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Extensively reared Iberian pigs versus intensively reared white pigs for the manufacture of frankfurters

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Abstract

Physico-chemical characteristics and different quality traits of the raw material (meat and adipose tissue) and the frankfurters elaborated from extensively reared Iberian pigs (IF) and intensively reared white pigs (WF) were evaluated. Hybrid frankfurters (HF) made with meat from white pigs and adipose tissue from Iberian pigs were also studied. The differences found between muscles and adipose tissues from Iberian and white pigs largely influenced the characteristics displayed by the frankfurters. Particularly remarkable are the higher amounts of substances with proven antioxidant activity such as tocopherols and phenolic compounds in tissues from Iberian pigs than in those from white pigs. No significant differences were found amongst frankfurters for their proximate composition though IF presented a higher iron content than WF and HF. IF exhibited a redder and darker colour than WF and HF. The latter were paler and showed higher hue values than IF. Concerning their fatty acid composition, IF had higher proportions of oleic acid and MUFA and smaller proportions of SFA and PUFA than WF. From a nutritional point of view, IF had a lower n-6/n-3 value than WF. The addition of adipose tissue from Iberian pigs to the HF modified its fatty acid composition compared to that of WF, significantly increasing the percentages of MUFA and reducing the proportions of PUFA, SFA and the n-6/n-3 value. Though no significant differences were found amongst frankfurters for their texture profile, a clear trend was detected, with the HF showing intermediate texture characteristics between IF and WF.

Keywords: Frankfurters; Iberian pigs; White pigs; Iron; Vitamin E; Colour; Texture profile; Fatty acids

1. Introduction

As far as Spanish livestock farming is concerned, the Iberian pigs are considered authentic gems. The products traditionally obtained from these animals such as dry-cured hams and dry-cured loins are highly appreciated by Spanish consumers. The reasons why these products from Iberian pigs are so highly prized compared to those from other pigs are thought to be related to their extraordinary sensory characteristics (Ventanas, Tejeda, & Petrón, 2001). Particular genetic traits, the extensive rearing in oak forests and the use of natural resources such as acorns and grass for the feeding of Iberian pigs are carefully taken into consideration in order to achieve high-quality products and, therefore, fulfil consumer's expectations (Ventanas et al., 2001).

As a result of the activity of slaughterhouses and meat factories, a large amount of by-products (back fat, boneless meat and some viscera) with high nutritional value are generated. In Spain, in the year 2000, 24,300 metric tons of fat was obtained as a result of the slaughter of 600,000 outdoor reared Iberian pigs (revised by Cava, Morcuende, Ramírez, & Estévez, 2004). This foodstuff is either used in local industry for the manufacture of low-quality products such as restructured meats or cured lards or removed, when the capacity of these processes is exceeded, at high cost and sometimes with environmental pollution. Estévez, Morcuende, Ramírez, Ventanas, and Cava (2004) suggested using

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back fat, meat and livers from Iberian pigs for the manufacture of liver pâtés, which is something that is being done in Spain. The consumers could be influenced by the image of quality of the Iberian dry-cured products and will pay more money for the Iberian liver pâté as a high quality product manufactured using low-cost materials. In fact, according to Estévez et al. (2004) and Estévez and Cava (2004), liver pâtés from Iberian pigs have higher quality characteristics than those from white pigs, based on compositional and nutritional points of view.

Frankfurters are non-fermented, emulsion type cooked sausages produced with meat and fat from beef or pork. The production of frankfurters in Spain is around 10% of the total cooked products (AICE, 2004). The higher levels of oleic acid and vitamin E in the tissues from Iberian pigs, compared to those from white pigs, are some of their most remarkable quality traits (López-Bote & Rey, 2001; Estévez et al., 2004). It is reasonable to consider that frankfurters from Iberian pigs must be rather different from commercial frankfurters, generally produced using material from intensively reared white pigs. Nevertheless, there is no information available concerning the quality characteristics of the Iberian frankfurters no a study comparing these characteristics with those displayed by frankfurters made from white pigs' tissues.

The aim of this piece of work was to study the physicochemical characteristics of the raw material (meat and adipose tissue) and the manufactured product (frankfurters) from extensively reared Iberian pigs and intensively reared white pigs. The effect of the addition of fat from Iberian pigs in frankfurters produced with meat from white pigs was also investigated.

