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ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorpjn@gmail.com

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Chemical Composition and Nutritional Categorization of Fish Meals Produced and Marketed in Senegal for Animal Feeding

S.B. Ayssiwede[1], V.C. Mouanda[1,2], Y.A. Issa[1,3], A.E. Djettin[1], M.B. Hane[1] and A. Missohou[1]
[1]Laboratoire d'Alimentation et de Nutrition Animale (LANA)/Service de Zootechnie-Alimentation, Ecole Inter-Etats des Sciences et Medecine Veterinaires (EISMV) de Dakar, BP: 5077 Dakar-Fann (SENEGAL)
[2]Departement de Chimie, Faculte des Sciences et Techniques, Universite Cheikh Anta Diop (UCAD) de Dakar, BP: 5088 Dakar-Fann (SENEGAL)
[3]Institut Universitaire des Sciences et Techniques d'Abeche (IUSTA), BP: 6077 N'Djamena (TCHAD)

Abstract: We assessed the chemical and nutritional compositions of 154 fish meal samples produced and marketed in Senegal. The fish meal samples (93 from 4 artisanal and 61 from 3 industrial units) were collected, stored and analyzed in the Laboratory of Nutrition and Animal Feeding (LANA) of EISMV-Dakar from September 2012 to July 2013. The results showed that the fish meals produced in Senegal were all fatty, regardless of whether they were artisanal or industrial. Overall, they showed significant variation ($p<0.05$) in the averages of all chemical constituents and energy contents. Artisanal fish meals were significantly richer in fat (12.4 vs. 10.4% DM), ash (40.4 vs. 24% DM) and minerals (Ca, P, Na and K) than were industrial fish meals, which showed significantly higher levels of dry matter (93.3 vs. 92.1%), crude protein (63.4 vs. 41% DM), gross energy (4567 vs. 3430 kcal/kg DM) and metabolizable energy (3203 vs. 2409 kcal/kg DM). With the exception of phosphorus and sodium, for which there was significant variation among artisanal companies, there were significant differences observed in the nutrient contents between artisanal and industrial units. Globally, fish meals of various levels of nutritional quality are produced and marketed in Senegal. Low-protein fish meals (types 40, 35) are the most commonly produced (36.4%), followed by medium-protein fish meals (33.1%) and then high-protein fish meals (30.5%). The medium-protein fish meals (CP types 55 to 45, with medium ash content) were produced by both artisanal and industrial companies (37.6 vs. 26.2% of the artisanal and industrial samples analyzed, respectively). High-protein fish meals (CP types 70 to 60, with low ash content) were produced mainly by industrial units (29.2 vs. 1.3%, or 73.8% of the industrial fish meal tested), whereas low-protein fish meals (CP types 40 to 35, with often high ash) were almost always produced by artisanal companies (35.4 vs. 0.0%, or 60.2% of the artisanal fish meal analyzed). Moreover, the increase in ash content was accompanied by decreases in the contents of crude protein and metabolizable energy.

Key words: Fish meal, artisanal and industrial companies, nutritional type categorization, Senegal

INTRODUCTION

The fishing and aquaculture industry, although it contributes to the well-being of people by generating income for poverty alleviation and by improving food security, continues to have negative impacts on both the environment and marine ecosystems because of the waste it often generates. These wastes are commonly termed fish co-products and represent the surplus of fishing catches, uneaten fish, low-commercial-value fish and residues of fishery products from pharmaceutical, biological and food processing (Durand and Lagoin, 1983; Arvanitoyannis and Kassaveti, 2008; FAO, 2012). The processing of fishery co-products has contributed to poverty alleviation and environmental pollution reduction and has led to three new categories of co-products with high biological and economic value: fish meal, fish oils and glues (Durand, 1976; Arvanitoyannis and Kassaveti, 2008; Mullon *et al*., 2009). Fish meal is produced from waste or whole fish and is one of the most frequently used protein sources in animal feed. In 2010, approximately 20.2 million tons of waste fish was used to make fish co-products globally; 75% of that waste fish was processed into fish meal and fish oil, compared with only 33% of the waste fish in 2006 (Hall, 2010; FAO, 2012). Fish meal has since been the subject of widespread commercial trade and its global price has changed from 0.6 $US/kg in 2002 to 1.6 $US/kg in 2010 (IFREMER, 2010; FAO, 2012), based mainly on its nutritional value, especially its protein and energy contents (Bourdon *et al*., 1984;

Corresponding Author: S.B. Ayssiwede, Laboratoire d'Alimentation et de Nutrition Animale (LANA)/Service de Zootechnie-Alimentation, Ecole Inter-Etats des Sciences et Médecine Veterinaires (EISMV) de Dakar, BP: 5077 Dakar-Fann (SENEGAL)

