Use of extruded products from the exotic species *Plecostomus punctatus*. Part 1: Production of balanced diets based on whole *Plecostomus punctatus* fishmeal

Utilización de productos extrudidos de la especie exótica Plecostomus punctatus. Parte 1: Producción de dietas balanceadas a base de harina de pescado entera de Plecostomus punctatus

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Abstract

To solve the problem that is presently going on at the Lic. Adolfo López Mateos dam, known as "El Infiernillo", in Michoacán, Mexico, created by the involuntary introduction of *Plecostomus punctatus*, known in the area as "Devil Fish", that has proliferated and dominated on the existing fisheries, this research suggests its use as protein source for extruded feedstuffs for other species with a higher commercial value. The objective was to obtain an extruded balanced feedstuff based on *Plecostomus punctatus* meal. A lab extruder made in Mexico and an imported lab extruder Wenger X-5 were started and put into operation to obtain the desired feedstuffs considering as protein source a commercial fish meal to evaluate its performance in preliminary experiments. Once the best processing conditions were established, *Plecostomus punctatus* meal was introduced in the selected diet suggested in the literature for tilapia (Oreochromis spp.) cultivated in aquaculture. A modification of the diet composition was done introducing other carbohydrates (wheat flour instead of finer wheat bran ("afrechillo" in Spanish) and coarse wheat bran instead of rice bran). Conclusions derived from this research were: An acceptable fillet contents was found in big specimens. However, the effort to extract it from the animals is important, and might affect the economic and technical feasibility of the process. If the fish is dried, its manual separation is much easier. There is an initiative to exploit "Devil Fish" fillets for human consumption, and considering that this project were viable, its residues would be adequate as part of the proposed diet, since its protein contents is 27%. The nutritional quality of the dehydrated fillet as well as the meal given by the methodology used make its unit operations satisfactory, since very low mass losses were found. Dried fillets might be used as "surimi" or to be directly sold as dried fish, such as Norway cod but to much lower price. Particle size of the different meals, fish and carbohydrates, play a very important role in the feedstuffs physical characteristics before and after extrusion. Thus, all raw materials were previously pretreated to comply with particle size specifications. Grinding and sieving unit operations are very important for industrial scaling-up and should be optimized to reduce costs. Based on bromatological analyses, "Devil Fish" integral meal has the necessary protein contents for tilapia extruded feedstuffs. Carbohydrates needed in the feed mixture to obtain good physical characteristics (hydrostability, matter losses, and expansion percentage) is 28%, according to this research. It also complies with its protein requirements. Finally, grinding and sieving operations should be optimized with the new materials available in the zone, such as sorghum, to minimize production costs.

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Keywords: Balanced diet, *Plecostomus punctatus*, Devil fish

Resumen

Para solucionar el problema que se presenta actualmente en la presa Lic. Adolfo López-Mateos, conocida como "El Infiernillo", en Michoacán, México, creado por la introducción involuntaria de Plecostomus punctatus, conocido en la zona como "Pez Diablo", que ha proliferado y dominado sobre las pesquerías existentes, esta investigación sugiere su utilización como fuente de proteínas para dietas extrudidas para otras especies de mayor valor comercial. El objetivo fue obtener una dieta extrudida balanceada a base de harina de Plecostomus punctatus. Se puso en marcha un extrusor de laboratorio fabricada en México y un extrusor de laboratorio importado Wenger X-5 para obtener los alimentos deseados considerando como fuente de proteína una harina de pescado comercial para evaluar su desempeño en experimentos preliminares. Una vez establecidas las mejores condiciones de procesamiento, se introdujo la harina de Plecostomus punctatus en la dieta seleccionada sugerida en la literatura para la tilapia (Oreochromis spp.) cultivada en acuicultura. Se hizo una modificación de la composición de la dieta introduciendo otros carbohidratos (harina de trigo en lugar de salvado de trigo más fino ("afrechillo" en español) y salvado de trigo grueso en lugar de salvado de arroz). La conclusión principal derivada de esta investigación fue que se encontró un contenido aceptable de proteína en los filetes de ejemplares grandes. Si el pescado está seco, su separación manual es mucho más fácil. Existe una iniciativa para la explotación de filetes de "Pescado Diablo" para consumo humano y, considerando que este proyecto era viable, sus residuos serían adecuados como parte de la dieta propuesta, ya que su contenido de proteína es del 27%. La calidad nutrimental del filete deshidratado así como la harina obtenida por la metodología empleada hacen que sus operaciones unitarias sean satisfactorias, ya que se encontraron pérdidas de masa muy bajas. Los filetes secos pueden utilizarse como "surimi" o venderse directamente como pescado seco, como el bacalao noruego, pero a un precio mucho más bajo. El tamaño de las partículas de las diferentes harinas, pescados y carbohidratos, juegan un papel muy importante en las características físicas de los alimentos antes y después de la extrusión. Por lo tanto, todas las materias primas fueron pretratadas previamente para cumplir con las especificaciones de tamaño de partícula. Las operaciones de la unidad de molienda y tamizado son muy importantes para la ampliación industrial y deben optimizarse para reducir los costos. Con base en análisis bromatológicos, la harina integral del pez diablo tiene el contenido de proteína necesario para alimentos extrudidos para tilapia. Los carbohidratos necesarios en la mezcla de alimento para obtener buenas características físicas (hidrostabilidad, pérdidas de materia y porcentaje de expansión) es del 28%, según esta investigación. También cumple con sus requerimientos proteínicos. Finalmente, las operaciones de molienda y tamizado deben optimizarse con los nuevos materiales disponibles en la zona, como el sorgo, para minimizar los costos de producción.

