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Total lipid content and fatty acid composition in edible offal from pigs

Gesamtlipidgehalt und Fettsäurezusammensetzung in essbaren Schlachtnebenprodukten von Schweinen

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Summary

The objective of this study was to investigate the lipid content and fatty acid profile in six edible organs, namely heart, brain, pancreas, kidney, liver, and tongue from commercial crossbred pigs. Results indicate that total lipid and fatty acid composition were significantly affected by organ type. Large differences in lipid contents were found, ranging from 1.4 to 6.8 g/100 g of tissue. Brain had the highest lipid content followed by tongue, pancreas, liver, kidney, and heart. The fatty acid profile revealed low relative proportions of saturated fatty acids (SFA) in heart. In contrast, higher amounts of unsaturated fatty acids were obtained for heart (PUFA), and tongue (MUFA). Heart and kidney had the most favourable PUFA/SFA ratio. However, the ratio of *n*-6 and *n*-3 PUFA in by-products from pigs was above to the nutritional recommendation for human diet, except in brain. Moreover, variations in fatty acid profile clearly highlight the differences between the organs as showed by principal component analysis. Our findings indicate that some edible offal from pig were relatively rich in SFA and, therefore, should be consumed moderately if integrated into a varied well-balanced diet.

Keywords: Edible by-products, Swine, Total fat, Fatty acid profile

Zusammenfassung

Das Ziel dieser Studie war es, den Lipidgehalt und das Fettsäureprofil aus sechs essbaren Organen (Herz, Hirn, Bauchspeicheldrüse, Niere, Leber und Zunge) kommerziell gehaltener Schweine Kreuzungsrassen zu untersuchen. Die Ergebnisse zeigten, dass der Gesamtlipidgehalt und die Fettsäurezusammensetzung signifikant vom Organtyp beeinflusst wurde. Große Unterschiede wurden in den Lipidgehalten (1,4 g bis 6,8 g / 100 g Gewebe) festgestellt. Den höchsten Lipidgehalt hatte Hirn gefolgt von Zunge, Bauchspeicheldrüse, Leber, Niere und Herz. Das Fettsäureprofil zeigte hohe Anteile an gesättigten Fettsäuren (SFA) in Leber, Bauchspeicheldrüse und Hirn. Im Gegensatz dazu wurden höhere Mengen an ungesättigten Fettsäuren in Herz und Niere (PUFA, mehrfach ungesättigte Fettsäuren) sowie Zunge (MUFA, einfach ungesättigte Fettsäuren) nachgewiesen. Herz und Nieren wiesen das günstigste PUFA/SFA-Verhältnis auf. Das Verhältnis von n-6 und n-3 PUFA in den Schweine Nebenprodukten lag jedoch, außer im Hirn, oberhalb der Empfehlung für die menschliche Ernährung. Darüber hinaus waren die Variationen im Fettsäureprofil zwischen den Organen sehr deutlich, wie die Hauptkomponentenanalyse zeigte. Unsere Ergebnisse zeigten, dass einige essbare Schlachtnebenprodukte von Schweinen reich an SFA waren und daher, integriert in einer abwechslungsreichen und ausgewogenen Ernährung, mäßig konsumiert werden sollten.

Schlüsselwörter: Essbare Nebenprodukte, Schweine, Gesamtfett, Fettsäureprofil

Introduction

Total carcass weight of pigs produced in slaughterhouses accounted for 22,942,840 tonnes in 2015 (Eurostat, 2016), of which considerable amounts came from commercial pig production (FAO, 2014). A huge quantity of the gross income from pork (up to 7.5 %) arises from by-products (Jayathilakan et al., 2012). Therefore, an effective utilization of these edible by-products in the processing is highly desirable for the productivity of meat industry (Toldrá et al., 2012). In addition, some of these edible by-products constitute part of the human diet and traditional dishes worldwide (Nollet and Toldrá, 2011).

