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Research Article

Mango meals (*Mangifera indica* L. var. Ataulfo) as an energy source in diets for juvenile Nile tilapia (*Oreochromis niloticus*): growth parameters and blood biochemistry

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ABSTRACT. The present study evaluated the growth and blood biochemistry response of juvenile Nile tilapia (*Oreochromis niloticus*) fed mango (*Mangifera indica* L. var. Ataulfo) by-products (peel, seed, and pulp) as an energy source in partial substitution for fish meal (FM). Six experimental diets were prepared with 10 and 20% FM replacement using mango peel, seed, and pulp meals, as well as a control diet without mango inclusions. All diets were formulated as isolipidic (7%) and isoenergetic (18 kJ kg^{-1}). For 60 days, juvenile tilapia (average initial weight of 2.4 ± 0.3 g) were fed with the diets. At the end of the experiment, weight gain, specific growth rate, and feed conversion ratio were significantly influenced by the mango energy source, with diets containing pulp (10 and 20% substitution) producing the best growth values. Likewise, the viscerosomatic index increased significantly when mango pulp was included in the diets. In contrast, the protein efficiency ratio was higher at the higher mango by-product inclusion level (20%), regardless of the type of by-product. In blood biochemistry, triglycerides and cholesterol decreased in fish-fed diets containing peel and seed meals, while total plasma protein decreased in diets with 20% of by-products. The present study demonstrates that it is possible to substitute up to 50% of the FM, as well as a saving of up to 25% of the total protein in the diet, with the use of mango pulp meal without affecting the growth or blood biochemistry of *O. niloticus*.

Keywords: by-products; vegetable meal; carbohydrates; fishmeal replacement; physiology; body composition

INTRODUCTION

Aquaculture is an important agricultural sector worldwide that contributes to food security and animal protein production; however, aquaculture is far from being a sustainable activity due to the high dependence on fishmeal (FM), which is reflected in the high cost of the feed used for this activity, which represent up to 60% of production costs; so, it is imperative to improve the production of this input (Han et al. 2018, Berger 2020, FAO 2024). Due to this, it is necessary to seek alternatives that reduce these ingredients in aquaculture

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feeds without compromising the growth and health of the organisms (Zhu et al. 2021). One widely used strategy is the use of vegetable meals as the primary source of energy. Among the advantages that this entails are their easy acquisition, high energy value (Arriaga-Hernández et al. 2021), and lower costs compared to FM (Ansari et al. 2021). Furthermore, it has been observed that diets with high levels of carbohydrates promote greater energy efficiency, resulting in savings in protein and production costs (Kumkhong et al. 2020, Srisakultiew et al. 2022), without affecting the growth of the organisms (Lu et al. 2018, Sulaiman et al. 2020). In this sense, different vegetable meals such as soybean (Godoy et al. 2019) and corn (Khalifa et al. 2018) have been tested in aquaculture feeds in freshwater fish such as Nile tilapia (*Oreochromis niloticus*) (Boonanuntanasarn et al. 2018, Zhu et al. 2021), common carp (*Cyprinus carpio*) (Cheng et al. 2019), gibel carp (*Carassius gibelio*) (Li et al. 2019), japanese flounder (*Paralichthys olivaceus*) (Yang et al. 2020) and Pac-Man catfish (*Lophiosilurus alexandri)* (Oliveira-Junior et al. 2021), where it has been shown that the replacement of energy from carbohydrates does not affect the health of organisms or various productive parameters such as weight gain, specific growth rate and survival. Although vegetable meals from cereals such as soybean (Zhou et al. 2018, Arriaga-Hernandez et al. 2021) and corn (Luo et al. 2016, Zhu et al. 2021) have been used, some fruits such as banana (e Silva et al. 2020), papaya (Hamid et al. 2022), and mango (Obasa et al. 2013, Souza et al. 2013, Souza et al. 2020, Adesina & Adesuyan 2021) have also been used as carbohydrate sources in fish diets with positive results.

Mango var. Ataulfo (*Mangifera indica* L.) is a fruit of great commercial importance in Mexico, where it ranks third in harvested area, accounting for 16.5% of the total harvested area in 2022 (SADER 2022). However, one of the industry's main problems is the generation of large volumes of by-products, resulting in approximately 32% of the fruit becoming waste since the peel and seeds are not utilized at an industrial level. Additionally, 18% of the production is lost in the orchards due to aesthetic damage to the fruit (Wall-Medrano et al. 2015). All these residues contain macronutrients, mainly carbohydrates, which can serve as an energy source, in addition to containing vitamins A, B, and C, as well as phenolic compounds with potential antioxidant capacity (Kim et al. 2010).

On the other hand, Nile tilapia is the third most cultivated species worldwide (FAO 2024). It is an omnivorous organism with biological characteristics that facilitate its production in captivity, such as easy reproduction, rapid growth, and tolerance of high culture densities (Coward & Bromage 2000, García-Trejo et al. 2016). The use of fruits as a source of carbohydrates has been evaluated in Nile tilapia, obtaining favorable results specifically on the growth and health parameters of the organisms, like Ugonna et al. (2018) with pawpaw *Carica papaya*, but also Souza et al. (2013) whom used mango meal with peel as carbohydrate source in substitution of corn for tilapia juvenile growth and after 45 days of feeding, researchers concluded that 33% of mango meal can be used in substitution for corn in Nile tilapia feed without damage for growth performance and carcass chemical composition. Otherwise, posteriori studies by Souza et al. (2020) evaluated the use of up to 30% mango pulp meal as an ingredient in extruded diets for Nile tilapia juveniles. However, the growth performance of the fish was negatively impacted; therefore, this study concludes that the inclusion of concentrations of 5% or greater resulted in metabolic changes in proteins and poor performance.

