Meat quality and performance of pigs fed diets with fish silage meal

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Abstract – The objective of this work was to determine the nutrient digestibility and metabolizable energy (ME) of fish silage, as well as to evaluate the effect of the dietary inclusion of fish silage meal (FSM) in diets on the performance, carcass characteristics, meat quality, sensory analysis of meat and mortadella, and economic viability of growing and finishing pigs. In the digestibility assay, 16 barrows (33.20±4.93 kg) received diets with and without FSM. The fish silage had 39.01% crude protein and 4,032 kcal kg^{-1} ME. In the performance assay, 32 barrows (26.00±1.68 kg) were fed diets containing different inclusion levels of FSM (0, 25, 50, and 75%). FSM, obtained from the mixture (1:1) of fish silage with corn, showed a quadratic effect on average daily gain, and the best result was obtained with the inclusion level of 25.83%. The results for feed conversion and economic viability indicate that up to 25% FSM, corresponding to 5.87% of fish silage based on dry matter, can be used in the pig growing and finishing phases.

Index terms: *Sus domesticus*, alternative feedstuff, digestibility, economic viability, fishing residue, sensory analysis.

Qualidade da carne e desempenho de suínos alimentados com dietas contendo farinha de silagem de pescado

Resumo – O objetivo deste trabalho foi determinar a digestibilidade de nutrientes e a energia metabolizável (EM) da silagem de pescado, bem como avaliar o efeito da inclusão de farinha de silagem de pescado (FSP) nas dietas sobre o desempenho, as características de carcaça, a qualidade da carne, a análise sensorial da carne e da mortadela, e a viabilidade econômica de suínos em crescimento e terminação. No ensaio de digestibilidade, 16 suínos machos castrados (33,20±4,93 kg) receberam dietas com e sem FSP. A silagem de pescado apresentou 39,01% de proteína bruta e 4.032 kcal kg^{-1}de EM. No ensaio de desempenho, 32 suínos machos castrados (26,00±1,68 kg) foram alimentados com rações contendo diferentes níveis de inclusão de FSP (0, 25, 50 e 75%). A FSP, obtida a partir da mistura (1:1) da silagem de pescado com milho, apresentou efeito quadrático sobre o ganho diário de peso, e o melhor resultado foi obtido com a inclusão de 25,83%. Os resultados de conversão alimentar e da viabilidade econômica indicam que até 25% de FSP, que corresponde a 5,87% de silagem com base na matéria seca, pode ser utilizada nas fases de crescimento e terminação de suínos.

Termos para indexação: *Sus domesticus*, alimento alternativo, digestibilidade, viabilidade econômica, resíduo da pesca, análise sensorial.

Introduction

The oscillating prices of corn and of soybean meal, the main raw materials of feed in pig farming, often make this activity economically unfeasible, leading to a constant search for alternative feedstuffs. These feedstuffs are usually residues and by-products from food processing aiming human nutrition. In this context, fishing residues stand out, mainly those from processed tilapia (*Sarotherodon niloticus*), which is the second most produced fish worldwide (FAO, 2014) and the most widely cultivated species in Brazil (IBGE, 2015).

When fish do not reach the desired size for commercialization and for fish removal, they are discarded and a great amount of residues is generated, which shows the importance of evaluating their possible use in animal feed (Pimenta et al., 2007). Using these residues for this purpose can reduce the environmental impact of fish farming (Geron et al., 2006), and the ensiling process, in which the residues undergo controlled fermentation, results in a product that can be stored for longer periods.

Among the main forms of ensiling fish residues, stand outs microbiological inoculation with bacteria that favor acidification by lactic acid production. According to Oliveira et al. (2013), fish silage is an ingredient with high protein content and high biological value. However, one of the obstacles for its use in animal feed is its high moisture content, which complicates its storage and use in natura. Fish silage meal (FSM) has been used to potentiate the use of this ingredient in poultry and pig feed, since dehydrated corn – which has a high dry matter content – is added to the silage. Therefore, FSM is a product that has a high dry matter content and that is easy to store and use in the formulation of diets for pigs.

Although researches show the possibility of including up to 6% fish silage in the diet of pigs (Silva & Landell Filho, 2003), the inclusion of even higher levels may be possible in the form of meal. However, information on the inclusion of FSM in diets is still scarce, and there are also concerns about the possible effects of this ingredient on phytosanitary issues and on the sensory characteristics of meat. Howe et al. (2002), for example, reported the occurrence of off-flavor in meat and eggs of animals fed ingredients obtained from fish residues.

