this was corroborated by analysis of the chemical composition of the whole fish at the end of the experiment, where it was observed that as the inclusion level of PLM increased the level of body lipids in the tilapia decreased, indicating that this species assimilates PLM optimally. Fish with low lipid levels (from 15.2 to 15.7%) were obtained when using substitutions of 80 to 100% of PLM meal, compared to those resulting from lower inclusions (16.6 to 18.9% with inclusions of 50 to 70%) However, OLIVEIRA et al. (2007) and HERNANDEZ et al.

Table 4 - Chemical composition (% dry matter) of whole fish of juveniles of tilapia fed with experimental diets (mean ± SD) and apparent digestibility coefficients (ADCs) of dry matter, protein, and lipids of the experimental diets (mean ± SD).

Chemical Analysis (g/100 g BS)	50% PLM– 50% SM	60% PLM– 40% SM	70% PLM– 30% SM	80% PLM– 20% SM	90% PLM– 10% SM	100% PLM– 0% SM
Moisture	7.05 ± 0.48	7.37 ± 0.12	7.00 ± 0.33	6.88 ± 0.15	7.40 ± 0.29	7.18 ± 0.54
Ash	14.75 ± 0.08	14.82 ± 0.32	15.21 ± 0.41	15.21 ± 0.32	14.84 ± 0.16	15.24 ± 0.45
Crude protein	53.48 ± 2.58	54.23 ± 0.51	52.60 ± 3.73	53.93 ± 0.77	55.74 ± 1.66	54.89 ± 1.23
Ether extract	18.87 ± 1.84	17.65 ± 1.36	16.57 ± 0.74	15.18 ± 1.40	15.67 ± 0.93	15.27 ± 0.30
Carbohydrates	5.82 ± 1.52	5.92 ± 1.42	8.60 ± 3.77	8.78 ± 1.00	6.33 ± 1.13	7.39 ± 1.79
Energy (Kcal/g)	4.97 ± 0.14	5.92 ± 1.42	4.86 ± 0.07	4.81 ± 0.05	4.82 ± 0.05	4.77 ± 0.06
ADC						
Dry matter	59.90 ± 2.87	62.83 ± 4.24	69.07 ± 4.38	68.10 ± 1.97	67.29 ± 0.56	67.82 ± 5.08
Protein	81.41 ± 0.78	84.15 ± 3.23	87.43 ± 2.90	89.20 ± 1.46	88.99 ± 0.55	89.56 ± 1.40
Lipids	88.89 ± 1.75	87.13 ± 1.54	90.48 ± 2.55	90.10 ± 2.17	93.49 ± 0.57	89.50 ± 0.84

(2009) reported low levels of body lipids in juvenile tilapia (5.07, 4.36 and 5.11%; 6.3, 7.5, 5.9 and 4.3%, respectively) when using poultry by-products (ensilages with inclusion levels of 0, 33.3, 66.6%) and fish by-products (ensilages with inclusion levels of 100 and 30%). These differences in quantities of body lipids when using poultry by-products and fish silage could be due to the manufacturing process and type of raw material used in the production of the silage (whole fish, parts or debris), since the acidic substances or microorganisms added to perform the hydrolysis reduce the amount of lipids in the silage by metabolic oxidation, so that elaboration with these substances produce diets low in fat (BELLO, 1997). In our case, could be possible that the high lipid content was due to the manufacturing process, we did not separated fat from the PLM meal. However, this did not affect the growth of the tilapia and therefore, from the point view of shelf life and flavor, the lower the level of body lipids (in fillets or whole body), the better the quality with regard to storage and consumption of the product.