Guerreiro and Retiere, 1992). Due to the increasingly important development of intensive livestock, especially that of non-ruminant animals, the market demand for fish meal has grown worldwide, particularly in sub-Saharan Africa (Mbaye, 2005; FAO, 2012). In 2009, the fish meal production in Senegal was estimated to be approximately 3000 tons and the feed, although sold locally, was mainly exported to other African countries such as Cameroon, Togo and Benin (DPM, 2010). Over the last decade, the fish meal production in coastal African countries (Senegal, Morocco, Mauritania and South Africa) has increased due to the installation of new fish meal manufacturing units, especially artisanal companies (Mbaye, 2005; DPM, 2004-2010; Tarbiya Mouhamedou, 2012; FAO, 2012). Consequently, the Senegalese and sub-regional markets were flooded with various fish meals with nutritional characteristics that were unknown or rarely reported and that rarely met the international nutritional standards sought for such products (Sow and Lagnane, 2010). This constituted an important problem related both to the real market value of these fish meals, whose price was always increasing and to their optimal and efficient use in animal feeding (Nijimbere, 2003; Ngom, 2004; FAO, 2012). In this context, the present work examined the chemical composition of the fish meals produced and marketed in Senegal and categorized them into various nutritional types to better meet the users' or actors' requirements.

MATERIALS AND METHODS

Collection and processing of fish meal samples: The fish meal samples used in this study were collected from both industrial and artisanal fish meal production companies located mainly in the Dakar and Thiès regions of Senegal. Fish meal sample collection occurred from September 2012 to July 2013. A total of 154 samples were collected, 93 of which were from four different artisanal units and 61 from three industrial companies (Table 1). Both artisanal and industrial samples were taken from batches of fish meal produced during this same period of collection. The appearance, particle size and color of the fish meal samples were variable. Fish meal samples from industrial companies were tan/brown in color and had a slight odor and a finer particle size than artisanal fish meal samples, which were dark brown, black or red in color, with a stronger odor and a fairly large particle size. We sampled the fish meals using livestock feed-chain sampling standards to ensure the consistency and reliability of our results. The fish meal samples were ground (especially those with large particles) and transferred to specific plastic pots and stored at 6-8°C until used for nutrient analyses. All samples were analyzed for energy and nutrient composition.

Chemical analyses and energy content of various fish meal samples: Nutrient analyses were carried out in the Laboratory of Nutrition and Animal Feeding (LANA) at the Inter-states School of Sciences and Veterinary Medicine (EISMV) in Dakar from September 2012 to July 2013. We analyzed the dry matter (DM), crude protein (CP), ether extract (EE), total ash and macro-mineral (calcium, phosphorus, sodium and potassium) content of each sample. The DM and total ash content were evaluated using the standard methods of the French Association for Standardization, AFNOR (1977). The EE and CP contents were determined using the reflux extraction method for 6 hours with diethyl ether using the Soxhlet apparatus and the Kjeldahl method (N*6.25), respectively. The calcium, sodium and potassium levels were measured according to the photometric absorption method of AFNOR (1984) and the total phosphorus content was determined using the spectrophotometric absorption method at 430 nm as described by AFNOR (1980). All analyses were performed in duplicate and all calculations of nutrient content were based on the dry matter quantification of each sample.

The gross energy (GE) content of fish meal samples was calculated based on the calorific values of crude protein and fat, 5.65 and 9.1 kcals/g, respectively (Jean-Blain, 2002) and the metabolizable energy (ME) value for poultry was determined according to the regression equation of Opstvedt applied to fishmeal (Bourdon *et al.*, 1984).

Nutritional type categorization of the analyzed fish meals: To assess the nutritional quality of the fish meals produced and their production frequencies by the various companies of fish meal production, we categorized the samples based on their crude protein, fat and ash contents. Then, the standard categorization of INRA (Bourdon *et al.*, 1984; Sauvant *et al.*, 2004) based on crude protein content was extended to type 35 following the same standard model (Table 2). Based on the ether extract content, three classes or types of fish meal were defined: lean (containing less than 9% DM lipids), fatty (containing from 9 to 15% DM lipids) and very fatty (containing more than 15% DM lipids). Based on the total ash content, an additional three groups of fish meal were defined: low (containing less than 25% DM), medium (containing 25 to 45% DM) and high ash (containing more than 45% DM) levels, which corresponded to fish meals with high, medium and low energy contents, respectively.

Statistical analyses: The data were subjected to descriptive analyses (e.g., scattergram, means, frequencies of nutritional type of fish meal produced) using the Statistical Package for Social Science (SPSS). Analysis of Variance (ANOVA) was used to compare the means of nutrient and energy content between fish

Table 1: Fish meal samples collected from artisanal and industrial manufacturers in Senegal

	----------- Artisanal units, AU (n = 4) ------------				-- Industrial units, UI (n = 3) --		
Units or manufacturers of fish meal production	AU_1	AU_2	AU_3	AU_4	IU_1	IU_2	IU_3
Number of fish meal samples	35	20	21	17	20	20	21
Total fish meal samples collected	93				61		

Table 2: Categorization of fish meal samples based on crude protein content

Fish meal protein	Type 70	Type 65	Type 60	Type 55	Type 50	Type 45	Type 40	Type 35
CP content (% DM)	75-68	68-63	63-58	58-53	53-48	48-43	43-38	<38

meals from different manufacturers and Duncan's test was used to verify significance. Student's t-test was used to compare the means between artisanal and industrial fish meal companies. All results are expressed as a percentage of dry matter (% DM) and presented as the mean±standard deviation.