2. Material and methods

2.1. Animals, feeds and sampling

Seven pure breed Iberian pigs were free-range reared and fed on natural resources (grass and acorns) following traditional livestock farming for Iberian pigs. The animals were slaughtered at ~150 kg live weight and an age of 14 months.

Seven white pigs were intensively reared under controlled conditions in a typical industrial livestock farm. The animals were fed on a mixed diet and slaughtered at 85 kg live weight and at the age of 7 months.

Iberian pigs and white pigs were slaughtered at the same slaughterhouse one week apart. After pig's slaughter and dress, a heterogeneous mixture of muscles derived from carcasses, and adipose tissues (porcine back-fat) were vacuum packaged and stored at −80 °C until the day of their analysis and the manufacture of the frankfurters.

2.2. Manufacture of the frankfurters

The experimental frankfurters were manufactured in a pilot plant. The same formulation was used for all frankfurters. Three different types of frankfurters were considered depending on the source of the raw material: frankfurters from Iberian pigs (IF), frankfurters from white pigs (WF) and hybrid frankfurters (HF) elaborated with muscles from white pigs and adipose tissue from Iberian pigs. For the manufacture of the sausages, meat and adipose tissues from seven different animals were used for each of the groups (Iberian and white pigs). The ingredients were as follows per 100 g of elaborated product: 50 g meat, 10 g adipose tissue, 37 g distilled water, 2 g sodium caseinate, 1 g potato starch. Sodium chloride (2%), sodium di- and tri-phosphates (0.5%) sodium ascorbate (0.05%) and sodium nitrite (0.03%) (all from ANVISA, Madrid, Spain) were also added. Following the aforementioned recipe, 1.3 kg of raw material was used for each group, to produce the experimental frankfurters. Firstly, the meat was chopped into small cubes (1 cm^3) and mixed with the sodium chloride, sodium nitrite and the sodium ascorbate in order to allow the nitrification of the samples 2 hours before the manufacture. Then, the meat was minced in a cutter (Foss Tecator Homogenizer, mod. 2094, Höganas, Sweden) for 2 minutes together with the starch and the 50% of the sodium caseinate which was previously dissolved in 100 mL water (75 °C). After that, the adipose tissue was added together with the remaining dissolved sodium caseinate and minced for 4 more minutes until a homogenous raw batter was obtained. Finally, the mixture was stuffed into 18 mm diameter cellulose casings, hand-linked at 10 cm intervals and given a thermal treatment in a hot water bath (80 °C/30'). The frankfurters were kept frozen (−80 °C) until required for analytical experiments.

2.3. Analytical methods

2.3.1. Compositional analysis of raw material and frankfurters

Moisture, total protein and ash were determined using official methods (AOAC, 2000). The method of Bligh and Dyer (1959) was used for determining fat content of raw material and frankfurters. Total iron was determined following the procedure described by Miller, Smith, Kanner, Miller, and Lawless (1994).

2.3.2. Vitamin E content

The levels of vitamin E in meat and adipose tissues were determined according to the method described by Rey, López-Bote, Soares, and Isabel (1997).

2.3.3. Phenolics compounds content

The Folin Ciocalteu reagent was used for the quantification of total phenolics as described by Turkmen, Sari, and Velioglu (2005) with minor modifications as follows: 0.5 g of meat (1 g of adipose tissue) was homogenised with 10 mL of water (meat) or 80% methanolic water (adipose tissue) and centrifuged for 5 minutes at 1500*g* and 4 °C. Phenolics were extracted from the pellets following the same procedure. The supernatants were combined and

1 mL aliquot was mixed with 5 mL of Folin Ciocalteau reagent (10% in distilled water) in test tubes. After 5 minutes, 4 mL of sodium carbonate (7.5% in distilled water) was added, the test tubes were screw-capped and the samples allowed to stand for 2 hours at room temperature in darkness. A standard curve with ethanolic gallic acid (ranged from 0.625×10^{-3} mg/mL to 0.02 mg/mL) was used for quantification. Results were expressed as mg of gallic acid equivalents (GAE) per gram of sample.

2.3.4. Instrumental colour measurement

Instrumental colour (CIE L^* a^* b^*; CIE, 1976) was measured in triplicate on the cross section of the frankfurters using a Minolta Chromameter CR-300 (Minolta Camera Corp., Meter Division, Ramsey, NJ) with illuminant D_{65} and 0° standard observer. CIELAB L^*, a^*, b^* values were determined as indicators of lightness, redness and yellowness, respectively. Chroma (C) and Hue angle (h°) values were obtained by using the following equations: $C = (a^{*2} + b^{*2})^{0.5}$; $H° = \text{arctg } b^*/a^*$.