***Palabras clave**: Dietas balanceadas, Plecostomus punctatus, pez diablo*

Introduction

In the Mexican dam "Lic. Adolfo López-Mateos, El Infiernillo", in Michoacán, Mexico, the accidental introduction of the species *Plecostomus punctatus*, locally known as "Devil fish" has created its proliferation and dominance on the existing ones, particularly tilapia (Oreochromis spp.) (Martínez, 2005; Morales, 2003). To cooperate in the solution of this problem, it has been proposed to use it as protein source for extruded feedstuffs for other fish varieties with a higher commercial value, as it is done with shrimp accompanying fauna, for example. The objective of this research is to obtain a low cost balanced extruded feedstuff using as protein source the whole meal of *Plecostomus punctatus* looking for similar characteristics to commercial counterparts.

Methodology

As the process to be used will be based on the studies performed in a laboratory scale extruder, the first set of experiments were conducted to characterize by physical, chemical, and physicochemical properties, the meals to be obtained from *Plecostomus punctatus* captured in the dam. Also, it will be studied the formulation of a diet for tilapia (Oreochromis spp.) cultivated in aquacultural conditions (Gaxiola, 2007), with some modifications to improve its performance (wheat flour by fine wheat bran (*afrechillo* in Spanish), other wheat byproducts by rice bran, etc.). Particle size of the ingredients should be less than 1.2 mm in average. The methodology followed in this research is presented in Figure 1.

Fish meal from *Plecostomus punctatus* (devil fish)

Capture, cooling, transportation, and preservation

Plecostomus punctatus exemplars were captured by cooperating fishermen of the community Churumuco at the Mexican dam "Lic. Adolfo López Mateos, El Infiernillo", in Michoacán, Mexico (Figure 2). Roughly 30 kg of fish were captured, refrigerated-frozen to -5°C, and immediately transported to

Mexico City's National Autonomous University of Mexico laboratories (*UNAM, Universidad Nacional Autónoma de México*). There the fish were classified in generally three sizes: Big, 35-45 cm long; medium size, 25-35 cm long, and small, less than 25 cm. From the whole lote, only five exemplars were big, with a body mass of 3 kg (10% total lot), 36 pertained to medium size, con 18 kg (60% total lot), about 0.5 kg each, and 40 were small, of about 200 g each, with a mass of 9 kg (el 30% total lot) (Photograph 1).

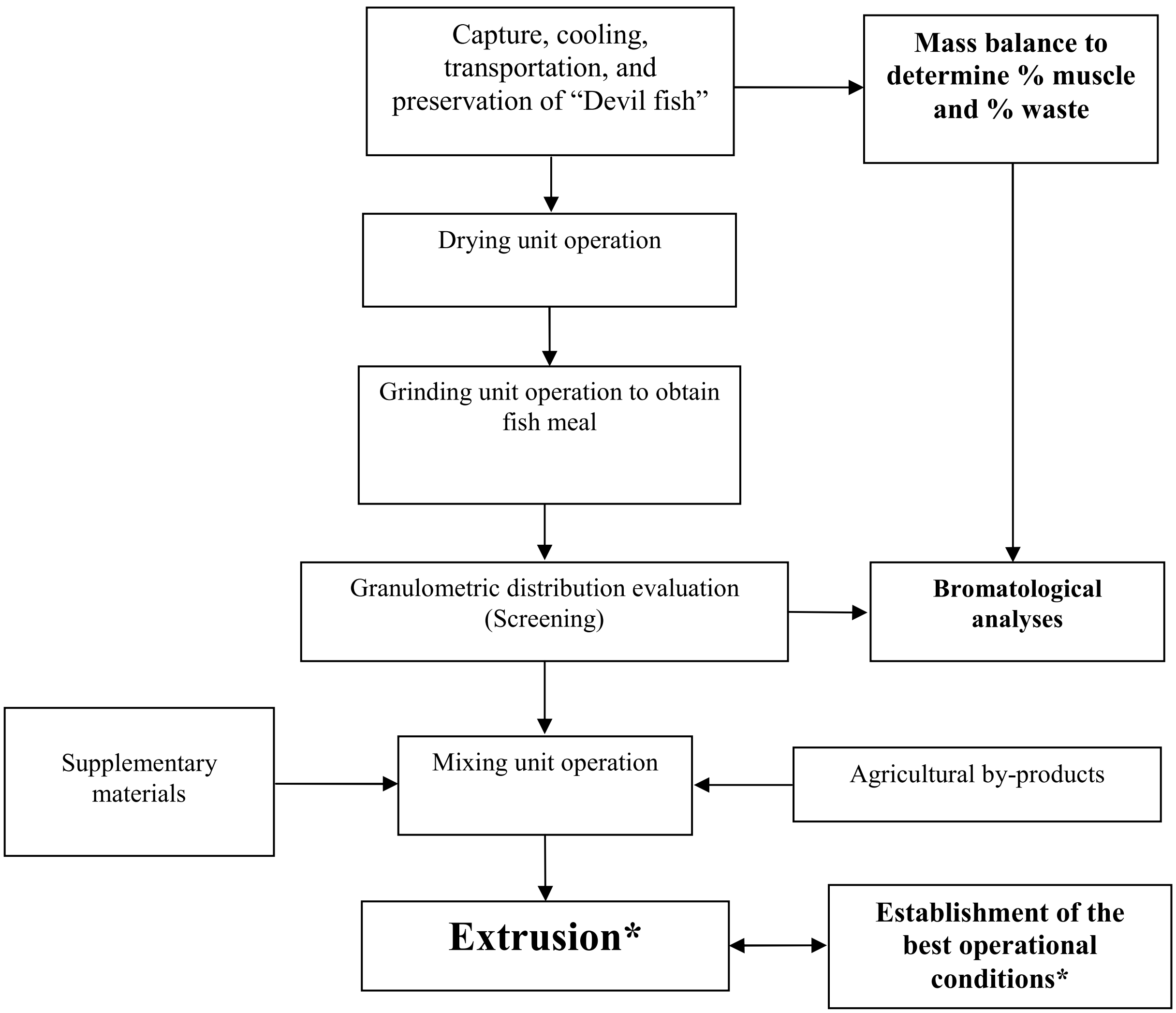


Figure 1. Blocks diagram for the methodology followed (*these operations are the core of Part 2)