RESULTS

Nutritional composition of the analyzed fish meal samples: The various chemical constituents determined for all 154 samples of artisanal (93) and industrial (61) fish meals analyzed are shown by the scattergram in Fig. 1. The analysis of this diagram shows that the crude protein (CP) and ash contents were the constituents that were mostly represented in the dry matter (DM), followed by the EE or fat and minerals such as calcium (Ca) and phosphorus (P). Sodium (Na) and potassium (K) were found in very small proportions in both the artisanal and industrial fish meals. The dry matter content (DM) varied between the two types of fish meal but was much higher in artisanal fish meals. The industrial fish meals had a significantly higher crude protein content than ash content, with a relatively high EE content, whereas the artisanal fish meals generally had CP and ash contents that were markedly similar and were accompanied by a significantly higher ether extract (EE) content. The CP, EE and ash contents varied more significantly in the artisanal fish meals than in the industrial fish meals. However, though an increased fat content in fish meal was accompanied by an improvement in the energy content, the high ash content in the artisanal fish meal was not accompanied by higher mineral contents, which remained relatively low in both artisanal and industrial fish meals.

Nutrient and energy content of analyzed fish meals: variation between artisanal and/or industrial units: The average nutrient contents, as determined for both artisanal and industrial fish meal production companies in Senegal, are reported in Table 3. This table shows that aside from the phosphorus (P) and sodium (Na) contents, for which a significant difference was observed ($p<0.05$), no significant change ($p>0.05$) was observed in the dry matter (DM), crude protein (CP), ether extract (EE), ash, calcium (Ca), potassium (K) and energy contents of fish meals across artisanal companies. Further, for only these nutrients and energy contents, no significant variation was observed ($p>0.05$) in fish meals from industrial production companies. However, the overall means of the nutrients and energy contents of fish meals from the artisanal (93) and industrial (61) production companies, as reported in Table 4, show clearly significant variations ($p<0.05$) in all of the chemical constituents and the energy contents. Artisanal fish meals were significantly richer in fat (12.4 vs. 10.4% DM), ash (40.4 vs. 24% DM) and minerals (Ca, P, Na and K) than were industrial fish meals, which were significantly richer in dry matter (93.3 vs. 92.1%), crude protein (63.4 vs. 41%) and both gross energy (4567 vs. 3430 kcal/kg DM) and metabolizable energy (3203 vs. 2409 kcal/kg DM).

Nutritional characteristics and energy content of fish meals categorized by protein and ash types: correlation between their crude protein and ash contents: In Senegal, the price of fish meal is largely dependent on its nitrogen content (the higher the protein content is, the more expensive the fish meal will be) and determining the crude protein content is the most common nutritional quality control performed. Published data show that fish meal with well-known nutritional characteristics must be widely used in animal feeding. Because nutritional analyses are often time-consuming and expensive, it would be appropriate to limit the number of such analyses; however, those that are carried out provide quite valuable and sufficient information for producers and users with average incomes. Therefore, it is interesting to establish nutrient profiles of the produced fish meals and correlations between their nutrient contents. Thus, the nutritional characteristics and energy content of the fish meals analyzed and categorized by protein and ash types according to their crude protein and ash contents are reported in Table 5 and 6, respectively. These tables show that all nutritional (protein and ash) types of fish meals categorized were fatty, i.e., they contained more than 9% DM lipids. Fish meals produced in Senegal fall into three quality categories: high-quality fish meals containing 58 to 75% DM crude protein with an ash content under 25% DM (fish meal protein types 60, 65 and 70); medium-quality fish meals containing 43 to 58% DM crude protein with an ash content between 25 and 45% DM (fish meal protein types 45, 50 and 55) and low-quality fish meals that contain less than 43% DM

Table 3: Nutritional and energy content of fish meals produced in artisanal and industrial companies and marketed for animal feeding in Senegal