2.3.5. Texture profile analysis (TPA)

The textural characteristics of the frankfurters were determined using a texturometer TA-XT2 TEXTURE ANALYSER (Stable Micro Systems Ltd., Surrey, England, UK). Uniform portions of 2 cm in length from the middle of the frankfurters were used as the test samples. The samples were compressed to 50% their original height at a crosshead speed of 5 mm/s through a two-cycle sequence. A 5 cm diameter probe was used in TPA measurements. Textural variables from force and area measurements were (Bourne, 1978): hardness (N/cm^2) = maximum force required to compress the sample (peak force during the first compression cycle); fracturability (N/cm^2) = the force during the first compression at which the material fractures; adhesiveness (N s) = work necessary to pull the compressing plunger away from the sample; springiness (cm)= height that the sample recovers during the time that elapses between the end of the first compression and the start of the second; cohesiveness (dimensionless) = extent to which the sample could be deformed prior to rupture (A_1/A_2,A_1 being the total energy required to for the first compression and A_2 the total energy required for the second compression); gumminess (N/cm^2) = the force needed to disintegrate a semisolid sample to a steady state of swallowing (hardness x cohesiveness); chewiness (N s) = the work needed to chew a solid sample to a steady state of swallowing (gumminess x springiness); resilience (dimensionless) = how well the product regains its original height, measured on the first withdrawal of the cylinder (area under the curve during the withdrawal of the first compression divided by the area of the first compression).

2.3.6. Fatty acid composition

Fatty acid methyl esters (FAMEs) were prepared by acidic esterification with methanol in sulphuric acid (5%) and sodium methylate, following the method of López-Bote, Rey, Sanz, Gray, and Buckley (1997). FAMEs were analysed using a Hewlett Packard HP-5890A gas chromatograph (Avondale, PA, USA), equipped with a flame ionisation detector (FID). The derivatives were separated on a semi-capillary column (Hewlett Packard FFAP-TPA fused-silica column, 30 m long, 0.53 mm internal diameter and 1.0 μm film thickness). The injector and the detector temperature were held at 230 °C. Column oven temperature was maintained at 220 °C. The flow rate of the carrier gas (N_2) was set at 1.8 mL/min. Identification of FAMEs was based on retention times of reference compounds (Sigma). Fatty acid composition was expressed as percent of total fatty acid methyl esters.

2.3.7. Data analysis

All experiments were carried out in quintuplicate. The results from the experiments were used as variables and analysed using an Analysis of Variance (ANOVA) (SPSS, 1997) in order to compare physico-chemical characteristics of meat and adipose tissue and frankfurters from Iberian pigs and white pigs. Statistical significance was predetermined at 0.05.

3. Results and discussion

3.1. Chemical composition of feeds

The analysis of the acorns (Table 1) revealed a high content of ether extract (5.0%) and oleic acid (67.3%) agreeing with previous reports (Cava et al., 1997; Ruiz et al., 1998). The grass had high levels of moisture (89.3%) and low ether extract (0.33%), linolenic acid (n-3) being the most abundant (57.8%) fatty acid, in agreement with other authors (López-Bote & Rey, 2001). The analysis of the mixed diet

Table 1
Compositional analysis of the finishing diets of Iberian pigs (acorns and grass) and white pigs (concentrated feed)

	Grass[b]	Acorn[b]	Concentrate
% Moisture	89.2	46.1	10.6
% Fat	6.26	5.05	2.32
% Protein	4.34	4.31	15.2
% Ash	0.91	1.17	9.09
% FAMEs[a]			
14:0	3.64	0.18	0.36
16:0	14.0	11.8	16.7
161:1 (n-7)	2.40	0.10	0.15
18:0	1.99	0.56	7.57
18:1 (n-9)	5.24	67.3	31.3
18:2 (n-6)	11.4	18.7	39.7
18:3 (n-3)	57.8	0.25	2.84
20:0	2.40	0.25	0.35
20:1 (n-9)	0.17	0.51	0.70
20:2 (n-6)	0.03	0.09	0.18
20:4 (n-6)	0.94	0.26	0.12

Fat, protein and ash expressed as percentage on fresh matter.
[a] FAMEs expressed as % of total fatty acids analysed.
[b] Previously published in Estévez et al. (2004).

revealed a higher content of protein (concentrate: 15.2%; acorn: 4.3%; grass: 4.3%) and lower ether extract (concentrate: 2.32%; acorn: 5.05%; grass: 6.26%), compared to the feed given to Iberian pigs (Table 1). Palmitic acid (16.7%), oleic acid (31.3%) and linoleic acid (39.7%) were the major fatty acids.