Fatty acid composition has been the subject of intensive work in order to improve the nutritional quality of pork (Alonso et al., 2010; Madeira et al., 2014). In contrast, the scientific information available regarding fatty acid composition of edible porcine offal is very restricted (Prates et al., 2011; Seong et al., 2014). Edible by-products may provide a valuable source of proteins, minerals and vitamins (Aristoy and Toldrá, 2011; Tomovic et al., 2015) or new products (Toldrá and Reig, 2011; Valta et al., 2015). However, these by-products, including internal organs, have been neglected and less studied than muscle tissue in spite of their impact on food safety and human health. Thus, the aim of the present study was to assess and compare the lipid content and fatty acid profile of the most important edible offal (heart, brain, pancreas, kidney, liver and tongue) from commercial crossbred pigs.

Materials and methods

Animal experiment and sample collection

The experiment was conducted at the experimental abattoir (Unidade de Investigação em Produção Animal, Instituto de Investigação Agrária e Veterinária, UIPA-INIAV) and all experimental procedures were performed in accordance to the European Union guidelines (Directive 86/609/EEC). The present trial was described in detail in a companion paper (Madeira et al., 2014). Six entire male commercial crossbred pigs (25 % Duroc, 25 % Pietrain, 25 % Large White and 25 % Landrace) with an initial body weight of 58.9 ± 1.59 kg (mean ± standard deviation) were selected and fed a standard concentrate diet from weaning until the beginning of the experiment. Then, pigs were assigned to a diet control, isoenergetically formulated (14 MJ metabolisable energy/kg), with 16·0% of crude protein (normal protein diet). The ingredients, chemical and fatty acid compositions of the experimental diet are presented in Table 1. Pigs were fed individually twice a day and had *ad libitum* access to water. The duration of the experiment was on average 40 days. Pigs were slaughtered at an average live body weight of 91.7 ± 1.6 kg using electrical stunning before exsanguination. Samples of heart, brain, pancreas, kidney, tongue, and liver were collected, trimmed of connective and visible adipose tissue, vacuum packed, frozen, and stored at –20 °C until analysis.

Determination of total lipid content and fatty acid composition

Total lipids of edible offal from commercial crossbred pigs were extracted from lyophilised samples (–60 °C and 2.0 hPa; Edwards High Vaccum International, UK), in duplicate, according to the method of Folch et al. (1957), modified by Carlson (1985), and gravimetrically measured by weighing the fat residue after solvent evaporation.

Fatty acid methyl esters (FAME), obtained from fatty acids after consecutive basic (0.5 mol/L sodium methoxide in anhydrous methanol, Sigma-Aldrich Ltd., St. Louis, MO, USA) followed by acid transesterification using hydrochloric acid in methanol (1:1 v/v) during 30 min at 50 °C and 10 min at 50 °C, respectively (Raes et al., 2001). FAME were analysed by gas chromatography (GC) using an HP7890A (Hewlett-Packard, Agilent Technologies, Santa Clara, CA, USA), equipped with a flame ionization detector (FID) and a capillary column Supelcowax® 10 capillary column (30 m × 0.20 mm internal diameter, 0.20 µm film thickness; Supelco, Bellefonte, PA, USA). Helium was used as carrier gas. The temperatures of injector and detector were set at 250 °C and 280 °C, respectively. The oven temperature began at 150 °C, held for 11 min and followed by an increase of 3 °C/min to 210 °C. The final oven temperature was retained for 30 min. Nonadecanoic acid methyl ester (C19:0, Sigma-Aldrich Ltd., St. Louis, MO, USA) was used as internal standard. Identification of FAME was based on commercial standard mixture (FAME mix 37 components, Supelco Inc. Bellefonte, PA; USA). Confirmation of FAME was performed by gas-chromatography coupled to mass spectrometry using a GC-MS QP2010-Plus (Shimadzu, Kyoto, Japan). The values of fatty acids were expressed as a percentage of the sum of identified fatty acids (% of total fatty acids).