Mass balance to determine % muscle and % waste

The most important inconvenience to take the little muscle of this fish is the hardness of its "skin". To four of the five big exemplars the muscle was extracted to quantify the ratio of muscle (edible portion), head, skeleton, "skin", and viscera to the total body mass. For the extraction of the muscle, an incision from the operculum on the dorsal side without dismembering the head was done turning the body to continue with the lower part also with a transversal incision from the equivalent to the operculum down to the anal fin (this is the only relatively "soft" part). The caudal extreme is cut and the fish is opened, extracting the viscera and cleaning, and then filleting the fish with a fine knife from the abdomen to the dorsal fin. Muscle was weighed and percentages were calculated, for muscle and the rest of the body, considered as "waste". The whole procedure was very cumbersome.

Figure 2. Location of the dam. Coordinates 18°16’23”N 101°53’34”W (http://en.wikipedia.org/wiki/Infiernillo_Dam)

Photograph 1. *Plecostomus punctatus* (before and after vacuum drying)

Drying

This unit operation was carried out in a tray vacuum drier (Photograph 2), J.P. Devine Co., model 3SPC Búfalo (US), located in the Laboratory of Unit Operations of the Chemical Engineering Department, Faculty of Chemistry, UNAM. It operated with saturated steam as heating medium, and vacuum is obtained with a pump. Operating conditions were 41 kPa (12 in Hg) at a fluctuating temperature (60 to 80ºC) during roughly 18 hours, as average drying time. Heat was provided by saturated steam. The batch was of 25.9±0.3 kg of frozen fish. For this research the whole fish was vacuum dried including inner organs. It was observed for the fifth big exemplar that, after the drying operation, the separation of the muscle was very simple. Thus, besides the big one some other were also taken to complete 1 kg of dried fillets, manually separated. The nutritional value might become an interesting asset after the bromatological analyses are to be performed, since most fish have very good nutrimental characteristics. This option might become an interesting collateral economical alternative for dehydrated *Plecostomus punctatus* without using the cumbersome procedure with fresh fish.

Grinding to obtain fish meal

Once the whole fish were dried, grinding was performed using an Imperial mill with cutting edges (flutes or teeth). The mill is manually operated by a handle that rotates a screw that passes the material to be ground by the teeth that also rotate, reducing particle size and forming a meal, that it is stored in a freezing chamber at -5°C. These "devil fish" meals were the basis of the balanced diet to be prepared (Photograph 3).

Proposed diet composition

To have a suitable expansion in the final *pellet*, it is necessary to have a starch balance in the mixture, since a floating feedlot should have at least 20% starch (Bortone, 2002). Another important aspect in the diet is the protein content. For that, a bromatological analysis of all components were performed, particularly for the growing stage, colloquially known as fattening stage. The formulation model developed by Gaxiola (2007) suggests a "*pellet"* size of 3 to 4 mm, a moisture content of 10%, a protein and carbohydrates content of 28% and of 35%, respectively. There characteristics will be considered to prepare the balanced diet and, in Part 2, to study the extrusion conditions to obtain such *pellets*. That will contain the "devil fish" meal. Table 1 shows the diet composition used in this study (Gaxiola, 2007).

Photograph 2. Vacuum tray dryer

Photograph 3. *Plecostomus punctatus* meal before regrinding and screening

Table 1. Commercial diet for tilapia (Oreochromis spp.) (Gaxiola, 2007)

Ingredients	%
Degreased soybean paste	25
Fish meal	15
Wheat bran or wheat flour	33
Rice bran	15
Soybean oil	3
Vitamins mixture (Vit mix)	1
Minerals mixture (Min mix)	4
Carboxymethylcellulose	4
Total	**100**

Evaluation of the granulometry distribution

Granulometry of meals, including the devil fish meal, was determined using a Montinox sieve with nine different mesh sizes trays: 10, 20, 30, 40, 50, 60, 70, 80, and 100. Besides the "devil fish" there were meals of different cereals, legumes, and agricultural by-products. Samples of 250 g from each meal were set in the equipment during 20 minutes, weighing the amounts retained in each mesh tray and calculating the equivalent percentage from the total sample mass. Graphs were drawn to corroborate average particle size. For those cases where a higher retention was obtained intermediate mesh sizes were used, corroborating if 80% of the particles were smaller than mesh No.18 (1.2 mm). In all cases, intermediate mesh (No. 14 and 18) between No. 10 and 20 were used. If this specification could not be complied a pulverizer should be used or a higher shear stress should be applied in the mill or grinder. This is necessary because big particles may interfere in the gelatinization of starches and form rupture points in the *"pellet"*, increasing losses of matter in the water column, as well as altering its floating capacity.

Bromatological analyses

Moisture content, crude protein, crude fat, crude fiber, and ash contents were determined for whole devil fish meal, fillet meal, and wastes meal, using the AOAC methods (1990) and, by difference to 100%, it was assumed that the rest were carbohydrates (Aragón and Novoa, 1994). Non proteic nitrogen for wastes meal was also evaluated following the methodology established by Tejada-de-Hernández (1992), to assess the real protein content of the feedstuffs that should be at least 25%.