3.2. General composition of meat and adipose tissue

The chemical composition of meat and adipose tissue from Iberian pigs and white pigs is shown in Table 2. No significant differences were found between groups which had similar contents of moisture, fat and protein. According to previous studies (Estévez, Morcuende, & Cava, 2003; Estévez et al., 2004), the higher content of iron in meat from Iberian pigs compared to that from white pigs was expected because of genetic traits, the higher age and weight at slaughter of Iberian pigs and the physical exercise performed by animals in extensive systems (Lawrie, 1998). Meat from Iberian pigs has been described as an excellent source of high bioavailable iron, even though this fact could imply the promotion of oxidative processes in this meat after cooking and refrigeration (Estévez et al., 2003). Compared to meat from white pigs, meat from Iberian pigs had a significantly higher amount of α- and γ-tocopherol, a likely result of the intake of grass with high levels of vitamin E by Iberian pigs (Rey, Isabel, Cava, & López-Bote, 1998). Samples were also analysed for the total amount of phenolic compounds. In accordance to results of vitamin E content, meat from Iberian pigs contained a higher amount of total phenolics than that of white pigs. The information concerning the occurrence of phenolic compounds in animal tissues is extremely scarce since such compounds are widespread in the plant kingdom and therefore, their presence in animal tissues is principally relegated to the intake of fresh natural resources by animals and their subsequent accumulation. The intake of grass and acorns by Iberian pigs could explain the higher amount of phenolic compounds in their tissues than in those from white pigs. In fact, Cantos et al. (2003) have recently reported elevated polyphenol levels in acorns.

As expected, fat was the principal component of adipose tissue from Iberian pigs and white pigs while moisture and protein were lower. Large differences were found between groups as far as the vitamin E content is concerned. Similar to the results presented above for meat, adipose tissue from Iberian pigs had significantly higher amounts of α- and γ-tocopherol than the adipose tissue from white pigs. The intake of pasture and acorns by free-range reared pigs is thought to increase the tocopherol levels in the animal tissues (Rey et al., 1998; Nilzén et al., 2001) which is consistent with the present results. Tocopherols are the most important natural antioxidants in meat and meat products and their protective activity against oxidation have been largely described in meat and several meat products (López-Bote & Rey, 2001; Nilzén et al., 2001). Results from the present study suggest that phenolic compounds are, contrary to tocopherols, mainly accumulated in muscles rather than in adipose tissue. The adipose tissue from Iberian pigs had also higher amount of phenolic compounds than that from white pigs. González, Tejeda, Moltiva, and Romero (2004) have recently reported data in relation to the amount of phenolic compounds in adipose tissue from Iberian pigs. The adipose tissue from Iberian pigs fed exclusively on natural resources (grass and acorns) had significant higher amounts of phenolic compounds than those fed with mixed diets, which is in accordance with results from the present study. Amongst phenolic compounds, some particular polyphenols derived from plants, are substances with proven antioxidant activity

Table 2
Chemical composition and instrumental colour of meat and adipose tissue from Iberian and white pigs

	Muscle			Adipose tissue		
	Iberian	White	p[a]	Iberian	White	p
Moisture[b]	60.1 ± 1.70	58.9 ± 1.13	0.216	9.74 ± 0.39	12.9 ± 0.54	<0.001
Fat[b]	18.3 ± 1.93	19.6 ± 1.17	0.243	83.2 ± 3.72	74.9 ± 2.02	0.002
Protein[b]	17.0 ± 0.37	17.0 ± 0.74	0.745	2.56 ± 0.49	4.06 ± 0.52	0.002
Ash[b]	0.81 ± 0.10	0.74 ± 0.17	0.457	0.11 ± 0.02	0.14 ± 0.04	0.203
Iron[c]	29.8 ± 1.09	23.0 ± 1.52	<0.000	Traces[e]	Traces	–
α-tocopherol[c]	3.75 ± 0.13	1.80 ± 0.83	0.001	17.2 ± 2.48	3.87 ± 1.53	<0.001
γ-tocopherol[c]	0.22 ± 0.02	0.08 ± 0.04	0.024	1.07 ± 0.35	0.00 ± 0.00	<0.001
Total phenolics[d]	1.53 ± 0.30	0.99 ± 0.06	0.004	0.46 ± 0.03	0.37 ± 0.02	<0.001
L^*	50.2 ± 1.42	58.3 ± 1.69	<0.000	82.1 ± 1.29	79.1 ± 1.71	0.015
a^*	24.2 ± 1.70	20.7 ± 0.47	0.002	3.31 ± 0.43	4.86 ± 0.59	0.001
b^*	13.2 ± 1.17	13.7 ± 0.64	0.422	5.93 ± 0.46	5.96 ± 0.37	0.930
Chroma	27.6 ± 1.80	24.8 ± 0.40	0.011	6.79 ± 0.57	7.69 ± 0.65	0.049
Hue	28.6 ± 2.12	33.4 ± 1.59	0.004	61.0 ± 2.32	50.9 ± 1.95	<0.001