	Artisanal units (AU) of fish meal production					Industrial units (AU) of fish meal production			
Composition	AU1	AU2	AU3	AU4	p-value	IU1	IU2	IU3	p-value
No. of fish meal samples	35	20	21	17	-	20	20	21	-
D M (%)	91.14±2.7	92.52±2.8	93.04±2.1	92.37±3.5	0.075	93.33±2	92.94±1.9	93.70±1.6	0.429
CP (% DM)	43.22±9.5	39.52±7.4	37.00±6.7	42.03±10	0.062	61.71±7.7	63.77±7.5	64.57±7.7	0.474
EE (% DM)	12.52±3.7	12.86±4.9	12.12±5.8	11.76±3.3	0.884	10.55±3.5	11.43±3.6	10.56±2.3	0.605
Ash (% DM)	40.12±8.0	39.58±8.7	42.51±8.1	39.42±8.2	0.604	25.85±6.2	23.06±5.6	23.32±6.4	0.284
Ca (% DM)	2,97±1.0	2.89±1.2	3.21±1.4	2.85±1.2	0.770	1.76±0.7	1.70±0.8	1.60±0.8	0.779
P (% DM)	2.62±0.8^b	2.05±0.6^a	2.05±0.5^a	2.38±0.6^{ab}	0.006	2.19±0.7	1.60±0.9	1.69±1.2	0.126
Na (% DM)	0.62±0.16^a	0.61±0.2^a	0.72±0.3^a	0.95±0.2^b	0.000	0.51±0.11	0.54±0.13	0.53±0.10	0.651
K (% DM)	0.67±0.14	0.62±0.1	0.63±0.1	0.72±0.1	0.061	0.56±0.11	0.50±0.1	0.50±0.09	0.091
GE (kcal/kg DM)	3581±578	3403±610	3193±743	3445±604	0.178	4447±516	4643±529	4609±436	0.410
ME (kcal/kg DM)	2515±405	2391±430	2243±524	2419±423	0.181	3118±362	3256±372	3232±305	0.410

(a,b): Numbers with different superscript letters in the same row are significantly different at a 5% level ($p<0.05$)
DM: Dry Matter, CP: Crude Protein, EE: Ether Extract, Ca: Calcium, P: Phosphorus, Na: Sodium, K: Potassium
GE: Gross Energy (kcal/kg DM) = 5.65*CP+9.1*EE, in (Jean-Blain, 2002)
ME, Metabolizable Energy (kcal/kg DM) = 39.5*CP+64.5*EE, in (Bourdon *et al*., 1984)

crude protein and more than 45% DM ash (fish meal protein types 35 and 40). Moreover, although the fat content did not vary between samples, there was a correlation between the ash and crude protein contents (CP = 89.42-1.17*Ash; with r^2 = 0.85), where an increase in ash was accompanied by a decrease in crude protein (Fig. 2).

Frequencies of production of different nutritional types of fish meal categorized by type of fish meal production company: Table 7 reports the frequencies of production of various nutritional (protein, fat and ash) types of fish meal that were obtained from both artisanal and industrial companies. It is clear that fish meals of all levels of protein were produced and marketed in Senegal. The low-protein fish meals (types 40, 35) were the most common (36.4%), followed by the medium-protein fish meals (33.1%) and then high-protein fish meals (30.5%). The high-protein fish meals were mainly produced by industrial units (29.2 vs. 1.3%, or 73.8% of industrial fish meal tested), whereas low-protein fish meals (types 40 and 35) were almost always produced by artisanal units (35.4 vs. 0.0%, or 60.2% of artisanal fish meal analyzed). The fish meals with medium protein levels (protein types 55, 50 and 45) were produced in a higher proportion by artisanal companies than by industrial companies (22.7 vs. 10.4%), corresponding to 37.6 and 26.2% of the artisanal and industrial fish meals analyzed, respectively.

Table 7 also shows that 59.1% of the fish meals produced and marketed in Senegal had medium fat contents but that 16.2% of them had high fat contents. The lean fish meals (24.7%), although present at equal rates in industrial and artisanal units (12.35 vs. 12.35%), were more often produced by industrial than by artisanal companies (31.2 vs. 20.4% of fish meal samples). The fatty fish meals were produced almost equally by artisanal and industrial companies (58 vs. 61% of fish meal samples), but the very fatty fish meals were mainly produced by artisanal units (21.5 vs. 8.2% of fish meal samples).

Concerning the ash levels, fish meals with medium ash content appear to be the most commonly produced (56.5%) in Senegal, followed by those with low ash content (25.3%) and then those with high ash content (18.2%). The high-ash fish meals were produced by artisanal companies (30.1 vs. 0.0%). The low-ash fish meals were mainly produced by industrial units (23.4 vs. 1.9%, or 59.2% of industrial fish meals tested), whereas the medium-ash fish meals were more frequently produced by artisanal units (40.3 vs. 16.2%).

DISCUSSION

Overall, the similar levels of nutrients and energy obtained for fish meals from industrial companies and for those from artisanal companies (except the for P and

Table 4: Nutritional and energy content of artisanal and industrial fish meals produced and marketed for animal feeding in Senegal