Statistical analysis

All variables were checked for variance homogeneity using the MIXED procedure of Statistical Analysis Systems Institute (SAS, 2009). The statistical model considered the organ type a repeated measure within the animal. Data were expressed as means ± standard error (SE). Significant multiple comparison test was carried out using the PDIFF

TABLE 1: *Ingredients and chemical composition and fatty acid compositions of the experimental diet.*

Ingredients (%)	
Maize	62.9
Barley	10.0
Soybean meal	18.9
Sunflower meal	1.64
Soybean oil	1.15
Calcium carbonate	0.73
Bi-calcium phosphate	1.21
Sodium bicarbonate	0.11
Salt	0.35
Vitamin-trace mineral premix	0.40
Acid mixture	0.10
Antioxidant mixture	0.005
Chemical composition (%)	
DM	87.5
Crude protein	16.0
Starch	38.3
Crude fat	3.36
Crude fibre	4.38
Ash	3.88
Ca	0.66
P	0.49
ME (MJ ME/kg)	13.8
Fatty acid composition (% of total fatty acids)	
C16:0	15.0
C18:0	2.72
C18:1c9	24.9
C18:1c11	1.05
C18:2*n*-6	53.0
C18:3*n*-3	3.32

DM: dry-matter; ME: metabolisable energy

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option adjusted with Tukey-Kramer to determine statistical differences among organs ($p < 0.05$). Additionally, a principal component analysis (PCA) was performed using the STATISTICA software (StatSoft, Inc., OK, 2004) in order to explore relationship between organs.

Results and discussion

Total lipids and fatty acid profile

Total lipids of heart, brain, pancreas, kidney, liver, and tongue from commercial pigs are displayed in Table 2. Total lipids were significantly affected by organ type ($p < 0.001$). Brain had the highest total lipid content (6.8 %) compared to the other organs, followed by tongue (3.6 %), liver (3.1 %), pancreas (2.6 %), kidney (2.4 %), and heart (1.4 %). Only brain may be considered fatter than lean meat (< 5 %) (Food Advisory Committee, 1990). However, the fat content of brain and pancreas were lower than those found by Ockerman and Basu (2004) for brain (8.6–9.2 %) and pancreas (4.0–15.0 %). In contrast, the fat content of liver was higher than those reported by the former authors (1.1–2.4 %). Seong and colleagues (2014) also found higher fat content in pork heart (4.6 %) and pancreas (7.2 %). When compared to the fat content in pig muscle tissue, in general, porcine by-products had similar or even higher fat contents (Mas et al., 2011; Alonso et al., 2012; Madeira et al., 2014). Multiple interacting factors, such as age (or weight), gender, genotype, castration and feeding, influence both total fat and fatty acid deposition in the various fat depots (Wood et al., 2008; Kouba and Sellier, 2011). As consequence of genetic selection towards reduced subcutaneous fat, the amount of intramuscular fat has been strongly reduced in crossbred commercial pigs (Jeremiah et al., 1999).

Fatty acid profile (expressed as percentage of total fatty acids), partial sums and ratios of fatty acids in the different edible organs are also presented in Table 2. The main fatty acids in pork by-products were oleic (C18:1*c*9),

TABLE 2: *Total lipids (% tissue), fatty acid composition (% total fatty acids), partial sums of fatty acids and related ratios of edible pork offal.*