[a] Statistical significance in a Student's t-test for independent variables.
[b] g/100 g of raw material.
[c] μg/g of raw material.
[d] mg GAE/g of raw material.
[e] Traces.

and the presence of such compounds in the animal tissues could protect them and products made with them from oxidative deterioration.

3.3. Colour characteristics of meat and adipose tissue

Table 2 shows colour characteristics of the raw material (meat and adipose tissues) from Iberian and white pigs. Compared to the meat from white pigs, the meat from Iberian pigs exhibited a redder colour (higher a^* value) which was more intense (higher chroma value) and closer to the true red axis (lower hue value). The meat from white pigs had, additionally, L^* values significantly higher than that from Iberian pigs. In previous studies (Serra et al., 1998; Estévez et al., 2003; Estévez et al., 2004), similar results comparing colour characteristics between muscles from Iberian and white pigs were obtained. The red colour in muscles is caused by the presence of heme pigments, and therefore, the CIE a^* values in meat are positively correlated with heme pigments and iron contents (Warris, Brown, & Adams, 1990). The present results are consistent with those previously reported by Serra et al. (1998), Lindahl, Lundström, and Tornberg (2001) and ourselves (Estévez et al., 2003) who described a higher a^* value, chroma and iron content in muscles from rustic pig breeds than in those from selected ones. In addition to the breed effect, the characteristics of the Iberian pigs' livestock farming could have influenced since the pigments and iron concentrations and the red colour of the muscles increase with the animal age and the physical exercise (Lawrie, 1998).

The colour characteristics of the adipose tissues were also different between groups since those from Iberian pigs exhibited significantly higher L^* values and those from white pigs showed a more intense (higher chroma) and redder colour (higher a^* values). These results agree with those reported in a previous paper in which the colour traits of adipose tissues from Iberian and white pigs were investigated (Estévez et al., 2004).

3.4. Fatty acid composition of meat and adipose tissue

The tissues from Iberian and white pigs showed clear differences in their fatty acid composition (Table 3). Compared to meat from white pigs, meat from Iberian pigs had a larger proportion of monounsaturated fatty acids (MUFA), mainly oleic acid and smaller percentages of

Table 3
Fatty acid composition (means ± standard deviation) of muscle, liver and adipose tissue from extensively reared Iberian pigs and intensively reared white pigs[a]