The objective of this work was to determine the nutrient digestibility and metabolizable energy (ME) of fish silage, as well as to evaluate the effect of the dietary inclusion of FSM in diets on the performance, carcass characteristics, meat quality, sensory analysis of meat and mortadella, and economic viability of growing and finishing pigs.

Materials and Methods

Two assays were conducted: the first one to determine the nutrient digestibility and metabolizable energy (ME) of fish silage in growing pigs; and the second, to evaluate the inclusion levels of FSM in the diets of growing and finishing pigs. The trials were carried out at the pig research center of Universidade Federal do Ceará, located in the state of Ceará, Brazil. The Ethics Committee on Animal Use (CEUA 79/2015) approved all the protocols adopted in the present study.

Fish silage was manufactured by Biotrends Soluções Biotecnológicas (Fortaleza, CE, Brazil), using tilapia (*S. niloticus*) residues. Whole fish were crushed and placed in 60-L tanks, to which were added specific concentrations of sugarcane molasses and inoculum composed of a consortium of bacterial strains characterized by anaerobic metabolism and lactic acid (*Lactobacillus* spp.) production. The fermentation process lasted seven days. The pH of the ensiled material was initially 6.4, but reached 4.5 at the end of the fermentation process. The product was refrigerated at 4°C in plastic containers, to be used in the digestibility assay. In the performance assay, the silage used was produced in 1,000-L tanks, following the same procedure previously described, in a partnership between Biotrends Soluções Biotecnológicas and Piscis Indústria e Comércio (Jaguaribara, CE, Brazil).

In the digestibility assay, 16 barrows with a mean initial weight of 33.2±4.93 kg were used. The design was completely randomized, with two treatments and eight replicates (each experimental unit consisted of one animal). At the beginning of the trial, the animals were weighed and distributed into two treatments: a control diet, based on corn and soybean meal, which met the nutritional requirements of barrows (Rostagno et al., 2011); and a test diet, composed of 50% control diet (Table 1) and 50% fish silage, based on natural matter.

The method of total collection of feces and urine was adopted. The animals were housed in metabolic cages similar to those described by Pekas (1968) for 12 days. During the first seven days, the animals were adapted to the experimental cages and diets, and individual feed intake was determined. Feces and urine were collected only in the last five days. The contents of dry matter (DM), crude protein (CP), ether extract (EE), and mineral matter (MM) in feces, diets, and fish silage were analyzed according to Horwitz (2005). The gross energy (GE) of fish silage and feed, as well as of feces and urine, was determined using the C 200 Ika calorimeter (Ika Works, Inc., Wilmington, NC, USA). From the values obtained in the analyses, the coefficients of nutrient digestibility and the ME of fish silage were calculated (Sakomura & Rostagno, 2007).

In the performance assay, 32 barrows, with average initial weight of 26.6±1.68 kg, from a commercial line, were distributed in a randomized complete block design, with four treatments and eight replicates of one animal each. The treatments consisted of four diets based on corn and soybean meal, with increasing levels of FSM: FSM0, control diet; FSM25, 25% inclusion; FSM50, 50% inclusion; and FSM75, 75% inclusion. Considering the final proportion of fish silage used in each meal, the experimental diets with 25, 50, and 75% FSM levels of inclusion had 5.9, 11.3, and 17.6% of the ingredient, respectively, based on DM. In this assay, considering the low DM content and the difficulty in using fish silage in natura, the meal was mixed with corn in equal proportions (1:1, by weight), based on natural matter. Subsequently, the mixture was sun-dried for three days, resulting in the FSM.

The experimental diets (Table 1) were formulated according to the nutritional requirements, of barrows with high genetic potential for productive performance (Rostagno, 2011), for the following phases: growing I, when the pigs weighed from 30 to 50 kg; growing II, from 50 to 70 kg; and finishing phase, from 70 to 100 kg. These phases corresponded to the periods: I, from 70 to 97 days; II, from 70 to 122 days; and III, from 70 to 157 days. The composition of feedstuffs was the same as proposed by Rostagno (2011). For the FSM, we considered the values of nutritional composition, corn ME (Rostagno, 2011), and of the fish silage, obtained in the digestibility assay. The amino acid composition of fish silage was determined by high-performance liquid chromatography (HLPC), resulting in 0.805% lysine, 0.602% methionine, 0.803% threonine, and 0.123% tryptophan, based on DM.