	Brain		Heart		Kidney		Liver		Pancreas		Tongue		*p*
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	value
Total lipids	6.77^{a}	0.182	1.40^{b}	0.118	2.42^{c}	0.111	3.10c^{d}	0.211	2.62c^{d}	0.168	3.57^{d}	0.231	***
Fatty acid composition													
C12:0	0.02^{a}	0.001	0.04^{b}	0.003	0.05^{b}	0.002	0.12^{c}	0.008	0.05^{b}	0.005	0.07^{d}	0.002^{a}	***
C14:0	0.35^{a}	0.015	0.12^{b}	0.007	0.20^{c}	0.014	0.28^{abc}	0.049	0.65^{d}	0.077	1.14^{e}	0.025	***
C14:1c9	0.01^{a}	0.001	0.04^{b}	0.008	0.01^{abc}	0.002	0.01^{ac}	0.003	0.01^{a}	0.001	0.02^{c}	0.002	**
C15:0	0.06^{a}	0.001	0.06^{ac}	0.008	0.10^{bd}	0.008	0.18^{adc}	0.051	0.09^{bc}	0.008	0.08^{acd}	0.008	**
DMA-C16:0	2.58^{a}	0.067	7.05^{b}	0.065	5.04^{c}	0.215	0.29^{d}	0.026	2.00e	0.305	0.47^{d}	0.066	***
C16:0	16.71^{a}	0.269	12.63^{b}	0.154	19.01^{c}	0.366	16.13^{a}	0.542	21.72^{d}	0.448	25.1^{d}	0.958	***
C16:1c7	0.76^{a}	0.028	0.16^{b}	0.007	0.34^{c}	0.025	0.37^{c}	0.045	0.39^{c}	0.027	0.40^{c}	0.024	***
C16:1c9	0.85^{a}	0.025	0.21^{b}	0.010	0.24^{b}	0.016	0.58^{a}	0.078	0.82^{a}	0.100	2.90^{c}	0.125	***
C17:0	0.22^{a}	0.003	0.31^{ad}	0.029	0.50^{b}	0.021	1.03^{c}	0.072	0.41^{bd}	0.040	0.39^{d}	0.019	***
C17:1c9	0.16^{a}	0.008	0.20^{b}	0.006	0.14^{a}	0.008	0.19^{ab}	0.018	0.16^{ab}	0.009	0.34^{c}	0.021	***
DMA-C18:0	3.66^{a}	0.054	4.33^{b}	0.170	0.94^{c}	0.045	0.33^{d}	0.038	0.44^{d}	0.057	0.13^{e}	0.023	***
DMA-C18:1	2.28^{a}	0.068	2.03^{a}	0.024	0.47^{b}	0.014	0.06^{c}	0.006	0.46^{b}	0.079	0.11^{c}	0.017	***
C18:0	18.17^{a}	0.212	11.64^{b}	0.245	15.58^{c}	0.280	27.39^{d}	1.240	16.82^{ac}	0.355	11.41^{b}	0.452	***
C18:1c9^{+}	21.06^{a}	0.249	8.81^{b}	0.317	12.10^{c}	0.700	13.61^{c}	0.953	21.00^{a}	1.873	37.65^{d}	0.796	***
C18:1c11	6.16^{a}	0.093	3.50^{b}	0.075	3.00^{c}	0.107	1.80^{d}	0.112	2.60^{c}	0.188	4.65^{e}	0.146	***
C18:2*n*-6^{++}	0.66^{a}	0.031	29.32^{b}	0.828	17.56^{c}	0.334	16.83^{c}	0.763	22.74^{d}	1.340	9.62^{e}	1.642	***
C18:3*n*-3	0.02^{a}	0.004	0.37^{b}	0.012	0.24^{c}	0.023	0.33^{bc}	0.041	0.60^{d}	0.025	0.37^{bcd}	0.071	***
C20:0	0.16^{a}	0.012	0.05^{b}	0.002	0.11^{a}	0.008	0.06^{b}	0.004	0.41^{a}	0.082	0.16^{a}	0.017	***
C20:1c11	1.06^{a}	0.061	0.14^{b}	0.003	0.28^{c}	0.031	0.21^{c}	0.010	0.43^{d}	0.043	1.19^{a}	0.050	***
C20:2*n*-6	0.13^{a}	0.012	0.80^{b}	0.013	1.17^{c}	0.066	0.49^{d}	0.036	0.43^{d}	0.036	0.54^{d}	0.068	***
C20:3*n*-6	0.38^{a}	0.025	0.62^{b}	0.019	1.36^{c}	0.162	0.52^{abd}	0.127	0.39^{a}	0.027	0.20^{d}	0.040	***
C20:4*n*-6	7.44^{a}	0.179	12.3^{b}	0.509	16.2^{c}	0.591	11.4^{abc}	1.550	5.02^{d}	0.542	0.90^{e}	0.210	***
C20:3*n*-3	0.003^{a}	0.002	0.13^{b}	0.006	0.31^{c}	0.010	0.62^{c}	0.11	0.05^{d}	0.003	0.13^{b}	0.005	***
C20:5*n*-3	0.04^{a}	0.003	0.24^{b}	0.010	0.34^{b}	0.044	0.34^{abc}	0.097	0.16^{c}	0.015	0.06^{a}	0.018	***
C22:4*n*-6	0.27^{a}	0.010	0.25^{a}	0.013	0.21^{a}	0.017	0.72^{a}	0.162	0.08^{b}	0.010	0.27^{a}	0.031	***
C22:5*n*-3	0.16^{a}	0.009	1.02^{b}	0.058	0.67^{c}	0.038	1.21^{bc}	0.236	0.28^{d}	0.027	0.17^{ad}	0.014	***
C22:6*n*-3	5.04^{a}	0.247	0.46^{b}	0.037	0.87^{c}	0.046	0.84^{bc}	0.157	0.10^{d}	0.023	0.09^{d}	0.010	***
Others	11.6^{a}	0.193	3.19^{b}	0.110	2.96^{bd}	0.236	4.07^{b}	0.313	1.68^{cd}	0.302	1.44^{c}	0.140	***
Partial sums of fatty acids													
Σ SFA	35.70^{a}	0.437	24.86^{b}	0.259	35.54^{a}	0.474	45.16^{c}	1.353	40.16^{c}	0.612	38.35^{ac}	1.387	***
Σ MUFA	30.32^{a}	0.309	13.06^{b}	0.384	16.11^{c}	0.779	16.76^{bc}	1.157	25.42^{a}	2.084	47.14^{d}	0.940	***
Σ PUFA	14.15^{a}	0.405	45.48^{b}	0.588	38.95^{c}	0.539	33.30^{cd}	2.317	29.85^{d}	1.895	12.35^{a}	1.994	***
Σ DMA	8.52^{a}	0.127	13.41^{b}	0.120	6.44^{c}	0.234	0.67^{d}	0.068	2.89^{e}	0.432	0.72^{d}	0.101	***
Σ *n*-6 PUFA	8.88^{a}	0.197	43.26^{b}	0.592	36.54^{c}	0.569	29.96^{cd}	1.989	28.66^{d}	1.852	11.53^{a}	1.931	***
Σ *n*-3 PUFA	5.27^{a}	0.248	2.21^{b}	0.050	2.42^{b}	0.077	3.34^{b}	0.278	1.19^{c}	0.048	0.82^{d}	0.070	***
Fatty acid ratios													
PUFA/SFA	0.40^{a}	0.013	1.83^{b}	0.039	1.10^{c}	0.026	0.75^{d}	0.074	0.75^{d}	0.056	0.33^{a}	0.061	***
n-6/*n*-3	1.68^{a}	0.057	19.59^{b}	0.553	15.21^{c}	0.646	8.98^{d}	0.857	24.02^{e}	0.806	13.67^{cd}	1.529	***