One of the tools for monitoring the health of organisms in culture is the evaluation of blood biochemistry parameters (Coz-Rakovac et al. 2018). Measuring these parameters enables us to identify health problems, deficiencies, and/or nutrient imbalances, as well as stress, anemia, and dehydration, among many other variables within the organism (Mirghaed et al. 2017). In Nile tilapia, it is common to analyze these variables as an indication of the health and well-being of the fish (Nascimento et al. 2019, Souza et al. 2020, Zhu et al. 2021); however, to date, there are few studies in which the effect of the use of mango by-products on the performance and blood biochemistry of juvenile Nile tilapia has been evaluated. Due to this, the present study utilizes agro-industrial waste (peel, seed, and pulp) from Ataulfo mango (*M. indica* L. var. Ataulfo) as a partial substitute for the energy of FM in diets for juvenile Nile tilapia, examining its effect on growth parameters and blood biochemistry.

MATERIALS AND METHODS

Obtaining raw materials (Ataulfo mango) and meal production

The peels and seeds of Ataulfo mango were donated by the dehydrating company "El Chalatal" located in Villa Union, Sinaloa, Mexico. The whole ripe mangoes were collected from two orchards in southern Sinaloa and northern Nayarit. All raw materials were transported to

the Laboratorio de Botánica Acuática de la Facultad de Ciencias del Mar, Universidad Autónoma de Sinaloa. The peels and seeds were transported on ice (4ºC), while the whole mango was transported in containers at room temperature. The peels and seeds were stored at -18°C, and the whole mango at 24°C, until the meals of each by-product were prepared.

The mango peel (without pulp) was cut into small pieces and dried at 80°C for 5 h in a dehydrating oven (Semillas de Vida, SS 06A, Mexico). The mango seeds were continuously sun-dried for 6-8 h (Quintana et al. 2019). Because the mango seed (kernel) contains compounds such as tannins, saponins, and cyanogenic glycosides in small amounts, the seed was extracted, cut into pieces, and washed according to the methodology of Dakare et al. (2012) and García & Jarquín (2015). Subsequently, the seed pieces were dried at 55°C for 12 h in a dehydrating oven (Semillas de Vida, SS 06A, Mexico). The mango pulp was sliced into thin sheets using a knife and then dried at 60°C for 12 h in a dehydrating oven (Semillas de Vida, SS 06A, Mexico). Once dried, the mango peels, seeds, and pulp were ground using a coffee grinder (Semillas de Vida, SS M700, Mexico) and then sieved to a 250 µm mesh size. The meals were stored in plastic containers at 4°C until they were used. The ingredients of the experimental diets were proximally chemically analyzed before formulation (Table 1).

Proximate chemical analysis

The total moisture, ash, crude protein, total lipids, and nitrogen-free extract (NFE) content of the ingredients, as well as the experimental diets and fish samples, were determined. Content moisture was determined using the AOAC (2002) method 4.1.06, in which the samples were placed in a drying oven at 105°C for 24 h. Ash content was processed using a muffle furnace at 550°C for 8 h (AOAC method 32.1.05). Crude protein was determined by the microKjeldahl method (N × 6.5; AOAC 954.01). Total lipids were determined using the method of Folch et al. (1957). The NFE was calculated using the following mathematical equation: NFE = 100% - (% ash + % crude protein + % lipids + % moisture) (Hossain & Alam 2015).

Experimental design and diet development

The experimental design consisted of six experimental diets with the Ataulfo mango by-products (peel, seed, and pulp) at two inclusion levels (10 and 20%) equivalent to 25 and 50% of replacement of FM respectively, which are identified as diets with 10 and 20% peel (PE10 and PE20, respectively), diets with 10 and 20% seed (SE10 and SE20, respectively), diets with 10 and 20% pulp (PU10 and PU20, respectively). A control diet (CT) with 0% mango by-products was also prepared. All diets were prepared to be isolipidic and isoenergetic (Table 2).

The diet preparation was done according to the modified methodology of Lizárraga-Velázquez et al. (2019). The ingredients were weighed on a scale (± 0.1 g), where the macro ingredients (FM, soybean meal, mango meal, wheat meal, corn meal, gluten, and corn starch) were mixed in a blender for 5 min until a homogeneous mixture was obtained. Subsequently, the micro-ingredients (vitamin mixture, mineral mixture, vitamin C, choline chloride, and alginate) were added and mixed for an additional 5 min. Finally, the liquid ingredients (previously mixed fish oil, soy lecithin, and 500 mL of water) were added and mixed for 8 min until a homogeneous mass was obtained, which was then passed through a meat grinder three times using a 3.5 mm diameter die. The pellets were dried for 5 h at 60°C in a dehydrating oven and stored at 4°C until use.

Fish culture and feeding conditions

All diets were evaluated in a triplicate bioassay, with the diets and replicas distributed randomly to comply with the statistical principle of randomness. For this, a culture system with 21 tanks with a maximum capacity of 150 L and a central gravity drainage system were used. Freshwater previously filtered through a 50 µm cartridge filter was used. The tanks had an aeration system connected to a blower and were covered with a 1 cm^2 mesh to prevent fish escape.

For the experiment, the fish were handled and slaughtered in accordance with the recommendations of the OIE (2019). After the selection of the fish, they were anesthetized with clove oil (0.2 mL L^{-1}) (Durville & Collet 2001). Subsequently, 210 juvenile Nile tilapia (with an initial average weight of 2.2 ± 0.5 g and an initial average size of 4.5 ± 0.9 cm) were randomly distributed in 21 tanks. During the 60 days of the experiment, the feeding rate used was 10% of the total biomass, divided into rations per day (9:00, 13:00, and 17:00 h) (Souza et al. 2013, Niang et al. 2020). Likewise, each week, a group of fish from each replicate was anesthetized (Durwille & Collet 2001) and weighed (± 0.1 g) to determine the biomass and adjust the feeding rations.

Daily temperature (ºC) and dissolved oxygen (mg L^{-1}) were measured twice daily (8:00 and 16:00 h) with an oximeter (YSI Pro20/Pro20i, OH 45387). Additionally, all tanks underwent a 10% water change daily and a 100% water change every seven days.

Table 1. Proximate composition (%, dry basis) of ingredients used for the design of the experimental diets. SBM: soybean meal, FM: fish meal, MPEM: mango peel meal, MSEM: mango seed meal, MPUM: mango pulp meal, WF: wheat meal, CG: corn gluten, NFE: nitrogen-free extract (Hossain & Alam 2015).