Animals, diets, and leftovers were weighed at the beginning and end of each phase to determine daily feed intake (DFI), daily weight gain (DWG), and feed conversion (FC) ratio. At the end of the trial, the animals were weighed, fasted for 12 hours, and transported to the slaughterhouse. After a rest period

Table 1. Centesimal, chemical, and energetic composition of the experimental diets for pigs fed increasing levels of fish silage meal (FSM) – 0, 25, 50, and 75% – at the growing and finishing phases.

Ingredient	Control diet	Growing phase I (30 to 50 kg)				Growing phase II (50 to 70 kg)				Finishing phase (70 to 100 kg)			
		FSM0	FSM25	FSM50	FSM75	FSM0	FSM25	FSM50	FSM75	FSM0	FSM25	FSM50	FSM75
Corn grain	74.32	70.19	48.02	24.39	0.69	74.20	51.10	27.31	3.98	78.69	55.07	31.37	7.68
Soybean meal	22.45	26.32	23.79	21.66	19.40	22.90	20.67	18.51	16.20	18.65	16.67	14.44	12.21
Soybean oil	0.20	0.57	0.06	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fish silage meal	0.00	0.00	25.00	50.00	75.00	0.00	25.00	50.00	75.00	0.00	25.00	50.00	75.00
Dicalcium phosphate	1.50	1.12	1.24	1.36	1.49	0.90	1.02	1.15	01.44	0.82	1.10	1.22	1.35
Limestone	0.50	0.65	0.61	0.56	0.52	0.61	0.56	0.52	0.50	0.59	0.48	0.44	0.39
L-lysine	0.25	0.21	0.27	0.32	0.38	0.24	0.29	0.35	0.41	0.29	0.33	0.39	0.45
DL-methionine	0.08	0.03	0.04	0.06	0.08	0.02	0.04	0.06	0.07	0.03	0.03	0.03	0.03
L-threonine	0.03	0.04	0.05	0.07	0.09	0.05	0.06	0.08	0.10	0.07	0.09	0.11	0.13
L-tryptophan	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.00	0.01	0.02	0.03
MVS(1)	0.40	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.30	0.35	0.37	0.39	0.41	0.33	0.35	0.37	0.42	0.32	0.35	0.37	0.40
Inert	0.00	0.00	0.00	0.62	1.37	0.00	0.38	1.12	1.35	0.05	0.33	1.06	1.79
Total	100	100	100	100	100	100	100	100	100	100	100	100	100
Cost (R$ kg^{-1})	0.99	0.99	0.98	0.97	0.97	0.95	0.94	0.94	0.95	0.92	0.91	0.91	0.91
						Calculated nutritional composition							
Metabolizable energy (kcal kg^{-1})	3230	3230	3230	3230	3230	3230	3230	3230	3240	3230	3240	3240	3240
Crude protein (%)	16.82	18.25	18.25	18.30	18.30	17.07	17.11	17.15	17.15	15.59	15.70	15.70	15.70
Calcium (%)	0.642	0.635	0.634	0.632	0.630	0.557	0.559	0.558	0.60	0.519	0.530	0.532	0.532
Available phosphorus (%)	0.319	0.314	0.314	0.312	0.315	0.278	0.279	0.279	0.30	0.258	0.281	0.282	0.280
Total lysine (%)	1.053	1.072	1.072	1.072	1.070	1.010	1.012	1.012	1.011	0.945	0.946	0.945	0.946
Total methionine+cysteine (%)	0.550	0.622	0.623	0.625	0.623	0.591	0.592	0.591	0.578	0.560	0.546	0.529	0.519
Total threonine (%)	0.743	0.739	0.744	0.741	0.742	0.702	0.703	0.701	0.701	0.670	0.671	0.672	0.673
Total tryptophan (%)	0.224	0.193	0.192	0.192	0.524	0.182	0.183	0.182	0.182	0.170	0.172	0.171	0.172
Sodium (%)	0.185	0.182	0.183	0.182	0.181	0.171	0.171	0.171	0.172	0.169	0.171	0.172	0.171

(1)MVS (mineral and vitamin supplement): the premix supplied the following ingredients per kilogram of feed: 2,500,000 IU vitamin A, 500,000 IU vitamin D3, 50 mg biotin, 50 mg choline, 10,000 mg niacin, 3,000 mg calcium pantothenate, 7 mg vitamin B12, 1,800 mg vitamin B2, 7,500 mg vitamin E, 1,000 mg vitamin K3, 40,000 mg iron, 35,000 mg copper, 20,000 mg manganese, 40,000 mg zinc, 360 mg cobalt, 840 mg iodine, and 120 mg selenium.