Selection of de supplementary materials and low cost agricultural by-products

A very important issue in the formulation of a low cost feedlot is the selection of supplementary materials and low cost agricultural by-products that provide energy and nutritional elements.

Considering that the area where the dam was built were originally agricultural lots, although almost two generations have evolved since its construction, it is important to start a parallel study to known which materials might substitute the traditional meals used in the Table 1 commercial diet presented before. Table 2, for example, in spite of the fact that data are more than 15 years old might give an insight on the possible by-products to be used in a study after this one.

Table 2. Example of agricultural production of the study area, 2006 Cycle: Spring-Summer, Agricultural year: 2006 Irrigation mode: Technified watering and rain (State of Michoacán, Mexico, INEGI, 2007)

Municipality	Product	Estimated production (t)	Obtained production (t)	Estimated yield (t/ha)	Obtained yield (t/ha)
Churumuco	Sesame	206.0	120.0	0.301	0.300
	Beans	8.0	8.0	1.000	1.000
	Maize grain	4,624.0	3,315.0	1.700	1.700
	Sorghum grain	5,420.0	4,040.0	2.000	2.000
La Huacana	Sesame	606.0	360.0	0.600	0.600
	Beans	12.0	12.0	1.200	1.200
	Maize grain	16,410.0	12,300.0	3.000	3.000
	Cucumber	400.0	400.0	20.000	20.000
	Sorghum grain	11,880.0	9,300.0	3.000	3.000
	Tomato (red)	450.0	450.0	15.000	15.000
Tumbiscatío	Sesame	175.0	105.0	0.500	0.500
	Beans	15.0	15.0	1.250	1.250
	Maize grain	7,920.0	5,800.0	2.000	2.000
	Sorghum grain	6,570.0	5,400.0	3.000	3.000
Total	**54,696.0**	**41,625.0**	**54.551**	**54.550**	-

Some calculations were done based on 1 kg of product. The amounts in grams are shown in Table 3. As it may be observed, total value exceeds 1000 g. This increase is due to water content, since moisture is a necessary variable to be controlled during extrusion of the diet ingredients, particularly for the desired expansion of the *pellets*. In Part 2, this issue will be thoroughly discussed. To carry out the appropriate preliminary mass balances, a 34% initial moisture content was hypothetically considered.

Table 3. Type and amount of ingredients for 1000 g of product

Type of ingredients	Mass of each ingredient (g)
Sorghum flour (SF) or wheat bran (WB) or wheat flour (WF)	330
Plecostomus punctatus meal (PM)	150
Degreased soybean paste (SP)	250
Soybean oil (SO)	30
Rice bran (RB) or wheat bran (WB)	150
Carboxymethylcellulose (CMC)	40
Vitamines mixture (Vit mix)	10
Minerals mixture (Min mix)	40
Water	340
Total	**1 340**

Initially, in the preliminary experiments, when a commercial fish meal was used to save the *Plecostomus punctatus* meal for the experimental design of Part 2, wheat bran was used for the prepared diets. However, floatability was affected. To improve feedlots physical characteristics, wheat flour was used since it has a higher starch percentage, that favors floatability. Maybe later, considering Table 2 information, this wheat flour might be substituted by sorghum flour, since this grain is cultivated in the study zone. These modifications will be the object of a new research. Following the same trend, rice bran was substituted by wheat bran, since rice cultivars are not in the nearby areas whereas wheat although is not so near either, is the third grain cultivated in Mexico after maize and sorghum (Durán, 1978; Sánchez-Tovar and Durán-Domínguez-de-Bazúa, 2009).

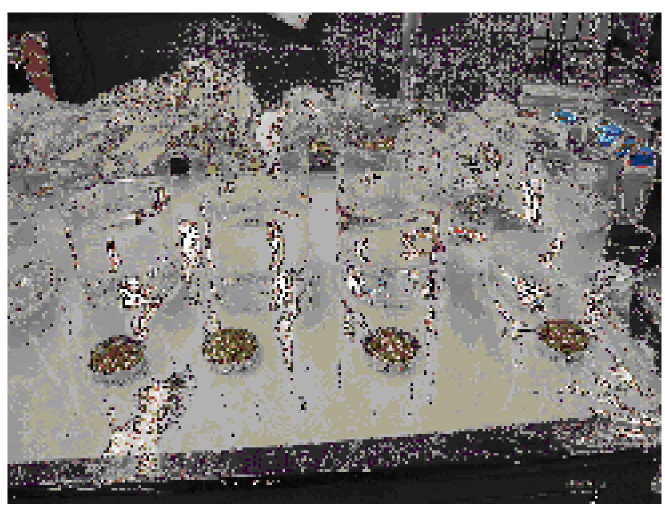
Mixing of diet ingredients

A laboratory 2 kg Hobart mixer, model N-50, was used to mix and humidify the diet components (Photograph 4). After approximately 10 minutes a homogeneous mixture was prepared with the suitable particle size of all ingredients. Water was added as an extra ingredient of the formulation. Dry basis calculations were done using an OHAUS modelo MB200 thermobalance with samples of 2 to 3 grams to reach 34% moisture initial concentration. A detailed procedure is presented in the literature (Tenorio-Fernández, 2009). Once the proper amount of water was slowly added to avoid lumps formation, soybean oil is also slowly added forming an emulsion mixing for about 10 minutes more. The moist diet is stored in a resealable plastic bag leaving it during 24 hours in refrigeration 5±2°C for homogeneization. After this period, lots are set in separated resealable plastic bags according to the number of runs for the extrusion experiments (see Part 2).