Proximal parameters	Ingredients						
	SBM	FM	MPEM	MSEM	MPUM	WF	CG
Moisture content	9.8	7.4	6.3	10.4	15.7	13.1	10.9
Dry matter	90.2	92.6	93.7	89.6	84.3	86.9	89.1
Crude protein	49.1	70.2	4.2	7.3	5.3	11.7	68.2
Total lipids	1.0	7.9	2.2	1.0	3.6	3.4	6.6
Ash	1.6	12.7	3.5	0.6	2.6	0.6	2.0
NFE	38.5	1.6	83.6	80.5	72.7	71.1	12.2
Energy kJ kg^{-1}	18.6	20.0	16.2	16.0	15.2	16.3	20.8

Zootechnical and biological indices

The zootechnical and biological indices were evaluated in terms of: weight gain (WG = final average weight (g) - initial average weight (g)); specific growth rate (SGR = (ln final weight (g) - ln initial weight (g) / number of days) × 100); feed conversion ratio (FCR = feed consumed (g) / weight gained (g)); protein efficiency ratio (PER = weight gain (g) / protein consumed (g)); survival (%S = (final number of organisms / initial number of organisms) × 100).

At the end of the 60-day experiment, tissues were obtained for corresponding analyses by euthanizing the organisms according to the Norma Oficial Mexicana-062-ZOO-1999 and the OIE (2019) guidelines. After obtaining the total weight, the visceral mass was removed and weighed from 12 fish per diet. These data were used to determine the viscerosomatic index (VSI = (viscera weight (g) / total body weight (g) × 100); hepatosomatic index (HIS = (liver weight (g) / total body weight (g)) × 100), and condition factor (CF = (total body weight (g) / total body length (cm^3)) × 100).

Blood biochemistry analysis

For blood biochemistry analysis, fish were fasted for 24 h and then anesthetized with clove oil at 0.2 mL L^{-1} (Durville & Collet 2001) for blood collection. Blood samples were taken from 12 fish per diet (four fish per tank). Blood was obtained by cardiac puncture using insulin syringes (1 mL) with 0.16 mL of 10% ethylenediaminetetraacetic acid (EDTA) anticoagulant solution (Valenzuela et al. 2002), and immediately transported to the Laboratorio de Biotecnología y Sanidad Acuícola de la Facultad de Ciencias del Mar, in rows with ice and in the absence of light, where the samples were centrifuged at 11,269 RCF for 5 min at 4ºC to recover plasma for analysis (Atencio-García et al. 2007). Standardized commercial kits (Pointe Scientific, USA) were used to determine the concentration of triglycerides (TG), glucose (GLU), total cholesterol (CHO), albumin (AL), and total protein (TP). The globulin (GBL) concentration was obtained with the following formula: GBL = TP (g dL^{-1}) - total albumin (g dL^{-1}); the AL:GBL ratio was obtained as follows: total albumin (g dL^{-1}) / total globulin (g dL^{-1}).

Statistical analysis

Before statistical analysis, the percentages (SGR, S, HI, VI, CF, and proximal parameters) were arcsine transformed (Zar 2010). The Shapiro-Wilk and Levene tests were performed to determine the normality and homoscedasticity of the data, respectively. A two-way analysis of variance (ANOVA) was performed to determine the main and interaction effects between the type of by-product (peel, seed, and pulp) and the inclusion level (10 and 20%). When significant results were obtained by a factor (type of by-product, inclusion level, or their interaction), a one-way ANOVA analysis was performed to determine differences between the diet groups. A Tukey's test was used when differences between means were found. All statistical analyses were executed at a significance level of $P < 0.05$. Data are reported as mean ± standard deviation. All analyses were performed with SigmaPlot 12.0 Software.

RESULTS

Growth parameters and zootechnical indices

The average water temperature during the experiment was 26.7 ± 1.1°C, and the dissolved oxygen concentration had an average value of 4.9 ± 0.5 mg L^{-1}, which is optimal for the development and growth of *O. niloticus*. Regarding productive parameters, the survival rate was

Table 2. Experimental diets (g 100 g^{-1}, dry basis) with different levels of Ataulfo mango by-product (*Mangifera indica* L.) for juvenile Nile tilapia (*O. niloticus*). FM: fish meal; SBM: soybean meal; WM: wheat meal; CM: corn meal; MPEM: mango peel meal; MSEM: mango seed meal; MPUM: mango pulp meal; CG: corn gluten; CT: control diet; PE10: diet with 10% replacement with mango peel meal; PE20: diet with 20% replacement with mango peel meal: SE10: diet with 10% replacement with mango seed meal; SE20: diet with 20% replacement with mango seed meal; PU10: diet with 10% replacement with mango pulp meal; PU20: diet with 20% replacement with mango pulp meal. NFE: nitrogen-free extract (Hossain & Alam 2015); P/E: protein/energy. [1]Selecta de Guaymas, S.A. de C.V. Guaymas, Sonora, Mexico. [2]Proteinas Marinas y Agropecuarias, S.A. de C.V., Guadalajara, Jalisco, Mexico. [3]Droguerıa Cosmopolita, S.A. de C.V. México, D.F., Mexico. [4]MUNSA Molinos, S.A. de C.V. Mazatlán, Sinaloa, Mexico. [5]GRUPO INDUSTRIAL MASECA S.A.B. de C.V. Monterrey, Nuevo León, Mexico. [6]Sigma-Aldrich Chemical, S.A. de C.V. Toluca, Estado de México, Mexico. [7]Premix: vitaminas y minerales. Trouw Nutrition Mexico S.A. de C.V. *Vitamin premix composition: vitamin A, 10,000,000 IU or mg g^{-1}; vitamin D3, 2,000,000 IU; vitamin E, 100,000 g; vitamin K3, 4.00 g; thiamine B1, 8.00 g; riboflavin B2, 8.70 g; pyridoxine B6, 7.30; vitamin B12, 20.00 mg; niacin, 50.00 g; pantothenic acid, 22.20 g; inositol, 153.80 g; nicotinic acid, 160.00 g; folic acid, 80 mg; biotin, 500 mg; vitamin C, 100.00 g; choline, 300.00 g; excipient q.s., 2,000.00 g. **Mineral premix composition: manganese, 100 g; magnesium, 45.00 g; zinc, 160 g; iron, 200 g; copper, 20 g; iodine, 5 g; selenium,400.00 mg; cobalt, 600.00 mg. Excipient q.s. 1,500.00 g. [8]DSM Nutritional Products Mexico S.A. de C.V., El Salto, Jalisco, Mexico. [9]62% active agent, ICN Biomedicals Inc., Aurora, OH, USA. [10]Values are means of three determinations.