of 3 hours, the animals were slaughtered and their carcasses were sawn in half lengthwise and weighed. Carcass yield was obtained as the ratio between hot carcass weight and live weight at slaughter, multiplied by 100. The carcasses were kept in a cold chamber, at 4ºC, for 24 hours, for later analyses of carcass length, mean back fat thickness, loin eye area, fat area, and fat/meat ratio according to Bridi & Silva (2009).

Loin and fat depths were measured at point P2, considering the joint between the last thoracic vertebra and the first lumbar vertebra, perpendicularly, at a point 5 cm off the midline. The loin and fat depths were used to calculate the lean meat content according to Guidoni (2000), and the percentage of lean meat was obtained as in Bridi & Silva (2009). Loin samples of approximately 400 g were taken to determine water retention capacity (Wilhelm et al., 2010), color, pH, cooking loss, and shear force of meat (Caldara et al., 2012).

The preparation of loin samples for sensory analysis was performed according to Caldara et al. (2012). The analysis was carried out in three sessions by six previously trained tasters. The intensity of the attributes taste, aroma, texture, color, and overall acceptance was evaluated using a 9-cm unstructured scale, according to Ferrão et al. (2009).

Mortadella was prepared with *Longissimus dorsi*, back fat, tapioca flour, soybean protein, salt, curing salt, and garlic paste. The ingredients were mixed in a Cutter crusher with 0.3 HP (BIMG-BRASIL Indústria de Máquinas para Gastronomia Ltda., Metvisa, Brusque, SC, Brazil). Subsequently, the mortadella were packed in plastic bags resistant to high temperatures, sealed, and cooked in a water bath for 40 min at 100ºC. For the sensory analysis of mortadella, samples of approximately 2 cm^3 were cut and heated at 170ºC for 2 min, before serving. The preference test using a nine-point scale (Lago et al., 2006) was adopted to determine the consumer's preference for taste, aroma, texture, color, and overall acceptance of the mortadella obtained from the different FSM inclusion levels, and conducted with 100 untrained tasters.

The economic evaluation of the treatments was done based on the cost of the diet in relation to performance and carcass characteristics. The feeding cost in August 2015, in the state of Ceará, was calculated in each phase using the prices of corn (R$ 0.63 kg^{-1}), soybean meal (R$ 1.63 kg^{-1}), fish silage (R$ 0.70 kg^{-1}), soybean oil (R$ 3.30 kg^{-1}), dicalcium phosphate (R$ 2.80 kg^{-1}), limestone (R$ 0.22 kg^{-1}), salt (R$ 0.20 kg^{-1}), L-lysine HCl (R$ 8.53 kg^{-1}), methionine (R$ 14.21 kg^{-1}), mineral and vitamin supplement (R$ 9.66 kg^{-1}), inert (R$ 0.05 kg^{-1}), threonine (R$ 14.07 kg^{-1}), and tryptophan (R$ 17.02 kg^{-1}). The feeding cost was determined from the total feed intake during the experimental period and from the cost of the diet in the respective phases. The average cost of feed per kilogram of live weight was obtained from the relation between the feeding cost and total weight gain of the animal during the respective phases. The economic efficiency index (EEI) and the average cost index (ACI) were calculated according to Gomes et al. (1991), as: EEI = LFC/ACIi x 100 and ACI = ACIi/LFC x 100, in which LFC is the lowest feed cost per kilogram of live weight gain, and ACIi is the average cost of the i-th treatment.

Data were subjected to the analysis of variance using the statistical program SAS, version 8.0 (SAS Institute, Inc., Cary, NC, USA), and the means were compared by Dunnett's test, at 5% probability. The degrees of freedom associated with the inclusion levels of fish silage, excluding the control treatment (FSM0), were sliced to second-degree polynomials. The performance was evaluated in the periods I, II, and III.

Results and Discussion

The evaluated fish silage can be considered a meal with a high CP content (39.01%) and a highly digestible protein fraction (93.58%), which is associated with the ensiling process (Table 2). According to Boelter et al. (1991), during ensiling, fish residue proteins are hydrolyzed by microorganisms, resulting in a source of autolyzed proteins with a high biological value. When compared with the meat and bone meal (Rostagno et al., 2011), the fish silage showed: high MM content, of 14.45%; high GE value, of 5,143 kcal kg^{-1}, due to its lipid fraction (29.78%); and high metabolizability, of 78.40%.