SE: standard error; Different superscripts within columns indicate significant differences among the means; Significance: **: $p < 0.01$; ***: $p < 0.001$; $^{+}$: This fatty acid co-elute with minor amounts of the C18:1t9; $^{++}$: co-elute with minor amounts of the C18:2t9t12. SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; DMA: dimethylacetals fatty acids. SFA: sum of C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, and C20:0; MUFA: sum of C14:1c9, C16:1c7, C16:1c9, C17:1c9, C18:1c9, C18:1c11, and C20:1c11; PUFA: sum of *n*-6 PUFA (C18:2*n*-6, C20:2*n*-6, C20:3*n*-6, C20:4*n*-6, and C22:4*n*-6), and *n*-3 PUFA (C18:3*n*-3, C20:3*n*-3, C20:5*n*-3, C22:5*n*-3, and C22:6*n*-3; DMA: sum of DMA-C16:0, DMA-C18:0, and DMA-C18:1; PUFA/SFA: polyunsaturated/saturated fatty acids ratio [(sum of C18:2*n*-6, C18:3*n*-3, C20:2*n*-6, C20:3*n*-6, C20:3*n*-3, C20:4*n*-6, C20:5*n*-3, C22:4*n*-6, C22:5*n*-3, and C22:6*n*-3)/(sum of C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, and C20:0)]; *n*-6/*n*-3: sum of *n*-6 fatty acids/sum of *n*-3 fatty acids ratio [(sum of C18:2*n*-6, C20:2*n*-6, C20:3*n*-6, C20:4*n*-6, and C22:4*n*-6)/(sum of C18:3*n*-3, C20:3*n*-3, C20:5*n*-3, C22:5*n*-3, and C22:6*n*-3).