Dependent or response variables

Hydrostability is defined as the behavior that *pellets* have in a water column (Pedroza-Islas, 2000). For tilapia (Oreochromis spp.), it is necessary that *pellets* remain in the water column surface. This variable was measured with respect of the feedlot that remained on the surface after a fixed period of time. Samples equivalent to the 10% of the total mass for each run were left on the surface of the water column contained in a 1 liter beaker during: 1, 15, 30, 60, 120, and 240 minutes. Using a plastic net, floating matter was removed and set in a weighting glass container (Photograph 4b). Humid *pellets* were introduced to a lab oven to dry, at a temperature between 110 and 120°C during the handled time to have a moisture content of 5±2%, then they were weighted and the feedlot proportion that remained in the surface with respect to the total initially set was calculated. Results in percentage were compared with those measured to a control of commercial feedlot ("Nutripez", Purina, Mexico).

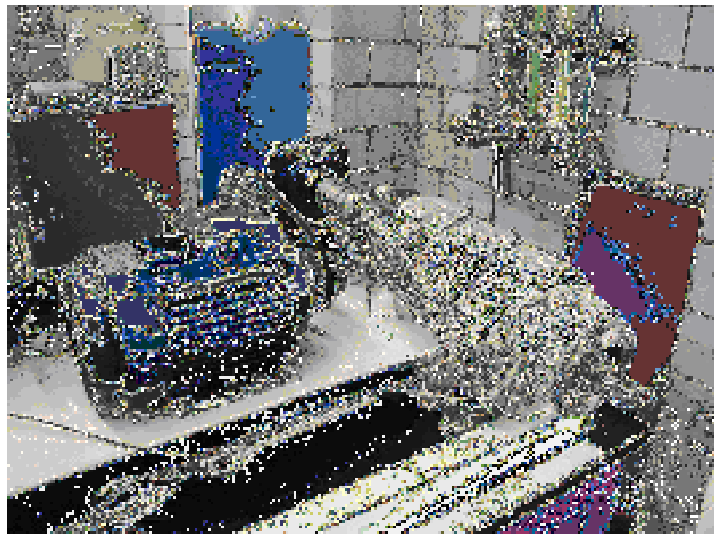
Photograph 4a. Hobart lab mixer



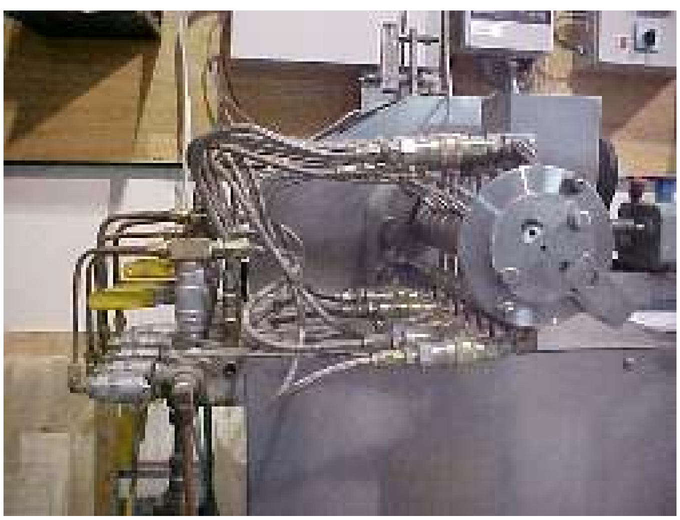
Photograph 4b. Hydrostability tests

The percentage of loss of matter in the water column is defined as the amount of matter that leaves the *pellet* with respect to time. It is evaluated at the same time lapses as hydrostability tests. To measure the amount of lost matter, the same volume of water used for the hydrostability tests is passed through a "quick filter" (Photographs 5 to 7a,b). Retained matter in the filter is also set in a lab oven at the same conditions that for the hydrostability tests. Mass differences provide the amount of material leaving the *pellets*. These values were compared with the amount of feedlot incorporated to the test at the zero time (10% in mass for each run). It is important to mention that those pellets that completely submerged were not considered in the calculations for the percentage of loss of matter in the water column (those that did not float). Those were extracted with pincettes and only partook the matter lost during the time they remained in the beaker. It was also considered negligible the material dissolved in water from the extruded products that was leaving the beakers during the filtration step.

Photograph 5. Test for loss of matter calculations



Photograph 6. Low cost extruder built in Mexico



Photograph 7a. Extruder Wenger X-5

Photograph 7b. Calculation of the expansion index in a Wenger X-5 extruder

The expansion index represents the percentage of growing or expansion of the *pellet,* once it is dried. A higher value indicates that the material will have a higher number of cells or pores, reducing its density and, thus, facilitating its floatability. It is calculated measuring the *pellet* diameter using a vernier and comparing it with the die orifice diameter (Photographs 6, 7a,b).

Controlable variables (constants)

Particle size is a variable that contributes to the interaction of the mixture components, since the smaller the particle is the more contact points with the other particles will have. This phenomenon will help with the starches gelatinization, and favoring the cells formation due to expansion. Besides, to obtain a smaller particle size it is necessary to increase the shear stress during grinding and that increases production costs affecting the project viability. Therefore, the challenge is to reduce particle size without increasing grinding costs in order to comply with the product physical specifications.

The proposed **diet formulation** was maintained constant in all runs, to study extrusion processing conditions. The diet formulation would be only changed if the physical evaluations, hydrostability and loss of matter, are not adequate or if the nutritional values would not be correct. It is important to mention that, as a specific amount of "devil fish" was available, stored at -5°C, preliminary experiments to define methodologies and extrusion conditions were done preparing the diets with commercial fish meal, considering that its bromatological composition be similar to the *Plecostomus punctatus* meal. Thus, a bromatological analysis of several commercial brands for fish meal were carried out and the one that had a similar content of protein, fat, ashes, and carbohydrates by difference, was the one employed.