The CP content of fish silage was lower than that obtained by Oliveira et al. (2006) for silage of tilapia filleting residue (48.30%). The EE content (29.78%) was higher than that observed by Ramírez et al. (2013), of 14.5%, which can be explained by the type of processing and raw material used. In the present study, whole tilapia was used, which increases the fat content, since the viscera and adipose tissue located in the ventral portion of the body were included. The

MM was high because scales, head, spine, bones, and fins were part of the ensiled material. Despite the high ash content, the digestibility coefficient of this fraction was reduced due to the low availability of minerals bound to the bone matrix of the fish.

Regarding GE, the obtained value (5,143 kcal kg^{-1}) was also higher than that reported by Oliveira et al. (2006), of 3,911 kcal kg^{-1}, for silage of tilapia filleting residue. This result can be explained by the higher lipid content of fish silage analyzed in the present study. Oliveira et al. (2014) pointed out that the high ME of fish silage represents the potential of the ingredient for use in broiler diets. In this sense, the ME (4,032 kcal kg^{-1}) and CP (39.01%) values reveal a strong possibility of using this meal in pig feed as a substitute for extruded whole soybean, which is a protein source widely used in diets for pigs.

Although the differences in the chemical composition and ME of fish silage can occur due to the raw material used, the differences between our results and those reported in the literature (Carvalho et al., 2006; Geron et al., 2006; Oliveira et al., 2006) can also be explained by the fish species (*S. niloticus*) and the type of ensiled material used.

In period I, no significant effects of FSM inclusion were observed on DFI and FC (Table 3). However, a quadratic effect was obtained for DWG, and the best level of inclusion was 25% FSM. Only animals fed a diet containing 75% FSM showed lower DWG than those fed the control diet (FSM0).

In period II, although there was no effect of FSM on DFI, a quadratic effect was observed for DWG, and the best result was obtained with 18% inclusion. However, FC worsened with the increase in FSM levels in the diets. Similarly to that observed in period I, only the DWG of animals fed the diet containing 75% FSM differed significantly from those that did not receive this ingredient. However, the FC of the animals fed 50 and 75% FSM was worse than that observed in FSM0.

In period III, a quadratic effect was found for DFI and DWG, and the best results were obtained with 30.23 and 25.83% inclusion; the same effect was

Table 2. Chemical composition, coefficients of digestibility and metabolizability, digestible nutrients, and metabolizable energy of fish silage.

Variable	Composition	Digestibility	Metabolizability	Digestible nutrients	Metabolizable energy
Dry matter (%)	30.69	47.80	-	14.68	-
Mineral matter (%)	14.45	25.19	-	3.64	-
Ether extract (%)	29.78	79.78	-	23.76	-
Crude protein (%)	39.01	93.58	-	36.50	-
Gross energy (kcal kg^{-1})	5,143.00	-	78.40	-	4,032.09

Table 3. Performance of pigs fed increasing levels of fish silage meal (FSM) at the growing and finishing phases.

Variable	FSM inclusion level (%)				CV (%)	Regression		
	0	25	50	75		Effect	p-value	Adjusted R^2
				Period I (70 to 97 days)(1)				
Daily feed intake (DFI, kg)	2.03	2.11	2.03	1.84	10.79	ns	0.086	0.38
Daily weight gain (DWG, kg)	1.07	1.11	1.06	0.95*	10.62	Quadratic	0.025	0.78
Feed conversion (FC)	1.89	1.91	1.93	1.95	9.40	ns	0.052	0.34
				Period II (70 to 122 days)(2)				
DFI (kg)	2.39	2.56	2.49	2.29	10.48	ns	0.086	0.42
DWG (kg)	1.06	1.09	1.01	0.89*	9.83	Quadratic	<0.01	0.82
FC	2.25	2.35	2.48*	2.51*	6.48	Linear	<0.01	0.89
				Period III (70 to 157 days)(3)				
DFI (kg)	2.50	2.59	2.60	2.28*	10.58	Quadratic	<0.01	0.81
DWG (kg)	1.03	1.10	1.02	0.94*	8.19	Quadratic	0.01	0.83
FC	2.34	2.35	2.55*	2.47*	7.04	Quadratic	<0.01	0.86