stearic (C18:0), palmitic (C16:0) and linoleic acids, followed by arachidonic acid (C20:4*n*-6). Madeira et al. (2014) found corresponding predominant fatty acids for *longissimus lumborum* muscle of crossbred pigs like analysed in by-products in this study. It is well documented that tissue fatty acid profile depends on the fat level based on the ratio of triacylglycerols and phospholipids (Wood et al., 2008). Moreover, the fatty acid composition in pork reflects both the tissue fatty acid biosynthesis and the fatty acid profile of the diets (Kouba and Mourot, 1999). While saturated fatty acid (SFA) and monounsaturated fatty acids (MUFA) are *de novo* synthesized and their concentrations are less influenced by diet, the essential polyunsaturated fatty acids (PUFA), namely linoleic (C18:2*n*-6) and alpha-linolenic (C18:3*n*-3) acids, cannot be synthesized *in situ* and, thus, have to be incorporated directly into tissue lipids with concentrations more predisposed to dietary changes (Wood et al., 2008).

The fatty acid composition was significantly influenced by organ type ($p < 0.001$). Tongue, brain and pancreas had the highest percentages of C18:1*c*9, whereas liver showed the highest percentages of C18:0. In addition, pancreas and tongue presented high proportions of C16:0. Heart, liver and tongue had relatively high levels of docosapentaenoic acid (C22:5*n*-3) compared to the remaining organs. Significantly higher amount of docosahexaenoic acid (DHA, C22:6*n*-3), as expected, was determined in brain of pigs. Seong et al. (2014) observed a similar fatty acid profile in some of these porcine by-products, namely heart, liver, and pancreas.