Type of fish meal production unit composition	Artisanal (n = 93)	Industrial (n = 61)	Global mean (n = 154)	p-value
Dry mater (%)				
Average	92.10±2.85[a]	93.33±1.87[b]	92.58±2.57	0.003
Minimum	84.89	89.33	84.89	
Maximum	97.85	97.47	97.85	
Crude protein (% DM)				
Average	40.80±8.55[a]	63.36±7.63[b]	49.74±13.88	0.000
Minimum	19.15	47.37	19.15	
Maximum	72.66	74.21	74.21	
Ether extract (% DM)				
Average	12.36±4.42[b]	10.44±3.15[a]	11.76±4.03	0.022
Minimum	6.09	5.76	5.76	
Maximum	30.55	22.51	30.55	
Ash (% DM)				
Average	40.42±8.18[b]	24.06±6.13[a]	33.94±10.92	0.000
Minimum	16.83	11.55	11.55	
Maximum	61.39	37.64	61.39	
Calcium, Ca (% DM)				
Average	2.98±1.18[b]	1.68±0.73[a]	2.47±1.21	0.000
Minimum	0.850	0.690	0.69	
Maximum	6.07	3.10	6.07	
Phosphorus, P (% DM)				
Average	2.33±0.73[b]	1.82±0.98[a]	2.13±0.87	0.000
Minimum	0.70	0.56	0.56	
Maximum	5.47	5.22	5.47	
Sodium, Na (% DM)				
Average	0.70±0.26[b]	0.52±0.12[a]	0.63±0.23	0.000
Minimum	0.26	0.26	0.26	
Maximum	1.58	0.81	1.58	
Potassium, K (% DM)				
Average	0.66±0.13[b]	0.52±0.10[a]	0.60±0.14	0.000
Minimum	0.38	0.32	0.32	
Maximum	1.23	0.75	1.23	
Gross energy (kcal/kg DM)				
Average	3430±637[a]	4567±494[b]	3881±807	0.000
Minimum	2011.08	3631.27	2011.08	
Maximum	5061.70	5445.69	5445.69	
Metabolizable energy poultry (kcal/kg DM)				
Average	2409±448[a]	3203±346[b]	2723±565	0.000
Minimum	1414.97	2547.31	1414.97	
Maximum	3547.96	3820.09	3820.09	

[(a,b)]: Numbers with different superscript letters in the same row are significantly different at a 5% level ($p<0.05$)

Na contents, which were significantly higher in company No. 4) confirmed the fact that the two types of fish meal production company use very similar raw materials, composed essentially of the whole fish for industrial companies and of fish waste for artisanal companies. However, artisanal fish meals were significantly richer in fat (12.4 vs. 10.4% DM), ash (40.4 vs. 24% DM) and minerals (Ca, P, Na and K) than the industrial samples, which were significantly richer in dry matter (93.3 vs. 92.1%), crude protein (63.4 vs. 41%) and both gross energy (4567 vs. 3430 kcal/kg DM) and metabolizable energy (3203 vs. 2409 kcal/kg DM). These results are consistent with those obtained in previously published studies on the same types of fish meal in Kenya and Uganda (Bastianelli *et al*., 2009) and in Senegal (Ngom, 2004; Nijimbere, 2003). However, although the energy content of our artisanal fish meal samples was similar to that found by Nijimbere (2003), the CP content (41% DM) and ash content (40.4% DM) in our samples were much higher than those of their samples (CP = 27% DM and ash = 47% DM). The crude protein content (61.7 to 64.6% DM, or 63.4% DM) of our industrial fish meal samples corresponded to a CP type 65 fish meal and was similar to the types of fish meals produced in Brazil (Cothenet *et al*., 2003). However, this CP content was higher than those previously recorded in South Asia (58%) (Cothenet *et al*., 2003) and in Senegal (58.5%) (Nijimbere, 2003). Furthermore, due to their relatively high fat content (10.4%), the metabolizable energy (3203 kcal/kg DM) of our industrial fish meals was similar to that of the CP type 65 fish meal (3010-3500 kcal/kg DM) reported by Sauvant *et al*. (2004) and Bourdon *et al*. (1984). The calcium (1.6 to 1.8% DM, or 1.7%), phosphorus (1.6 to 2.2% DM, or 1.8%), sodium and potassium (0.52% DM) levels recorded in this study for industrial fish meals were lower than those reported

Table 5: Nutritional characteristics and energy contents of fish meals produced for animal feeding in Senegal and categorized by protein level

Fish meal CP type	No. of sample	DM (%)	CP (% DM)	EE (% DM)	Ash (% DM)	Ca (% DM)	P (% DM)	Na (% DM)	K (% DM)	ME (kcal/kg DM)
Type 70 (75-68% CP)	20	92.78±1.83	71.62±1.69	10.53±1.86	17.83±2.83	1.10±0.26	1.12±0.53	0.49±0.08	0.51±0.11	3508±132
Type 65 (68-63% CP)	16	92.85±1.86	66.19±1.35	10.36±1.97	21.93±2.36	1.43±0.46	1.59±0.76	0.53±0.10	0.53±0.12	3283±137
Type 60 (63-58% CP)	11	93.41±1.57	59.82±1.49	12.99±5.58	27.04±3.93	1.95±0.85	1.89±0.59	0.60±0.13	0.57±0.11	3200±353
Type 55 (58-53% CP)	16	92.46±2.99	55.90±1.36	10.46±2.93	31.09±3.81	2.15±0.60	2.77±1.14	0.59±0.18	0.59±0.14	2883±170
Type 50 (53-48% CP)	10	92.31±3.72	50.56±1.47	10.64±2.28	33.25±5.16	2.41±0.67	2.44±0.79	0.56±0.21	0.59±0.16	2683±160
Type 45 (48-43% CP)	25	91.71±2.81	45.11±1.58	13.35±4.38	36.65±4.47	2.56±0.72	2.15±0.57	0.63±0.23	0.65±0.12	2643±280
Type 40 (43-38% CP)	21	91.48±1.92	39.91±1.14	12.51±4.91	40.31±6.45	2.69±0.88	2.68±0.83	0.63±0.16	0.67±0.09	2383±317
Type 35 (<38% CP)	35	93.49±2.78	32.70±5.06	12.06±4.64	46.54±6.32	3.84±1.18	2.29±0.57	0.81±0.30	0.64±0.15	2069±368