Another constant is the **extruder screw type and length**. Screws have different configurations, some have closer flights, or more open, with higher clearances or widths, etc. (Figure 3).

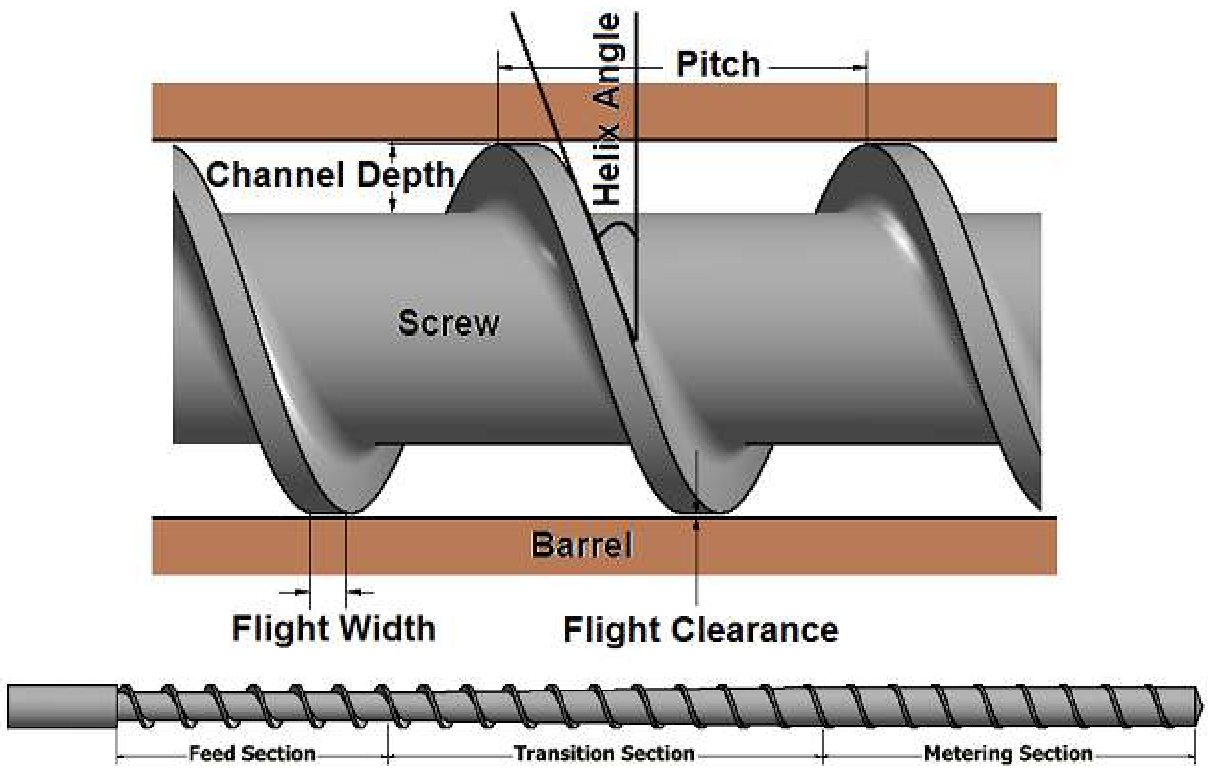


Figure 3. Schematic representation of a simple screw and detail of its geometry (modified from Eslami, 2014)

These configurations imply more or less shear stress on the material to be extruded. Channel depth defines the real flow passing through the extruder determining the velocity with which the mixture is transported to the die and defining the retropressure before the material exits. For this research, extruder screw length is constant and the only modification will be the use of a low cost extruder built in Mexico and a Wenger X-5 (Kansas, US). Part 2 includes the extrusion experimental.

Statistical analysis

Data were analyzed using the conventional methods (Montgomery, 2006).

Results and discussion

Plecostomus punctatus filleting

Table 4 shows the results obtained for the devil fish muscles recovery, using the bigger exemplars. The average percentage of total fish mass was around 23%. The rest, approximately 77%, was "skin", head, viscera and skeleton. Filleting was a very complicated task due to the "skin" hardness and the size of the head (Photograph 8).

Table 4. Muscle proportion for *Plecostomus punctatus* (% mass)

Sample	Total mass (g)	Horizontal length (cm)	Muscle mass (g)	By-products mass (g)	% Muscle
PD-1	546.5	40	108.5	436.0	19.8
PD-2	575.4	42	132.9	439.3	23.2
PD-3	639.2	44	137.6	499.0	21.5
PD-4	775.6	46	209.8	563.0	27.0

Photograph 9. "Devil fish" (*Plecostomus punctatus*)

Vacuum drying and grinding

At the end of the drying operation 4.535 kg dry fish with a moisture content of 5% (dry basis, d.b.) were obtained. Drying efficiency gave a 21.7% dry matter. For grinding, overall efficiency was 95%, obtaining 4 535 g of devil fish meal ready to be mixed and extruded.

Figure 5 shows the mass balance for the operations of drying and grinding.