The differences observed for the partial sum of fatty acids reflect the variation described earlier for the predominant individual fatty acids. The distribution pattern observed for the sums of fatty acids showed that the percentages of SFA predominates in liver (45 % of total fatty acids), pancreas (40 %) and tongue (38 %). In contrast, heart had the lowest proportions of SFA (25 %). Seong et al. (2014) reported similar SFA amounts in liver (44 %) and pancreas (47 %), with the exception of heart (40 %). According to the literature, it appears that high proportions of SFA raise the low-density lipoprotein cholesterol and the risk of coronary heart diseases (Siri-Tarino et al., 2010). In turn, the percentages of MUFA were higher in tongue (47 %) in relation to the remaining edible organs. PUFA, as well as the sum of *n*-6 fatty acids, were higher in heart followed by kidney and liver. Among the pork by-products examined, the amounts of *n*-3 PUFA were relatively low, except in brain. However, pig by-products had higher *n*-3 PUFA proportions compared with muscle tissue (Honikel, 2011; Madeira et al., 2014). Summing up, in general, the partial sums of fatty acids in porcine by-products agree with those found elsewhere (Prates et al., 2011). In the context of a healthy dietary pattern, and according to specific dietary guidelines for fat, it is encouraged to reduce the intake of SFA (<10 % of calories from SFA) and concomitantly to increase the intake of MUFA (15–20 %) and PUFA (6–11 %) (Burlingame et al., 2009). It is well known the positive health effects of long chain *n*-3 PUFA, in particular eicosapentaenoic acid (C20:5*n*-3) and DHA, on physiological processes, such as cardiovascular disease, cancer and immune function (Department of Health, 1994; Burdge and Calder, 2005). Regarding the sum of dimethylacetals (DMA) in porcine offal, the values ranged from 0.7 % to 13 %. The amounts of DMA in the pork by-products analysed are slightly higher to those of beef by-products, except in liver and tongue (Alfaia et al., 2017). Pérez-Palacios et al. (2010) found in pig muscle tissue (2.7–11.7 % of total FAME) similar DMA proportions.

Significant differences in PUFA/SFA and *n*-6/*n*-3 ratios were found among the internal organs ($p < 0.001$). The optimal PUFA/SFA ratio recommended for the human diet should be above 0.45 and the *n*-6/*n*-3 ratio lower than 4.0 (British Department of Health, 1994; Enser et al., 2000). Tongue and brain had PUFA/SFA ratios below 0.4, while liver, pancreas, kidney, and heart showed PUFA/SFA ratios 2 to 4 times higher than the recommended level. Within PUFA, the *n*-6/*n*-3 ratios in offal were above to the recommended value, except in brain. Heart and pancreas presented the highest *n*-6/*n*-3 ratios, whereas brain (1.7) the lowest ones. Similar *n*-6/*n*-3 ratios were found by Prates et al. (2011) and Seong et al. (2014). Madeira et al. (2014) reported comparable PUFA/SFA (0.65) and *n*-6/*n*-3 (16.4) ratios in pig *longissimus lumborum* muscle. It is well known that cereal-based diets, rich in *n*-6 PUFA, increase the *n*-6/*n*-3 ratios in pig tissues (Wood et al., 2008).

Principal component analysis of fatty acids

Figure 1 shows the projection of PC1 and PC2 in the plane using the proportion of individual fatty acids common to all six organs (heart, brain, pancreas, kidney, liver, and tongue). Both PC joined explained 59.7 % of the total variance (Table 3). The PC1 was characterised by variables with positive loadings, such as C14:0 (0.806), C16:0 (0.675), C16:1*c*9 (0.791), C18:1*c*9 (0.897), C18:1*c*11 (0.724), and C20:1*c*11 (0.927), and by variables with negative loadings, like C18:2*n*-6 (–0.655), C20:3*n*-6 (–0.644), C20:4*n*-6 (–0.874), and C22:5*n*-3 (–0.856) (Fig. 1A). The PC2 was positively defined by C12:0 (0.820), C17:0 (0.731), and C20:3*n*-3 (0.582), and negatively by DMA-C16:0 (–0.756), DMA-C18:0 (–0.895), and DMA-C18:1 (–0.922) (Fig. 1A). Projection of scores in the PC1 × PC2 plane (Fig. 1B) set apart four quadrants with six clusters: liver located in quadrant a, pancreas and tongue located in quadrant b, heart and kidney located in quadrant d and brain located in quadrant c. Liver and brain were well discriminated from the remaining organs reflecting the most aforementioned variations in fatty acid profile. Liver cluster, in contrast to