(1)Quadratic effect, $Y = 1.1516 + 0.0025x - 0.00005x^2$. (2)Quadratic effect, $Y = 1.0676 + 0.0018x - 0.00005x^2$; and linear effect, $Y = 2.0436 + 0.00357x$. (3)Quadratic effect, $Y=2.3283 + 0.0133x - 0.00022x^2$ (DFI), $Y = 1.0481 + 0.0031x - 0.00006x^2$ (DWG), and $Y = 2.0671 + 0.0083x - 0.00008x^2$ (FC). *Significant differences between the treatment and the control according to Dunnett's test, at 5% probability. nsNonsignificant.

verified for FC, for which the best result occurred with the inclusion of 51.87%. In this period, animals fed 75% FSM had lower DFI and DWG than those fed the control diet. Regarding FC, only the animals fed 25% FSM did not differ from those fed the control.

Based on FC in period III, FSM can be included up to 25% in the diet without impairing animal performance. This inclusion level, in the present study, represents the average inclusion of 5.87% of fish silage based on DM. These results corroborate those of Silva & Landell Filho (2003), who observed that the inclusion of up to 6.0% silage of fish fillet residue, based on DM, does not impair weight gain and feed conversion in growing pigs.

The variables slaughter weight, hot carcass weight, carcass yield, carcass length, lean meat content, percentage of lean meat of the carcass, loin eye area, fat/meat ratio, and bonification index were not affected by FSM inclusion levels (Table 4). However, linear reductions were observed in mean back fat thickness, fat depth, and fat area, which are desirable characteristics, since there is great demand for lean cuts. Although loin depth decreased linearly with FSM levels, carcass yield and lean meat content were not affected. These results indicate that the inclusion of FSM did not impair carcass characteristics.

There were no differences in mean back fat thickness, fat depth, fat area, and loin depth of pigs fed 25 or 50% FSM, compared with those fed the control diet.

FSM inclusion levels also had no effects on pH, water retention capacity, color (L*, a*, and b*), cooking losses, and shear force of meat (Table 4). Silva & Landell Filho (2003), in a study with different inclusion levels (0, 3, and 6%) of silage of fish filleting residue, also did not find differences in meat quality parameters of pigs during the growing and finishing phases.

In the sensory analysis, the attributes meat aroma, taste, color, and juiciness were not affected by the different FSM levels (Table 5). Regarding the overall acceptance, a negative linear effect of FSM levels was

Table 4. Carcass characteristics and meat quality of pigs fed increasing levels of fish silage meal (FSM) at the growing and finishing phases.

Variable	FSM inclusion level (%)				Coefficient of variation (%)	Regression		
	0	25	50	75		Effect	p-value	Adjusted R²
				Quantitative characteristics[1]				
Slaughter weight (kg)	98.45	101.83	96.08	88.31	4.38	ns	0.187	0.12
Hot carcass weight (HCW, kg)	72.12	73.49	69.38	62.95	5.27	ns	0.171	0.25
Carcass yield (CY, %)	73.26	72.17	72.21	71.28*	2.15	ns	0.058	0.36
Carcass length (CL, cm)	0.91	0.92	0.90	0.93	3.39	ns	0.935	0.23
Mean back fat thickness (MBT, mm)	2.73	2.37	2.58	1.98*	19.99	Linear	0.036	0.69
Loin depth (LD, mm)	6.36	6.54	5.96	5.78*	10.19	Linear	0.024	0.78
Fat depth (FD, mm)	1.02	0.97	0.98	0.87*	32.24	Linear	0.028	0.82
Lean meat content (LMC, kg)	45.49	43.84	43.52	44.58	4.28	ns	0.163	0.28
Percentage of lean meat (LM, %)	63.78	64.06	63.84	64.13	0.44	ns	0.112	0.38
Loin eye area (LEA, cm²)	40.54	38.46	38.18	37.82	12.37	ns	0.534	0.21
Fat area (FA, cm²)	10.97	9.28	8.72	8.14*	20.79	Linear	0.017	0.79
Fat/meat ratio (F/M)	3.83	4.35	4.39	4.65	15.83	ns	0.812	0.22
Bonification index (BI)	118.43	118.45	118.15	118.65	0.26	ns	0.174	0.36
				Qualitative characteristics				
pH	5.78	5.69	5.69	5.79	1.63	ns	0.049	0.48
Water retention capacity (WRC, %)	1.76	1.72	1.72	1.74	2.98	ns	0.358	0.25
Lightness (L*)	56.99	57.43	70.12	56.84	29.11	ns	0.365	0.36
Chromaticity coordinates (a*)	14.96	16.30	15.70	15.42	6.53	ns	0.090	0.39
Chromaticity coordinates (b*)	10.78	11.67	10.44	10.85	9.05	ns	0.110	0.37
CL (%)	23.37	24.63	23.42	22.45	17.38	ns	0.763	0.29
Shear force (SF, kgf cm⁻²)	8.52	7.67	8.27	9.69	6.80	ns	0.429	0.42