Ingredients	Experimental diets						
	CT	PE10	PE20	SE10	SE20	PU10	PU20
FM[1]	40.90	30.90	20.90	30.90	20.90	30.90	20.90
SBM[2]	26.40	26.40	26.40	26.40	26.40	26.40	26.40
Oil fish[3]	0.33	1.20	2.07	0.66	1.00	1.05	1.78
WM[4]	5.00	5.00	5.00	5.00	5.00	5.00	5.00
CM[5]	10.22	10.22	10.22	10.22	10.22	10.22	10.22
MPEM	0.00	10.00	20.00	0.00	0.00	0.00	0.00
MSEM	0.00	0.00	0.00	10.00	20.00	0.00	0.00
MPUM	0.00	0.00	0.00	0.00	0.00	10.00	20.00
Corn starch[3]	6.00	5.13	4.26	5.67	5.33	5.28	4.55
CG[6]	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Premix[7]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Soy lecithin[8]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin C[8]	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Antioxidant[8]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Choline chloride[9]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Alginate[3]	2.00	2.00	2.00	2.00	2.00	2.00	2.00
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Proximate composition (%, dry basis)[10]							
Moisture content	6.6	10.9	7.0	10.0	9.1	8.6	10.6
Dry matter	93.4	89.1	93.0	90.0	90.9	91.5	89.4
Crude protein	47.3	39.6	34.4	40.6	35.2	41.7	33.4
Total lipids	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Ash	9.2	8.0	6.9	7.5	6.2	7.8	6.9
NFE	29.1	35.0	45.3	35.4	42.8	35.1	42.2
Energy kJ kg^{-1}	18.9	18.1	18.6	18.4	18.4	18.6	18.0
Ratio P/E (mg kJ^{-1})	25.0	21.8	18.4	22.0	19.1	22.3	18.6

higher than 90% in all experimental groups, without showing a statistically significant difference ($P > 0.05$) (Table 3). On the other hand, the two-way ANOVA indicated that, independently, the inclusion levels (10 and 20%), as well as the type of by-product (peel, seed, or pulp), produced significant effects on WG, which decreased with the increase in the inclusion of seeds and peels, but that in fish fed with pulp up to 20%, there were no differences ($P < 0.05$) concerning the control without by-products (Table 3). The interaction of factors influenced the SGR, both the type of by-product and its inclusion level, so it can be observed that the fish fed with the highest inclusion of seed (SE20) presented the lowest SGR (3.0 ± 0.4% d^{-1}), showed a difference

Table 3. Zootechnical parameters of Nile tilapia (*O. niloticus*) fed with experimental diets with inclusion of mango by-products (*Mangifera indica* L.). WG: weight gain; SGR: specific growth rate; S%: survival; FCR: feed conversion ratio; PER: protein efficiency ratio. Values are mean ± standard deviation. Different superscript capital letters (A,B,C) in the same column indicate significant differences with respect to the inclusion level (10 and 20%); different superscript lowercase letters (a,b,c) in the same column indicate significant differences with respect to the type of by-product (peel, seed and pulp); last letters of the alphabet (v,w,x,y,z) in superscript in the same column indicate significant differences by the interaction of factors: substitution level × by-product type. Different superscript letters within rows indicate significant differences ($P < 0.05$) as determined by Tukey's test.

Inclusion	By-products	WG (g)	SGR (% d^{-1})	S (%)	FCR	PER
0	Control (CT)	22.9 ± 5.7^{Aa}	3.8 ± 0.4^{vw}	100 ± 0.0	1.2 ± 0.1^{c}	1.7 ± 0.1^{B}
10	Peel (PE10)	18.7 ± 6.8^{Bb}	3.5 ± 0.5^{wx}	90 ± 17	1.5 ± 0.1^{a}	1.8 ± 0.1^{B}
	Seed (SE10)	15.8 ± 4.7^{Bb}	3.2 ± 0.5^{xyz}	90 ± 0.0	1.4 ± 0.1^{a}	1.7 ± 0.1^{B}
	Pulp (PU10)	23.8 ± 5.0^{Ba}	3.8 ± 0.3^{v}	100 ± 0.0	1.3 ± 0.1^{b}	1.9 ± 0.2^{B}
20	Peel (PE20)	13.7 ± 3.6^{Cb}	3.0 ± 0.3^{y}	100 ± 0.0	1.4 ± 0.1^{a}	2.0 ± 0.1^{A}
	Seed (SE20)	13.5 ± 3.7^{Cb}	3.0 ± 0.4^{yz}	93 ± 12	1.4 ± 0.1^{a}	2.1 ± 0.1^{A}
	Pulp (PU20)	21.5 ± 4.6^{Ca}	3.7 ± 0.3^{vw}	100 ± 0.0	1.3 ± 0.1^{b}	2.1 ± 0.1^{A}
By-product		<0.001	0.001	0.270	0.017	0.075
Inclusion		<0.001	0.009	0.289	0.057	<0.001
By-product x inclusion		0.216	0.007	0.597	0.252	0.473

($P < 0.05$) with PU20 that presented average values of $3.7 \pm 0.3\%$ d^{-1}. However, no differences ($P > 0.05$) were observed between the PE10, PU10, and PU20 diets and the CT ($3.8 \pm 0.4\%$ d^{-1}). Regarding the FCR, this was mainly influenced by the type of by-product, as both pulp diets (FCR values of 1.3 ± 0.1) were lower than those observed with mango peel and seed (Table 3). The two-way ANOVA showed significance concerning the inclusion level for the PER; the highest values were obtained in the diets with 20% inclusion (2.0 ± 0.1) being statistically different ($P < 0.05$) to those of 10% inclusion (1.8 ± 0.1) who obtained the lowest values without significant differences ($P > 0.05$) with the CT (1.7 ± 0.1).