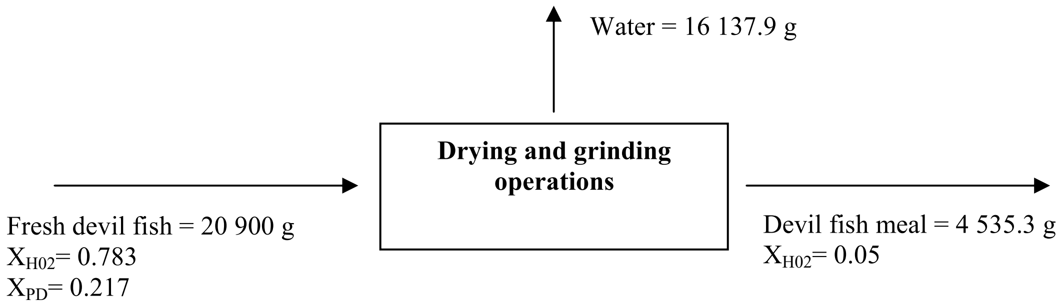


Figure 5. Mass balance for drying and grinding operations

Dry muscle separation

Before grinding dehydrated fish, it was observed that fillets were intact and due to shrinkage they could be easily separated. In order to evaluate the % muscle in the dry specimens, some were chosen and average mass of dry fillets was 17% of the fish body mass. If a higher quality fish meal were to be desired, this might be an interesting way of separation.

Granulometric distribution

Figures 6 to 9 show the granulometric distribution for the different meals used to prepare the diet, according to Table 3. In most cases, 80% of the particles were below 1.2 mm (mesh No. 18) without using the pulverizer. For the devil fish meal and wheat bran mix shear stress had to be increased to reach this parameter. However, no particle bigger than 1.2 mm went to the extrusion process. A standardization was reached according to the recommendations for the diets (Bortone, 2002; Gaxiola, 2007).

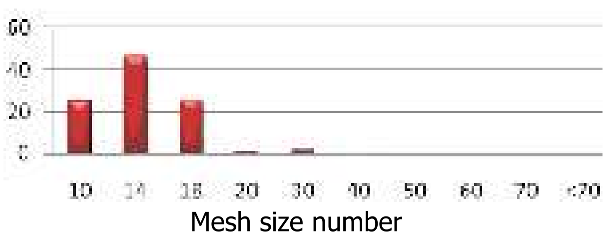


Figure 6. Granulometric distribution for devil fish meal

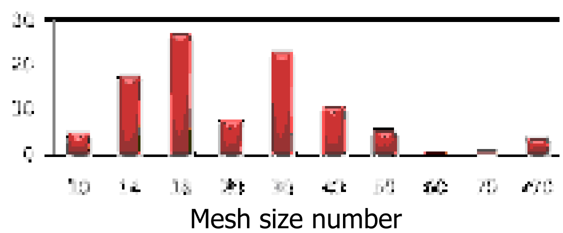


Figure 7. Granulometric distribution for degreased soybean paste

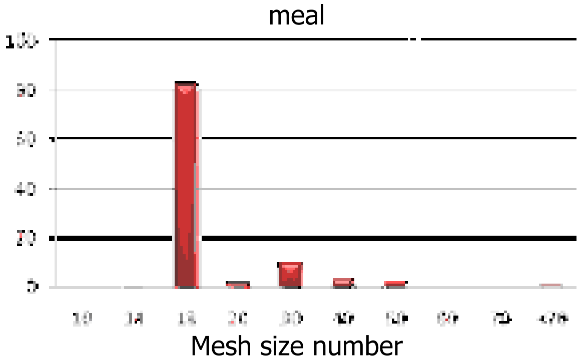


Figure 8. Granulometric distribution for finer wheat bran (*afrechillo* in Spanish)

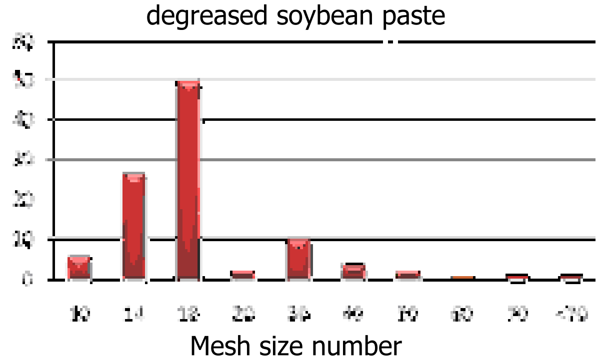


Figure 9. Granulometric distribution for coarse wheat bran (*afrecho* in Spanish)

Bromatological analyses

Results for the bromatological analyses for whole *Plecostomus punctatus* meal, for commercial fish meal, for *Plecostomus punctatus* dry fillets, for *Plecostomus punctatus* by-products, and for fresh

Plecostomus punctatus are presented in Tables 5 to 9, respectively. Also, as important parameter for the Part 2 extrusion experiments the bromatological analysis of the commercial feedstuffs for tilapia (Oreochromis spp.) are included.

Table 5. Bromatological analysis for the whole devil fish meals

Chemical analysis	% Wet basis	% Dry basis	Standard deviation
Dry matter	99.7	-	-
Moisture content	0.3		0.124%
Crude protein (Nitrogen factor, 6.25)	**47**	**47**	**0.079%**
Ether extract (crude fat)	15	15	0.192%
Ashes	32	32	0.183%
Crude fiber	3	3	0.072%
Extract free of nitrogen	3	3	-

Table 6. Bromatological analysis for the commercial fish meals

Chemical analysis	% Wet basis	% Dry basis	Standard deviation
Dry matter	92	-	-
Moisture content	8	-	0.051%
Crude protein (Nitrogen factor, 6.25)	**30**	**33**	**0.057%**
Ether extract (crude fat)	4	5	0.042%
Ashes	25	27	0.314%
Crude fiber	8	7	0.281%
Extract free of nitrogen	25	28	-

Table 7. Bromatological analysis for devil fish by-products

Chemical analysis	% Wet basis	% Dry basis	Standard deviation
Dry matter	34.4	-	-
Moisture content	65.6	-	0.049%
Crude protein (Nitrogen factor, 6.25)	**14.8**	**43.0**	**0.056%**
Ether extract (crude fat)	3.6	10.5	0.034%
Ashes	13.9	40.3	0.054%
Crude fiber	1.5	4.4	0.098%
Extract free of nitrogen	0.6	1.7	