[(1)]Linear effect, Y = 72.9726 - 0.0235x (MBT), Y = 2.6485 - 0.0081x (LD), Y = 6.3191 - 0.0092x (FD), and Y = 1.1138 - 0.0051x (FA). *Significant differences between the treatment and the control according to Dunnett's test, at 5% probability. [ns]Nonsignificant.

observed; whereas, for meat hardness, a quadratic effect was found, with the lowest value estimated for the inclusion of 41.97%. Only the treatment with 75% FSM differed significantly from the control for overall acceptance. However, regarding hardness, all treatments with FSM differed from the control.

Silva & Landell Filho (2003) reported that the inclusion of silage of fish filleting residues in the diet modified the taste of pig meat. The lower hardness value observed in the present study with the inclusion of FSM can be explained by the higher intramuscular fat in the meat of animals fed this ingredient, since deposits of this kind of fat represent 20 to 35% of total fat and can be modulated according to the diet. Intramuscular fat might make the meat softer because of its positive effect on meat juiciness and tenderness (Barbosa et al., 2006), explaining the best juiciness scores for cuts with the highest amount of this type of fat (Cannata et al., 2009). For hardness and overall acceptance, contrary to the results obtained in the present study, Tibbetts et al. (1981) did not observe effects of the inclusion of fish silage in the diet on the softness, juiciness, taste, or acceptance of pig meat.

The inclusion levels of FSM did not affect the aroma and texture of mortadella (Table 5). However, quadratic effects were observed for the attributes taste, color, and overall acceptance, and the highest values were obtained, respectively, with the inclusion levels of 40.05, 51.95, and 49.58% FSM. Regarding color, better results were found for mortadella made with meat from animals fed 25% FSM rather than the control diet. In relation to the attributes taste and overall acceptance, animals fed diets containing 25 and 50% FSM produced mortadella with better acceptance. However, the inclusion of 75% FSM in the diet may have contributed to the presence of off-flavor in mortadella, resulting in lower acceptance. According to Howe et al. (2002), the use of fish residues in pig feed may cause negative effects on the sensory characteristics of the meat; however, in the present study, adding this ingredient did not have any effect on processed pig meat.

The economic analysis carried out in period I showed a linear increase in the ACI as a function of FSM levels in the diet (Table 6). In period II, a linear increase for average cost of the feed per kilogram of live weight was observed with the increase of FSM inclusion levels. Moreover, a quadratic effect was verified for feeding cost, and the level of 28.03% FSM showed the highest cost. In this same period, the EEI decreased and the ACI increased linearly with the FSM levels, indicating that the farmer’s income reduces concurrently with the increase in use of this alternative feedstuff. Similarly, in period III, there was

Table 5. Sensory analysis of meat and mortadella produced from pigs fed increasing levels of fish silage meal (FSM) during the growing and finishing phases.

Parameter	FSM inclusion level (%)				Coefficient of variation (%)	Regression		
	0	25	50	75		Effect	p-value	Adjusted R^2
				Meat[(1)]				
“Normal” aroma	5.69	5.70	5.38	5.69	31.57	ns	0.924	0.12
“Strange” aroma	1.36	0.82	1.11	0.81	36.00	ns	0.509	0.10
“Normal” taste	4.72	5.38	5.43	5.32	37.71	ns	0.479	0.23
“Strange” taste	1.25	0.52	1.16	0.73	43.62	ns	0.735	0.18
Color	4.65	4.10	4.30	5.00	39.71	ns	0.276	0.11
Hardness	4.31	3.43*	2.80*	3.92*	50.25	Quadratic	0.022	0.78
Juiciness	4.17	3.98	4.25	2.81	57.31	ns	0.129	0.25
Overall acceptance	5.28	5.13	4.97	4.15*	27.89	Linear	0.015	0.83
				Mortadella[(2)]				
Aroma	7.07	7.18	7.51	7.16	18.41	ns	0.139	0.15
Taste	6.01	6.49*	6.37*	6.18	17.78	Quadratic	0.040	0.75
Color	7.11	7.45*	7.93*	7.60*	26.36	Quadratic	0.018	0.82
Texture	6.47	6.86	7.07	6.85	23.53	ns	0.069	0.12
Overall acceptance	6.84	7.28*	7.49*	7.29	17.65	Quadratic	0.013	0.81