DM: Dry Matter, CP: Crude Protein, EE: Ether Extract, Ca: Calcium, P: Phosphorus, Na: Sodium, K: Potassium, ME: Metabolizable energy for poultry

Table 6: Nutritional characteristics and energy contents of fish meals produced in Senegal for animal feeding, categorized based on their ash content

Fish meal content	No. of sample	DM (%)	CP (% DM)	EE (% DM)	Ash (% DM)	Ca (% DM)	P (% DM)	Na (% DM)	K (% DM)	ME (kcal/kg DM)
Less than 25% DM of Ash	39	93.05±1.85	67.56±6.40	11.61±3.97	17.74±3.15	1.19±0.36	1.38±0.71	0.51±0.1	0.53±0.12	3417±177
From 25 to 45% DM of Ash	87	92.15±2.68	47.22±8.26	12.16±4.13	35.16±5.23	2.46±0.68	2.36±0.85	0.63±0.2	0.62±0.12	2650±349
More than 45% DM of Ash	28	93.27±2.91	32.75±6.16	10.73±3.72	49.92±3.78	4.26±0.97	2.44±0.43	0.81±0.32	0.65±0.17	1986±314

DM: Dry Matter; CP: Crude Protein, EE: Ether Extract, Ca: Calcium, P: Phosphorus, Na: Sodium, K: Potassium, ME: Metabolizable Energy for poultry

in the literature: 3-6%, 2-4%, 0.9-1.2% and 0.7-1% DM, for Ca, P, Na and K, respectively (Sauvant *et al*., 2004; Cothenet *et al*., 2003; Bourdon *et al*., 1984). However, the significant differences in crude protein, fat, ash, mineral and energy contents between artisanal and industrial fish meals can be explained both by the quality or species of raw materials used and by the fish meal production process (Guerreiro and Retiere, 1992). In Senegal, artisanal companies primarily produce fish meal from poor fish co-products such as fish waste collected from local markets, tuna canning and thread factories, whereas industrial companies produce fish meal mainly from whole fish (Mbaye, 2005; Peron *et al*., 2010; Sow and Lagnane, 2010). Accordingly, using fish waste or poor fish co-products decreases the protein and energy content and increases the ash content of the fish meal. However, the high ash content in artisanal fish meal did not correspond to an increase in mineral content, which remained relatively low in both artisanal and industrial fish meals. This observation was similar to observations made in Senegal by Ngom (2004) and in Kenya and Uganda by Bastianelli *et al*. (2009) for artisanal fish meal and can be explained by the fact that the ash of the analyzed fish meals contained some impurities (Sauvant *et al*., 2004), such as silica, in addition to minerals. This reflects contamination in the fish meal due to poor manufacturing conditions (especially for artisanal fish meal) and the fraudulent nature of some producers who did not hesitate to add solid wastes other than those from fish co-products to their fish meals.

The significantly higher fat content that we observed in artisanal fish meals (12.4 vs. 10.4%) may occur because the lipid extraction process used during manufacturing in industrial companies is more efficient than that used in artisanal companies. Although the artisanal fish meals contained a higher fat content, they had a lower energy content than industrial fish meals. This can be explained by the fact that the metabolizable energy content of fish meal is closely related to its crude protein and fat contents. The relatively high temperature changes in the tropics and the inadequate storage conditions cause the high fat content in fish meal to oxidize and go rancid quickly. This explains the dark, wet appearance and offensive odor of the artisanal fish meal samples (Flanzy *et al*., 1962; Guerreiro and Retiere, 1992). Furthermore, the high fat content in fish meal makes it subject to deterioration; thus, the addition of appropriate antioxidants in standardized conditions is occasionally recommended to allow longer storage of the fish meal. According to Issa *et al*. (2009), both drying fish meal in the sun and the poor hygiene conditions of artisanal fish meal companies induce the development of many types of bacteria at much higher rates than the level permitted by the standard.