Table 8. Bromatological analysis for devil fish dry fillets

Chemical analysis	% Wet basis	% Dry basis	Standard deviation
Dry matter	95.9	-	-
Moisture content	4.1	-	0.050%
Crude protein (Nitrogen factor, 6.25)	**80.8**	**84.3**	**0.178%**
Ether extract (crude fat)	5.7	5.9	0.087%
Ashes	4.4	4.6	0.041%
Crude fiber	0.03	0.03	0.024%
Extract free of nitrogen	4.9	5.2	-

Table 9. Bromatological analysis for devil fish fresh fillets

Chemical analysis	% Wet basis	% Dry basis	Standard deviation
Dry matter	16.9		
Moisture content	83.1		0.041%
Crude protein (Nitrogen factor, 6.25)	**14.3**	**84.7**	**0.018%**
Ether extract (crude fat)	0.7	3.3	0.005%
Ashes	1.0	6.6	0.008%
Crude fiber	0	0	0.000%
Extract free of nitrogen	0.9	5.3	

Some results for bromatological analyses are given in wet basis. For this study, dry basis results were considered more suitable for comparisons among them. The bromatological analyses for fresh devil fish allowed evaluation of possible losses of volatile components during the drying and grinding operations. It could be seen that these unit operations did not alter the composition of the products. Results are enlightening concerning the possible uses for the *Plecostomus punctatus* different body parts. For example, fresh and dried fillets have very low ashes content (6.1 and 4.6%, respectively), whereas devil fish by-products have a high ashes content due to the skeletons plates (40.3%).

These data indicate that ashes in fish meals (32%) come from the skeletal structures, including the "skin", viscera, and head, that are the socalled by-products. Something similar occurs with the ether extract (crude fat).

For feedstuffs, especially for the growing stage of tilapia, the most important nutrient is protein content. Whole devil fish, and even its by-products, have an interesting amount of this nutrient. Fillets are, evidently, a very important source of protein. Considering that their "skin", in fact armor plates, may contain chitin (Flores-Ortega et al., 2004), non proteinic nitrogen analyses were also carried out (NNP). Data shown in the above tables assume that all nitrogen is of protein origin but considering this fact, it becomes important to analyze non proteinic nitrogen. Also, commercial fish meals were analyzed. Results are presented in Table 10.

Table 10. Non proteinic nitrogen analyses, NNP

Componente	% Non proteinic nitrogen	% Total nitrogen	% Protein nitrogen
Devil fish meal	14.83	47.16	32.33
Devil fish by-products meal	15.92	43.30	27.38
Commercial fish meal	2.7	30.37	27.67

As it is shown in Table 10, the highest amount of non proteinic nitrogen is to be found in the devil fish by-products meal, as expected. When this value is deducted from the total Kjeldahl nitrogen, the content of protein nitrogen is calculated. It is interesting to corroborate that devil fish meal is within the parameters of the commercial fish meals (de 25 a 35%) with no significant differences between them ($p<0.05$).

Tables 11 and 12 present the protein and starch mass balances obtained during the preparation of a 1000 g diet with the components proposed by Gaxiola (2007) in Table 3, with the exception of the fish meal that was substituted by devil fish meal in the experiments presented in Part 2. Protein contents are within the recommended range for tilapia (Oreochromis spp.) in the growing stage (20-30%). Differences between the use of *Plecostomus punctatus* meal and commercial fish meal in the formulation are not significant ($p<0.05$) indicating that these feedstuffs are suitable for the tilapia.

Table 11. Protein mass balance in the diet

(1000g)	% in the mixture	Mass (g)	% protein[1]	Protein (g)
Degreased soybean paste[1]	25	250	50	125
Devil fish meal	15	150	32	48
Fine wheat bran[2]	33	330	17	56.1
Coarse wheat bran[3]	15	150	25	37.5
Total protein mass, g				**266.6**
Percentage of protein in the diet, %				**26.66**

[1](Baduí, 2006)
[2](Gallardo, 2003)
[3](Calaveras, 1966)

Table 12. Starch mass balance in the diet

(1000g)	% in the mixture	Mass (g)	% starch	Starch (g)
Fine wheat bran[1]	33	330	30[1]	99.0
Coarse wheat bran[1]	15	150	66[1]	99.0
Degreased soybean paste [2]	25	250	33[2]	82.5
Total starch mass, g				280.5
Percentage of starch in the diet, %				**28.5**

[1](Calaveras, 1966)
[2](Baduí, 2006)

Concerning starch, Table 12 indicates that this feedstuff excedes 20% of the necessary amount to have an adequate hydrostability (floatability). For this diet, starch does not exceed the necessary amount to warrant a suitable hydrostability (floatability). This issue will be studied in Part 2.

Conclusions

According to the objective of this first part of the research, the following conclusions can be drawn:

- Particle size of the different ingredients, including fish meals, play a very important role in the physical characteristics of the balanced feedstuffs before extrusion, and as it will be seen in Part 2, after extrusion. For this research, all raw materials were prepared to comply with the particle size specifications. The unit operations of grinding and screening are very important for a scaling up of the process and should be optimized to reduce costs in order to have an economically feasible project, especially for the fishermen of the surrounding communities near the dam "El Infiernillo"

- Considering the bromatological analyses, the whole meal produced from *Plecostomus punctatus* has the necessary protein to be successfully used in the preparation of extruded feedstuffs for valuable commercial species, such as tilapia (Oreochromis spp.)

- Starch percentage in the diet seems to be adequate to reach good physical characteristics in the feedstuff (hydrostability, loss of matter, and % of expansion). Its value is around 28% according to the mass balances carried out in this part of the research.

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