[(1)]Quadratic effect, $Y = 4.387778 - 0.067156x + 0.000800x^2$; and linear effect, $Y = 5.256389 + 0.005922x$. [(2)]Quadratic effect, $Y = 6.027259 + 0.022069x - 0.000272x^2$ (taste), $Y = 7.091873 + 0.026601x - 0.000256x^2$ (color), and $Y = 6.838970 + 0.025088x - 0.000253x^2$ (overall acceptance). *Significant differences between the treatment and control according to Dunnett’s test, at 5% probability. [ns]Nonsignificant.

Table 6. Economic viability of different inclusion levels of fish silage meal (FSM) in diets for pigs at the growing and finishing phases.

Variable	FSM inclusion level (%)				Coefficient of variation (%)	Regression		
	0	25	50	75		Effect	p-value	Adjusted R^2
				Period I (70 to 97 days)(1)				
Cost per kg (R$)	0.99	0.98	0.97	0.97	-	-	-	-
Cost per live weight (R$)	1.89	1.88	2.06	2.07	12.27	ns	0.166	0.25
Feeding cost (R$)	40.43	41.44	40.03	40.53	8.07	ns	0.462	0.30
Economic efficiency index	99.96	100.00	99.54	99.04	9.76	ns	0.141	0.34
Average cost index	100.00	100.09	102.66	103.74	8.09	Linear	0.029	0.79
				Period II (70 to 122 days)(2)				
Cost per kg (R$)	0.95	0.94	0.94	0.94	-	-	-	-
Cost per live weight (R$)	2.21	2.22	2.35*	2.38*	5.35	Linear	<0.01	0.81
Feeding cost (R$)	99.93	105.55	102.71	88.55	12.25	Quadratic	0.011	0.89
Economic efficiency index	100.00	96.69	91.13*	89.57*	6.93	Linear	<0.01	0.76
Average cost index	100.00	101.78	107.71	109.40	6.56	Linear	<0.01	0.75
				Period III (70 to 157 days)(3)				
Cost per kg (R$)	0.92	0.91	0.91	0.91	-	-	-	-
Cost per live weight (R$)	2.25	2.27	2.33*	2.34*	6.68	ns	0.103	0.36
Feeding cost (R$)	162.74	163.04	165.74*	168.86*	7.32	ns	0.368	0.45
Economic efficiency index	100.00	98.39	91.04*	91.79*	7.70	Linear	0.034	0.79
Average cost index	100.00	100.47	110.10*	110.05*	6.73	Linear	<0.01	0.82

(1)Linear effect, Y = 136.1210 + 0.0677x. (2)Linear effect, Y = 2.4285 + 0.00262x (cost per live weight), Y = 77.9744 -0.1208x (economic efficiency index), and Y=129.7533 + 0.1653x (average cost index); and quadratic effect, Y = 113.1421 + 0.4454x - 0.00791x^2 (feeding cost). (3)Linear effect, Y = 85.8010 - 0.1093x (economic efficiency index), and Y = 115.8582 + 0.1863 (average cost index). *Significant differences between the treatment and the control according to Dunnett's test, at 5% probability. nsNonsignificant.

a reduction in the EEI and an increase in the ACI. In period I, the treatments did not differ from the control for all economic variables; however, in period II, only the treatment with 25% FSM did not differ from the control. In period III, there was a negative linear effect of FSM on the EEI and a positive linear effect on the ACI. In the combined evaluation of all economic variables, only the animals fed 25% FSM did not differ from those fed the control diet in this period.

Therefore, since the feasibility of using an alternative feedstuff depends on its similarity to the conventional diet, 25% FSM can be economically viable in diets for pigs at the growing and finishing phases.

Conclusion

Regarding feed conversion and economic viability, up to 25% fish silage meal – which corresponds to the inclusion of 5.87% of fish silage based on dry matter – can partially replace corn and soybean meal in diets for pigs at the growing and finishing phases.

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