The chemical compositions of various fish meals, categorized by the crude protein and ash contents in this

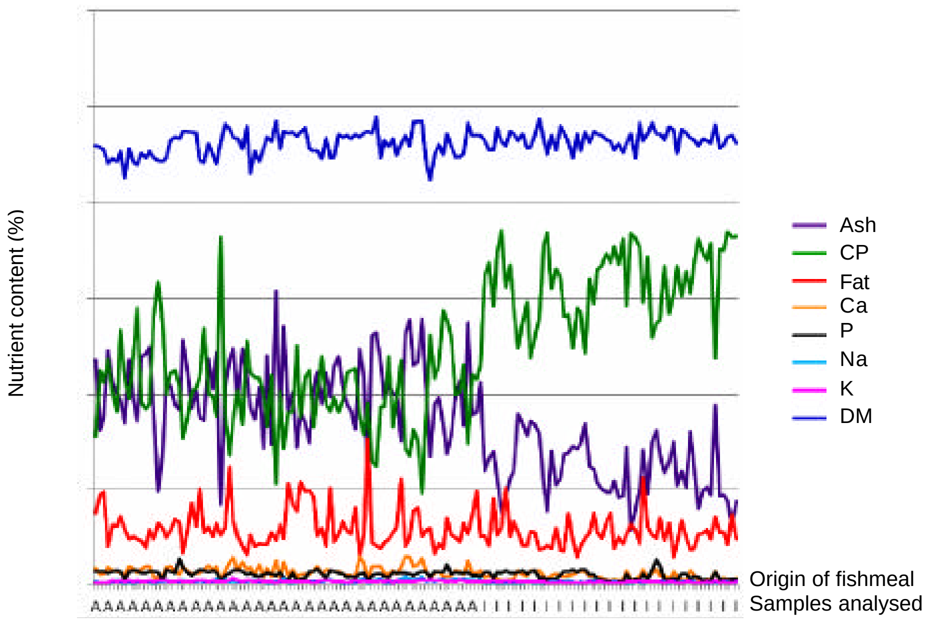

Fig. 1: Scattergram of nutrient contents of artisanal (A) and industrial (I) fish meals produced and marketed in Senegal for animal feeding

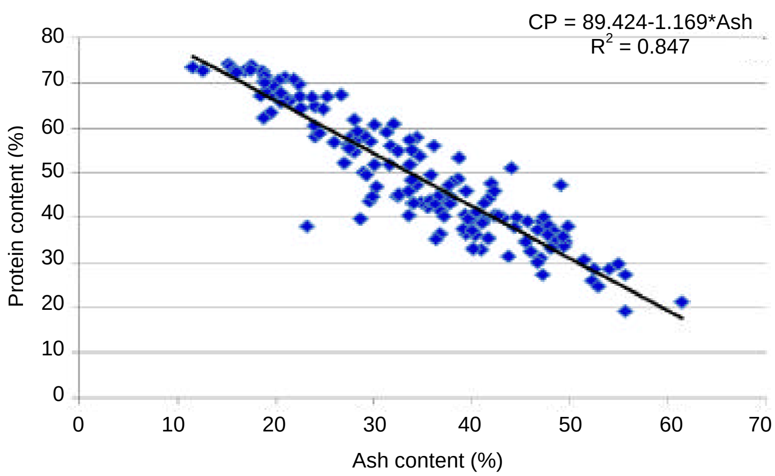

Fig. 2: Correlation between the contents of crude protein and ash in fish meals produced and marketed for animal feeding in Senegal

study, showed that aside from slight variations in the recorded mineral content, the nutritional characteristics of CP types 70, 65 and 60 fish meals produced in Senegal were similar to those found for fish meals produced elsewhere with the same CP classifications. Their CP content (71.92 to 59.20%), high energy content (3566-3200 kcal ME/kg DM) and relatively low mineral content matched those of fish meals that are considered high quality and beneficial in animal feeding (Bourdon *et al*., 1984; Sauvant *et al*., 2004). Fish meals of CP types 55, 50 and 45 can be considered medium-quality fish meals and share similar nutritional characteristics (55.86 to 45.23% DM of crude protein, 2584.50 to 2877 kcal ME/kg DM, medium content in ash, 31 to 37% and minerals); thus, they can be used in animal feeding, although they are not widely recognized by international animal feed standards. The low-quality fish meals (CP type 40 and 35) had low nutritional values (40 to 33% DM of CP, 2390 to 1986 kcal ME/kg DM and ash content up to 40% DM with relatively important minerals: 2.7-5% calcium, 2.3-2.7% phosphorus) and may also be used in animal feeding, though with special attention to diet

Table 7: Production frequencies (%) of fish meals produced by artisanal and industrial companies in Senegal and categorized by nutritional type

Units of fish meal production Nutritional type categorization	Artisanal (n = 93)	Industrial (n = 61)	Total (n = 154)
Fish meal crude protein type production			
Type 70 (75-68% DM of CP)	0.65 (1.07)	12.35 (31.15)	13.00
Type 65 (68-63% DM of CP)	0.65 (1.07)	9.75 (24.60)	10.40
Type 60 (63-58% DM of CP)	0.00 (0.00)	7.14 (18.03)	7.14
Type 55 (58-53% DM of CP)	4.55 (7.53)	5.85 (14.75)	10.40
Type 50 (53-48% DM of CP)	3.25 (5.37)	3.25 (8.19)	6.50
Type 45 (48-43% DM of CP)	14.93 (24.74)	1.29 (3.28)	16.20
Type 40 (43-38% DM of CP)	13.64 (22.58)	0.00 (0.00)	13.64
Type 35 (Under 38 % DM of CP)	21.72 (37.64)	0.00 (0.00)	22.72
Fish meal lipid type production			
Lean fish meal (less than 9% DM lipid)	12.35 (20.43)	12.35 (31.15)	24.70
Fat fish meal (from 9 to 15% DM lipid)	35.07 (58.06)	24.03 (60.65)	59.10
Very fat fish meal (more than 15% DM lipid)	12.98 (21.51)	3.22 (8.19)	16.20
Fish meal ash type production			
Low ash fish meal (less than 25% DM)	1.95 (3.23)	23.37 (59.02)	25.32
Medium ash fish meal (from 25 to 45% DM)	40.27 (66.67)	16.23 (40.98)	56.50
High ash fish meal (more than 45% DM)	18.18 (30.10)	0.00 (0.00)	18.18