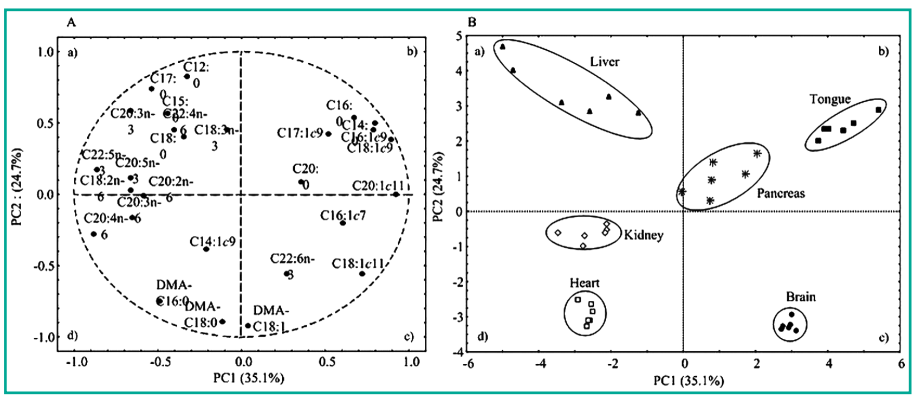

FIGURE 1: *Loadings plot of the first and second principal components (PC) of the pooled fatty acids (A) and components score vectors (B) of pork offal (heart, brain, pancreas, kidney, liver and tongue).*

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TABLE 3: *Loadings for the first two principal components*[1].

Variable	PC1	PC2
C12:0	–0.322	0.820
C14:0	0.806	0.498
C14:1c9	–0.202	–0.386
C15:0	–0.434	0.562
DMA-C16:0	–0.480	–0.756
C16:0	0.675	0.530
C16:1c7	0.613	–0.208
C16:1c9	0.791	0.446
C17:0	–0.536	0.731
C17:1c9	0.527	0.418
DMA-C18:0	–0.107	–0.895
DMA-C18:1	0.048	–0.922
C18:0	–0.344	0.402
C18:1c9	0.897	0.378
C18:1c11	0.724	–0.556
C18:2*n*-6	–0.655	0.022
C18:3*n*-3	–0.083	0.444
C20:0	0.365	0.078
C20:1c11	0.927	–0.004
C20:2*n*-6	–0.580	–0.016
C20:3*n*-6	–0.644	–0.172
C20:4*n*-6	–0.874	–0.281
C20:3*n*-3	–0.658	0.582
C20:5*n*-3	–0.655	0.115
C22:4*n*-6	–0.394	0.444
C22:5*n*-3	–0.856	0.171
C22:6*n*-3	0.277	–0.564
Proportion of variance (%)	35.06	24.68
Cumulative variance (%)	35.06	59.74

[1] PC: principal component.

brain (rich in DHA), showed a higher dispersion pattern. Likewise, the distinctive metabolism of each organ might be responsible for the observed fatty acid scatter pattern.

Conclusions

Although the range of total lipids in edible offal from crossbred pigs (heart, brain, pancreas, kidney, liver, and tongue) varied widely, the values were comparable to lean pork (except in brain). Fat content and fatty acid profile were significantly influenced by organ type. Oleic, stearic, palmitic and linoleic acids, followed by arachidonic acid, were the most prevalent fatty acids. Heart showed the lowest SFA percentages, whereas tongue had the highest MUFA proportions. Heart had higher amounts of PUFA and, thus, the most favourable PUFA/SFA ratio. In turn, the *n*-6/*n*-3 PUFA in organs were above the current recommendations for human diet, except in brain. Among tissues, brain had higher *n*-3 PUFA percentages, in particular of DHA. This study also emphasizes the existence of a distinct fatty acid distribution between organs, as shown by PCA analysis. From the nutritional point of view, these edible offal raw materials from pigs should be ingested only in limited amounts and if integrated into a varied well-balanced diet.

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Conflict of interest

The authors declare no competing interests.

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