Biological indices

The lowest CF values were observed in fish fed with 10% of any of the by-products (average values of 1.64-1.70), which were significantly different compared to the CT (1.84 ± 0.05) ($P < 0.05$) (Table 4). On the other hand, diets with 20% inclusion showed CF values (average values of 1.69-2.00), with no significant differences observed ($P > 0.05$) to the CT. The VSI was shown to be altered by the type of by-product, in which, regardless of the quantity (10 or 20%), the pulp induced a higher VSI compared to the diets with peel or seed. However, the values observed in all experimental diets were not significantly different ($P > 0.05$) from those of CT. In the case of the HSI, no significant differences ($P > 0.05$) were found with any of the diets.

Proximal composition of whole fish

The proximate composition of the fish, including crude protein and total lipids, was significantly influenced by the interaction between by-products and their inclusion level (Table 5). Likewise, the comparative analyses between diets show that fish fed both pulp levels (10 and 20%) and those with 20% seed obtained the highest values of body crude protein (16.2-16.3%). In comparison, those fed with peel at a 10% inclusion rate had the lowest values ($15.2 \pm 1.0\%$), while the other diets did not show significant differences among them ($P > 0.05$). Regarding ash, the CT ($5.3 \pm 1.0\%$) and PU20 ($5.0 \pm 1.7\%$) showed the highest values, although, in the case of PU20, its value was not significantly different ($P > 0.05$) from the rest of the diets. In the case of total lipids, although no main effect or interaction was observed with respect to by-products and their inclusion levels, the analysis comparing the experimental diets with CT ($2.1 \pm 0.4\%$) revealed that the latter was lower.

Blood plasma biochemistry

The results obtained from blood plasma biochemistry indicate that the different parameters analyzed in this study were influenced by at least one of the research factors, either through the principal effect or the interaction effect (Table 6). Thus, in the case of GLU, the effect of the inclusion level and type of by-product was independent, with pulp inducing the highest values (above 53 mg dL^{-1}). Meanwhile, the 20% peel level

Table 4. Biological indices of *Oreochromis niloticus* fed with experimental diets with inclusion of mango by-product meal (*Mangifera indica* L.). CF: condition factor; VSI: viscerosomatic index; HSI: hepatosomatic index. Values are mean ± standard deviation. Different superscript capital letters (A,B,C) in the same column indicate significant differences with respect to the inclusion level (10 and 20%); different superscript lowercase letters (a,b,c) in the same column indicate significant differences with respect to the type of by-product (peel, seed and pulp); last letters of the alphabet (v, w, x, y, z) in superscript in the same column indicate significant differences by the interaction of factors: inclusion level x by-product type. *Indicates significant differences of the CT with respect to the experimental diets. Different superscript letters within rows indicate significant differences ($P < 0.05$) as determined by Tukey's test.

Inclusion	By-products	CF	VSI	HSI
0	Control (CT)	1.84 ± 0.05^{A}	9.33 ± 1.30^{ab}	1.43 ± 0.23
10	Peel (PE10)	1.70 ± 0.7^{B}	9.23 ± 1.29^{b}	2.12 ± 0.44
	Seed (SE10)	1.64 ± 0.13^{B}	8.13 ± 0.82^{b}	1.96 ± 0.50
	Pulp (PU10)	1.69 ± 0.18^{B}	10.97 ± 0.73^{a}	2.37 ± 1.39
20	Peel (PE20)	1.73 ± 0.13^{AB}	8.43 ± 1.37^{b}	2.16 ± 0.43
	Seed (SE20)	1.69 ± 0.11^{AB}	8.12 ± 1.83^{b}	1.94 ± 0.19
	Pulp (PU20)	2.00 ± 0.37^{AB}	10.77 ± 2.23^{a}	1.90 ± 0.22
By-products		0.077	<0.001	0.738
Inclusion		0.037	0.499	0.509
By-products x inclusion		0.169	0.749	0.595

Table 5. Proximal chemical analysis (% wet basis) of whole fish from juvenile Nile tilapia (*O. niloticus*) fed experimental diets with inclusion of mango by-products (*Mangifera indica* L.). Values are mean ± standard deviation. Different superscript capital letters (A,B,C) in the same column indicate significant differences with respect to the inclusion level (10 and 20%); different superscript lowercase letters (a,b,c) in the same column indicate significant differences with respect to the by-product type (peel, seed and pulp); The last letter of the alphabet (v,w,x,y,z) in superscript in the same column indicate significant differences by the interaction of factors: inclusion level x by-product type. The symbol *Indicates significant differences of the CT with respect to the experimental diets. Different superscript letters within rows indicate significant differences ($P < 0.05$) as determined by Tukey's test.

Inclusion	By-products	Moisture	Dry matter	Crude protein	Total lipids	Ash
0	Control (CT)	73 ± 1.4	26 ± 1.4	15.1 ± 3.1^{yz}	$2.1 \pm 0.4^{*}$	5.3 ± 1.0^{y}
10	Peel (PE10)	74 ± 2.2	26 ± 2.3	15.2 ± 1.0^{z}	3.0 ± 0.5	4.1 ± 1.4^{yz}
	Seed (SE10)	74 ± 2.2	26 ± 2.3	16.1 ± 2.8^{yz}	3.1 ± 0.6	4.2 ± 3.0^{yz}
	Pulp (PU10)	75 ± 1.2	25 ± 1.2	16.3 ± 1.1^{y}	3.0 ± 0.6	4.2 ± 0.7^{yz}
20	Peel (PE20)	74 ± 2.1	26 ± 2.1	16.1 ± 2.3^{yz}	3.0 ± 1.3	4.0 ± 1.0^{z}
	Seed (SE20)	74 ± 2.0	26 ± 2.0	16.2 ± 1.9^{y}	3.1 ± 0.7	4.2 ± 0.5^{yz}
	Pulp (PU20)	73 ± 1.4	27 ± 1.4	16.3 ± 1.1^{y}	3.1 ± 1.0	5.0 ± 1.7^{yz}
By-products		0.311	0.245	0.118	0.859	0.167
Inclusion		0.447	0.221	0.204	0.888	0.624
By-products x inclusion		0.435	0.411	0.004	0.391	0.021

showed significantly lower values (37.6 ± 13.1 mg dL^{-1}). However, the CT diet (50.5 ± 10.7 mg dL^{-1}) showed significant differences ($P < 0.05$) compared to the PE20 diet and was not significantly different ($P > 0.05$) from the PU10 and PU20 diets.