[a,b]: Numbers in ( ) are the proportions calculated based on number of samples collected per unit or company

formulation and good adaptation to the nutrient requirements of the animal species; however, these fish meals are still excellent for use as manure or organic fertilizer for gardening and agriculture (Sadreddine, 2003, Sow and Lagnane, 2010). The correlation (CP = 89.42-1.17*Ash; with r^2 = 0.85) established in this study between the crude protein and ash contents of fish meals produced in Senegal was perfectly consistent with that obtained (CP = 84.2-0.93*Ash; with r^2 = 0.86) by Bastianelli *et al.* (2009) for fish meals produced in Kenya and Uganda. Both equations show that an increase in ash content is accompanied by a decrease in crude protein content. Thus, in the case of a single determination of crude ash, for example, it is easy to determine the crude protein content and, subsequently, the ether extract (EE) and energy contents; thus, in the case of fish meal, we had a ternary system in which CP+Ash+EE = 100. Obtaining this information is extremely important and valuable for both the formulators of animal diets and the producers and sellers of fish meals.

Fish meals with low protein (60.2 vs. 0.0%), high fat (21.5 vs. 8.2%) and high ash (30.1 vs. 0.0% of fish meal samples) contents were mainly produced by artisanal units. This result can be explained by the fact that artisanal companies generally use fish waste or co-products as raw materials and have inefficient lipid extraction processes during manufacturing, whereas industrial companies use mainly whole fish to produce fish meals with high nutritional quality (51.2 vs. 2.14% samples for high protein content, 59 vs. 3.23% samples for low ash content). The overall similar proportion of fish meals with medium nutritional quality (37.6% vs. 26.2% samples for CP types 55 to 45; 58.1 vs. 61% samples with a fat content from 9 to 15 and 67% vs. 41% samples for ash content from 25 to 45%) produced by artisanal and industrial companies is because the artisanal units occasionally use whole fish in addition to fish co-products and the industrial units occasionally use fish waste in addition to whole fish as raw materials.

Conclusion: Our study showed that the nutritional and energy contents of fish meals produced and marketed in Senegal were variable. Overall, the fish meals exhibited significant variation ($p<0.05$) in the average values for all chemical constituents and energy contents. All of the analyzed fish meal samples were fatty, regardless of whether they came from artisanal or industrial companies. Artisanal fish meals were significantly richer in lipids (12.4 vs. 10.4% DM), ash (40.4 vs. 24% DM) and minerals (Ca, P, Na and K) than were industrial fish meals, which were significantly richer in dry matter (93.3 vs. 92.1%), crude protein (63.4 vs. 41% DM) and both gross energy (4567 vs. 3430 kcal/kg DM) and metabolizable energy (3203 vs. 2409 kcal/kg DM). Apart from phosphorus and sodium, for which there was significant variation among samples from different artisanal companies, significant differences were observed for nutrient contents between fish meals from artisanal and industrial companies. Overall, fish meals of all nutritional qualities were produced and marketed in Senegal. Of the fish meals sampled, 36.4% were low in protein, 33.1% had medium protein levels and 30.5% were high in protein. Medium-quality fish meals (CP types 55 to 45, with medium ash content) were produced by both artisanal and industrial companies (37.6 vs. 26.2% of artisanal and industrial samples analyzed). High-quality fish meals (CP types 70 to 60, with low ash content) were produced mainly by industrial companies (29.2 vs. 1.3%, or 73.8% of industrial fish meal) and low-quality fish meals (CP types 40 to 35, often with high ash contents) were almost always produced by artisanal units (35.4 vs. 0.0%, or 60.2% of artisanal fish meal). Moreover, an increase in ash content in the fish meal was accompanied by a decrease in crude protein content and, consequently, a decrease in metabolizable energy content. Establishing a standardized nutritional categorization for the fish meals produced and marketed in Senegal would profit both producers and users of fish meal because it would ensure that industrial and artisanal fish meal manufacturers improve the quality of the manufacturing process and the raw materials used and would allow fish meal users to better regulate the quality control of the fish meal through nutritional, microbiological and toxicological tests before using them as animal feeds. The use of artisanal fish meals in animal feeding in Senegal or Africa requires caution because they are low quality and may contain dangerous agents that can have adverse effects on livestock.

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