If the ADCs of nutrients are considered together with the chemical analysis of the whole fish, this will allow a higher estimation of the nutritive value of protein sources in diets for fish (KÖPRÜCÜ et al., 2005; MOHANTA et al., 2006). In this regard, the ADCs of dry matter (60–67%), protein (81–89%), and lipids (89–93%) using PLM were increased as the inclusion level of meal increased, the ADCs of protein being within the ranges mentioned by CHO et al. (1990) and AKSNES and OPSTVEDT (1998) as being suitable for feeding fish. Thus the values obtained were high when using PLM, so that differences in the coefficients of apparent digestibility for protein ingredients may vary depending on the type of ingredient used in the replacement, its level of substitution, chemical composition and origin, and the processing of ingredients used and the methods of collection of feces (KÖPRÜCÜ et al., 2005; GABER et al., 2006). In this same sense, the ADCs obtained in this study corroborate the possibility of using substitutions of 90–100% of SM by PLM by presenting high values and a high content of corporal protein (55–56%), indicating that the digestion, retention and use of PLM protein is adequate in juvenile tilapia.

The above results show that, despite several alternative protein sources (marine by-products and land animals such as poultry) showing good results in the growth and development of tilapia, there are still limitations on the availability (collection of wet ensilage and shrimp industry by-products, poultry by-products, meat and bone, blood, etc., as well as of seeds and leaves of plants) and processing of raw materials to obtain high-quality protein, coupled with the lack of some essential amino acids and, in some cases, the need to use ingredients or substances that act as attractors to improve the palatability of the diet (BORGESON et al., 2006).

Pterygoplichthys meal is considered a good ingredient, in future fat shoud be separated from PLM in order to have a better understanding of the protein replacement, replacing SM without having to include palatable, attractive substances or additional essential amino acids in the formulations, since the ingredient has the nutritional and biochemical characteristics necessary to meet the of protein and amino acid requirements of tilapia (ESCALERA et al., 2006).

However, the disadvantage presented in the preparation of PLM lies in the collection of *Pterygoplichthys* spp., since despite being considered a highly invasive species introduced into the country several decades ago by the aquarium industry, its availability in the aquatic environments where it is found is currently unknown, so there are no records of the volume of its total catch or the feasibility of creating a sustainable fishery for its use in the production of feed for aquatic organisms. Therefore, it is necessary to carry out short-term studies referring to catch volumes, to determine whether it can be considered as a fish resource and thus be utilized not only as fishmeal but with the aggregate value as hydrolyzed or ensilaged feed in the aquaculture or other industries (MENDOZA et al., 2009).

It is important to point out that the production of fishmeal for use in aquaculture worldwide has been increasing, as has its cost (BORGESON et al., 2006); however, the trend in production for future years shows a decrease due to various factors, including climatic phenomena (El Niño and La Niña), pollution, and over exploitation of fishery resources, etc. (PETERS et al., 2004). Despite the great developments in aquaculture in the last two decades, the use of fishmeal has not increased substantially, because its inclusion in diets has decreased with the current tendency of replacing it with other meal (animal and plants) of similar nutritional quality to that of fishmeal but with lower costs (FENUCCI et al., 2007; GONZALEZ et al., 2007).

Under this scenario, it is necessary to seek out new alternative sources of protein that cover the requirements of protein, amino acids and essential fatty acids for the proper functioning and development of aquaculture species such as *O. niloticus*. This omnivorous species allows and facilitates the use of a wide range of ingredients in the formulation of diets, as this study has shown by the use of PLM, but can also take advantage of industrial alternatives such as hydrolysates, ensilages and attractors that can be manufactured with lower requirements in terms of raw materials than that of SM and consequently at lower cost.

CONCLUSION

Finally, this study showed that *Pterygoplichthys* spp. meal is a good ingredient that can be substituted at up to 90% without affecting the weight gain, feed conversion or protein efficiency in juveniles of *O. niloticus*.

ACKNOWLEDGMENTS

This research was supported by the National Council for Science and Technology and the Tropical Aquaculture Laboratory of the UJAT-DACBIOL, Villahermosa, Tabasco, Mexico.

DECLARATION OF CONFLICT OF INTEREST

All the authors declare no conflicts of interest. The founding sponsors had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript; nor in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

BIOETHICS AND BIOSECURITY COMMITTEE APPROVAL

Fish were handled in accordance with the Declaration of Helsinki and the Norma Oficial Mexicana approved by the Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (NOM-062-ZOO-1999).

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