Regarding triglycerides, the CT diet had the highest values (108.4 ± 31.9 mg dL^{-1}). No significant differences are observed ($P > 0.05$) in the pulp diets at both levels (values above 96 mg dL^{-1}). The lowest values were obtained in the diet fed with SE10 (42.9 ± 16.9 mg dL^{-1}). CHO, on the other hand, showed an increasing trend in its values with the increase in the by-product level, with 125.2 mg dL^{-1} overall average for the 20% level compared to the 10% level (112.9 mg dL^{-1}); in the case of the by-product type effect, it was the pulp that induced a higher average CHO concentration. However, the values obtained for the CT (122.5 ± 14.0 mg dL^{-1}) only showed significant differences ($P < 0.05$) with the PE10 and SE10 diets. The TP concentration was found to be highly influenced

Table 6. Blood biochemistry of *O. niloticus* fed experimental diets replacing fishmeal with mango by-product meals (*Mangifera indica* L.). Values are mean ± standard deviation. GLU: glucosa; TGL: triglycerides; CHO: cholesterol; TP: total protein; AL: albumin; AL:GLB: albumin-globulin ratio. Different superscript capital letters in the same column indicate significant differences with respect to the inclusion level (10 and 20%); different superscript lowercase letters in the same column indicate significant differences with respect to the type of by-product (peel, seed and pulp); last letters of the alphabet (v,w,x,y,z) in superscript in the same column indicate significant differences by the interaction of factors: inclusion level x by-product type. Different superscript letters within rows indicate significant differences ($P < 0.05$) as determined by Tukey's test.

Inclusion	By-product	GLU (mg dL^{-1})	TGL (mg dL^{-1})	CHO (mg dL^{-1})	TP (g dL^{-1})	AL (g dL^{-1})	GLB (g dL^{-1})	AL:GLB
0	Control (CT)	50.5 ± 10.7^{Aa}	108.4 ± 31.9^{a}	122.5 ± 14.0^{Aa}	3.84 ± 0.61^{B}	3.05 ± 0.37^{ab}	0.78 ± 0.49^{x}	3.91 ± 1.36^{x}
10	Peel (PE10)	52.8 ± 15.0^{Ab}	61.3 ± 30.5^{b}	98.5 ± 11.3^{Bb}	4.70 ± 0.82^{A}	2.89 ± 0.29^{b}	1.80 ± 0.69^{w}	1.60 ± 0.96^{z}
	Seed (SE10)	49.2 ± 12.7^{Ab}	42.9 ± 16.1^{b}	112.4 ± 19.0^{Bb}	4.69 ± 1.19^{A}	2.78 ± 0.18^{b}	1.03 ± 0.65^{xy}	2.69 ± 1.09^{y}
	Pulp (PU10)	53.4 ± 11.2^{Aa}	96.1 ± 45.3^{a}	127.7 ± 19.0^{Ba}	4.76 ± 0.96^{A}	3.24 ± 0.43^{a}	1.90 ± 1.23^{w}	1.70 ± 1.12^{z}
20	Peel (PE20)	37.6 ± 13.1^{Bb}	46.6 ± 22.8^{b}	119.7 ± 15.9^{Ab}	3.61 ± 0.74^{B}	2.78 ± 0.23^{b}	1.16 ± 0.52^{yz}	2.39 ± 0.62^{y}
	Seed (SE20)	41.9 ± 13.8^{Bb}	56.4 ± 27.5^{b}	129.8 ± 22.7^{Ab}	3.99 ± 0.51^{B}	2.83 ± 0.38^{b}	1.90 ± 0.60^{w}	1.48 ± 0.89^{z}
	Pulp (PU20)	54.9 ± 14.6^{Ba}	96.7 ± 46.0^{a}	126.1 ± 29.2^{Aa}	4.20 ± 1.26^{B}	3.18 ± 0.62^{a}	1.12 ± 0.82^{yz}	2.83 ± 1.10^{y}
By-products		0.040	<0.001	0.012	0.487	<0.001	0.984	0.707
Inclusion		0.031	0.978	0.012	<0.001	0.632	0.348	0.176
By-products x inclusion		0.110	0.342	0.123	0.614	0.776	0.002	0.015

by the inclusion level, with significant differences ($P < 0.05$) between diets with 10% inclusion (PE10, SE10, and PU10) (4.71 g dL^{-1} overall mean value) and diets with 20% inclusion (PE20, SE20, and PU20) (3.93 g dL^{-1} overall mean value). The PU20 diet (4.20 ± 1.26 g dL^{-1}) did not show significant differences ($P > 0.05$) compared to the CT diet. Unlike TP, AL was significantly influenced by the type of by-product, with pulp (PU10 and PU20) presenting the highest average values (3.24 and 3.18 g dL^{-1}, respectively), showing no significant differences ($P > 0.05$) in relation to the CT diet.

AL:GLB ratio were significantly influenced by the interaction of the evaluated factors (by-product type *vs*. inclusion level), which, in the case of GLB, was the 10% level that induced a higher average concentration (1.58 g dL^{-1} overall average value), except for the SE10 diet that showed the lowest values concerning all diets (1.03 ± 0.65 g dL^{-1}) which no significant differences presented ($P > 0.05$) with CT (0.78 ± 0.49 g dL^{-1}). Finally, and in inverse response to the previous parameter, the AL:GLB ratio was lower in diets SE20 (1.48 ± 0.89), PE10 (1.60 ± 0.96), and PU10 (1.70 ± 1.12), being statistically different ($P < 0.05$) from the rest of the diets where CT obtained the highest average (3.91 ± 1.36).

DISCUSSION

Aquaculture has utilized plant-based ingredients as an economical energy source in diets for various animal species, yielding positive results (Herath et al. 2016, Han et al. 2021, Cruz-García et al. 2022, Neves et al. 2024). Other studies have investigated the effects of mango by-product inclusion on various fish species, including Nile tilapia (Souza et al. 2013, Niang et al. 2020, Souza et al. 2020, Outama et al. 2022, Fontana et al. 2024, Lubis et al. 2025). The present research is valuable in terms of the relevant information regarding the growth and health outcomes obtained from juvenile Nile tilapia fed high levels of mango var. Ataulfo by-product meals. Different studies report survival rates related to those reported (95%) by us when using diets with different fruits, such as mango and its by-products (Souza et al. 2013, Niang et al. 2020, Outama et al. 2022, Fontana et al. 2024), which confirms that Nile tilapia is a species that adapts to feeding conditions (Fitzsimmons, 2005, Fájer-Ávila et al. 2017), which is key to increasing the production and profitability of aquaculture crops (Wang et al. 2019). However, as part of the most relevant results of our research, it was to obtain information on which fish fed with Ataulfo mango pulp, replacing up to 20% of FM, obtained the highest values of WG and SGR, which coincides with those reported by other authors who mention that adding mango pulp (de Lima et al. 2011, Melo et al. 2012) or peel (Lubis et al. 2025) to Nile tilapia diets does not affect their growth. However, it is important to mention that the quantity and origin of the pulp may be important, since what was reported by Souza et al. (2020) indicates that Nile tilapia fed up to 16% of Tommy variety mango pulp did not obtain good growth results, in contrast with our study, where we added up to 20% of pulp. The differences with the previous study may be related to the fact that the Ataulfo mango variety contains a higher amount of simple carbohydrates, such as fructose (6.18%), which facilitates its use as an energy source (Berto et al. 2015, Palpandian et al. 2019). Likewise, another possible cause is that the pulp of the Tommy mango has a lower percentage of crude protein (4.5%) than the pulp of the Ataulfo mango (5.1%) (Maldonado-Celis et al. 2019) since the quality of the protein in the diet is an important factor to consider (Montoya-Camacho et al. 2019, Outama et al. 2022). In this study, crude protein levels in the diets ranged from 47% (CT) to 33% (PU20), suggesting that pulp diets (with lower crude protein content in diets) not only provided the energy levels required by Nile tilapia they also provided the necessary quantity and quality of protein required by tilapia, which was reflected in the efficient use of dietary protein, allowing its reduction without altering growth and feed efficiency with these diets (diets with mango pulp).

The FCR values obtained in this study are generally lower compared to those reported by other authors, including 9 and 27% mango meal (Niang et al. 2020). As mentioned, the Ataulfo mango pulp treatment presented the highest growth values compared to the other by-products. Likewise, it was the mango pulp that induced better FCR values, indicating a more efficient use of feed and therefore suggesting that it is possible to reduce production costs (Zafra-Trelles et al. 2019) by reducing the use of FM for energy purposes without affecting productive performance. On the other hand, unlike diets with mango pulp, the other diets (peel and seed) presented lower weight gain and higher FCR. In other research, where only 0.5% of mango seeds have been included, an increase in WG was observed compared to the seedless CT. However, their inclusion is lower than that reported in this research (El-Houseiny et al. 2017). Mango generally contains high levels of carbohydrates, such as fructose and sucrose (Zhou et al. 2022), which are quickly and efficiently absorbed and metabolized (Kathane et al. 2017).

On the other hand, high amounts of fiber (present in by-products such as the peel and seed) are poorly digested by omnivorous species like tilapia, so they do not provide energy or nutritional content. At high levels, its inclusion implies more significant energy expenditure for the animals that consume it (Watts & Ristow 2017). This effect can be seen in an increase in FCR because this compound is not utilized, and it also increases intestinal movement, which indirectly affects the digestion and absorption of other nutrients (Erfanullah & Jafri 1995). Therefore, the lower growth results and higher FCR obtained using Ataulfo mango peel and seed meals could also be related to their high fiber content.

Regarding biological indices, it has been reported that a CF value of 1 or less for Nile tilapia may indicate malnutrition, while values greater than 3 could indicate tissue fat accumulation (Paredes-Trujillo et al. 2021, Zhu et al. 2021). In wild environments, an average CF of 2.0 has been recorded in juvenile tilapia (Agumassie 2018). Under culture conditions, values ranging from 1.5 to 3.2 have been reported (Nehemia et al. 2012, Vides Redondo et al. 2023), similar to the values observed in this study. Likewise, the PER was higher in pulp diets, indicating that protein was utilized more efficiently in these diets. On the other hand, the VSI values were also higher in fish fed diets with pulp at both percentages, so our results are similar of other studies, which report a significant accumulation of fat in tissues with increasing dietary carbohydrates (Zhu et al. 2021), where amounts of 35 to 50% carbohydrates increase the expression of genes related to lipogenesis and, therefore, transform sugars into lipids that will be stored in the liver and peripheral tissues (Cheng et al. 2017, Chandel 2021, Zhu et al. 2021), which promotes an increase in indices such as VSI or HSI or lipid accumulation in whole fish (Herath et al. 2016, Xie et al. 2017, Han et al. 2021, Zhu et al. 2021). However, the values of HSI, as well as the proximal composition of crude protein and lipid in the whole fish of our study, are within those reported for this species under culture conditions (Izquierdo-Córser et al. 2000, Olopade et al. 2016).

Mango pulp is mainly composed of fructose, the simplest and most bioavailable carbohydrate, so organisms can use it more efficiently as a source of energy or transform it into fat (Faeh et al. 2005, Kamalam et al. 2017, Zhu et al. 2021). Since glucose from dietary carbohydrates is distributed throughout the body via the blood, it is essential to monitor it to understand its distribution and metabolism (Norton 2022). In the present study, fish fed diets containing only 10% Ataulfo mango pulp showed the highest weight gain (23.8 ± 5.0 g), as well as blood glucose values greater than 54 mg dL^{-1}, and also the highest values of TGL, CHOL, and AL. Similar results were observed in fish fed the CT, in contrast to fish fed diets containing mango seed and peel, particularly at an inclusion level of 20%, which also showed significant differences. The above suggests that these diets (with seed or peel), with similar total carbohydrates content (like NFE) to the diets with pulp (for each level of inclusion), were not sufficiently available (may be related to what we explained before about fiber), which was insufficient to cover the basal energy demands of the fish and made them burn other nutrients, like proteins and lipids as we saw the performance and VSI parameter (Boonanuntanasarn et al. 2018). Likewise, an excess of energy in the diets, for example a high concentration of carbohydrates with high bioavailability in the diets, the metabolism transforms said energy into TGL (Grant 2015, Seibel et al. 2021), however, this capacity is dependent on the stage of the species and the type of feed (Burgos-Aceves et al. 2019) like we see in fish with the highest weight gain (fed with CT, PU10, and PU20) which also showed the highest concentration of TGL, while fish fed with seed or peel showed the poor WG but also the lowest TGL values. Reports by Fazio (2019) indicate that TGL values below 35 mg dL^{-1} may suggest malnutrition in teleost fish, liver damage, or an inability to absorb nutrients at the metabolic level. Although these low values were not achieved in the present study, our results suggest that maintaining TGL values above 96 mg dL^{-1} is more advisable for early juveniles of Nile tilapia.

On the other hand, CHO, another kind of lipid, has reported values for tilapia between 110-290 mg dL^{-1} (Awad et al. 2022), while other authors reported values between 80-90 mg dL^{-1} of total CHO without apparent health issues of the fish (Bradley et al. 2019, Kesbiç et al. 2020, Souza et al. 2020) since low plasma CHO is not considered a risk factor (Luo et al. 2020). In the present study, although CHO levels were influenced by the type of by-product and its inclusion level, the range of observed values (98-129 mg dL^{-1}) remained within the previously mentioned data. Additionally, our CHO results did not reveal a trend related to WG or the composition of the fish.

Regarding TP in the blood plasma of tilapia, a reference range of 2.9-5.5 g dL^{-1} has been reported (Hrubec et al. 2000, Souza et al. 2020). Likewise, it is known that, as in most animals studied, the main components of TP are AL and GLB (Seibel et al. 2021).

AL plays a fundamental role in fish's metabolic processes, contributing to the transport of metabolites and maintaining osmotic pressure (Kovyrshina & Rudneva 2012). Low levels of AL in the blood may reflect liver damage and malnutrition processes, while high protein levels may indicate dehydration (Haris et al. 2023). Previous studies report different ranges of AL values for Nile tilapia. For instance, Hrubec et al. (2000) report values ranging from 1.3 to 2.6 g dL^{-1}, whereas Souza et al. (2020) report values from 0.31 to 0.80 g dL^{-1}. Although the latter mentions that these values could be related to liver damage processes, the only organ where this protein is synthesized, they do not report the type of damage. In our study, the TP results are within the range reported above, but with a tendency to increase in diets with only 10% of any by-product; however, in the case of AL concentration, the values of all our diets are above the previously mentioned values, but within those reported by Oluwalola et al. (2020) with average AL values of 3.25 g dL^{-1}. On the other hand, in our study, we observed that the lowest AL values (<3.0 g dL^{-1}) were obtained from fish with lower growth and feed efficiency. As we pointed out before, diets with peel and seed may affect nutrient availability, mainly proteins, because AL, a protein usually used as a source of reserve amino acids, decreases its synthesis.

GLB, the second most important group concerning the TP components in blood plasma, is mainly related to the immune defense system, and its increase is usually associated with the presence of pathogens or stress processes (Bobe et al. 2010, Chernyavskikh et al. 2019). For tilapia, reference values ranging from 1-4.2 g dL^{-1} have been reported (Hrubec et al. 2000). In the present investigation, the lowest GLB values were observed in fish fed the CT, which, together with the pulp diets, obtained the best growth, suggesting that the fish in these diets were not only in excellent nutritional condition but also had the lowest stress levels.

The AL:GLB ratio helps identify potential health issues in fish (Haris et al. 2023), indicating whether the organism is fighting an infection or has sustained permanent liver damage (Seibel et al. 2021). For this investigation, the fish-fed experimental diets did not present values lower than one; based on this, we can assume that the tilapia was in good health.

CONCLUSIONS

The inclusion of up to 20% (50% FM) of mango pulp meal Ataulfo mango did not affect growth, alter blood biochemistry, or change the proximate composition of juvenile Nile tilapia during the experimental period. On the other hand, the response of plasma variables, such as glucose, triglycerides, albumin, and globulins, was significantly influenced by the carbohydrate and protein composition of the diet, making them useful tools for monitoring fish health under different nutritional conditions. We suggest conducting further experiments using larger fish or at other stages for further comparisons and to determine during which stage the use of 10-20% mango pulp meal is most viable. It would be important to incorporate inclusions of 15-25% mango pulp meal to determine whether it is possible and viable to reduce further the amount of FM used in feeds and thereby reduce costs. In this regard, it is essential to conduct a cost analysis to extend this experimental phase to a real crop and thoroughly determine its viability. Finally, due to the low yield values obtained with up to 10% replacement of Ataulfo mango peel and seed, further research is recommended at lower levels, particularly in combination with other plant sources.

Author contribution credit

A. Benitez-Hernández: conceptualization, validation. funding acquisition, project administration, supervision, methodology; J.A. López-Ceseña: methodology, formal analysis, data curation, writing-original draft; M.I. Bañuelos-Vargas: methodology, data curation, formal analysis, review and editing; C.E. Lizárraga-Velázquez,: supervision, methodology, review, and editing; E. Martínez-Montaño: supervision, review, and editing; G.A. Rodríguez-Montes de Oca: supervision, methodology, review, and editing. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare that they have no conflict of interest with the publication of this research work.

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