	Muscle			Adipose tissue		
	Iberian	White	p[b]	Iberian	White	p
12:0	0.01 ± 0.00	0.02 ± 0.02	0.278	0.01 ± 0.00	0.01 ± 0.00	0.005
14:0	1.11 ± 0.01	1.22 ± 0.02	0.000	1.04 ± 0.03	1.03 ± 0.03	0.851
16:0	22.5 ± 0.03	24.8 ± 0.20	0.000	18.3 ± 0.25	22.1 ± 0.18	<0.001
17:0	0.21 ± 0.01	0.42 ± 0.01	0.000	0.29 ± 0.00	0.48 ± 0.01	<0.001
18:0	10.8 ± 0.07	15.5 ± 0.23	0.000	8.01 ± 0.31	12.8 ± 0.47	<0.001
20:0	0.12 ± 0.06	0.25 ± 0.06	0.009	0.16 ± 0.02	0.21 ± 0.02	0.006
Σ SFA	34.8 ± 0.13	42.3 ± 0.46	0.000	27.8 ± 0.58	36.6 ± 0.53	<0.001
16:1 (n-7)	3.02 ± 0.03	2.48 ± 0.01	0.000	2.01 ± 0.05	2.36 ± 0.08	<0.001
17:1 (n-7)	0.21 ± 0.00	0.38 ± 0.00	0.000	0.29 ± 0.00	0.47 ± 0.02	<0.001
18:1 (n-9)	52.4 ± 0.20	42.8 ± 0.49	0.000	57.4 ± 0.43	46.8 ± 0.28	<0.001
20:1 (n-9)	1.08 ± 0.01	1.03 ± 0.03	0.007	1.69 ± 0.04	1.08 ± 0.02	<0.001
22:1 (n-9)	0.02 ± 0.01	0.02 ± 0.00	0.548	0.03 ± 0.00	0.02 ± 0.00	<0.001
Σ MUFA	56.7 ± 0.18	46.7 ± 0.52	0.000	61.4 ± 0.47	50.7 ± 0.33	<0.001
18:2 (n-6)	6.74 ± 0.05	9.05 ± 0.07	0.000	8.85 ± 0.11	10.7 ± 0.13	<0.001
18:3 (n-6)	0.10 ± 0.00	0.16 ± 0.01	0.000	0.14 ± 0.00	0.18 ± 0.01	<0.001
18:3 (n-3)	0.46 ± 0.01	0.51 ± 0.02	0.002	0.65 ± 0.02	0.60 ± 0.02	0.003
20:2 (n-6)	0.20 ± 0.06	0.44 ± 0.02	0.010	0.58 ± 0.01	0.48 ± 0.05	0.003
20:3 (n-3)	0.15 ± 0.01	0.05 ± 0.01	0.000	0.06 ± 0.00	0.15 ± 0.00	<0.001
20:3 (n-6)	0.04 ± 0.01	0.04 ± 0.01	0.350	0.02 ± 0.00	0.03 ± 0.00	<0.001
20:4 (n-6)	0.47 ± 0.03	0.37 ± 0.01	0.000	0.12 ± 0.00	0.19 ± 0.01	<0.001
20:5 (n-3)	0.10 ± 0.00	0.10 ± 0.01	0.713	0.18 ± 0.01	0.12 ± 0.00	<0.001
22:2 (n-6)	0.04 ± 0.00	0.07 ± 0.01	0.001	0.04 ± 0.01	0.05 ± 0.01	0.019
22:4 (n-6)	0.02 ± 0.01	0.03 ± 0.01	0.739	0.03 ± 0.00	0.04 ± 0.00	0.003
22:5 (n-3)	0.09 ± 0.00	0.11 ± 0.00	0.000	0.05 ± 0.02	0.08 ± 0.00	0.036
22:6 (n-3)	0.12 ± 0.01	0.12 ± 0.01	0.327	0.08 ± 0.00	0.09 ± 0.01	0.030
Σ PUFA	8.54 ± 0.09	11.0 ± 0.13	0.000	10.8 ± 0.15	12.7 ± 0.17	<0.001
n-6/n-3	8.38 ± 1.36	11.5 ± 0.37	0.001	9.56 ± 0.38	11.5 ± 2.20	0.096
Nutritional ratio[c]	0.40 ± 0.00	0.50 ± 0.01	0.000	0.29 ± 0.01	0.40 ± 0.01	<0.001

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids.

[a] Fatty acids expressed as percentages of total fatty acids analysed.

[b] Statistical significance in Student t-test for independent variables.

[c] Nutritional ratio: (12:0 + 14:0 + 16:0)/(18:1 + 18:2).

saturated fatty acids (SFA), such as palmitic and stearic acids. Meat from white pigs had a higher proportion of polyunsaturated fatty acids (PUFA), such as linoleic and arachidonic acids than that from Iberian pigs. Meat from Iberian pigs had smaller values in particular ratios closely associated to healthy characteristics of meat (Okuyama & Ikemoto, 1999) such as the n-6/n-3 ratio and that between hyper- (lauric, myristic, palmitic) and hypocholesterolemic (oleic, linoleic) fatty acids (Table 3).

The fatty acid profiles of adipose tissue are presented in Table 3. Four fatty acids (palmitic, stearic, oleic and linoleic acids) comprised more than the 90% of the total fatty acids analysed. As expected, oleic acid was the most abundant (57.4–46.8%) followed by palmitic (18.3–22.1%), stearic (8.0–12.8%) and linoleic acid (8.9–10.7%). In agreement with the results aforementioned for the meat, the fatty acid compositions of the adipose tissues were largely different between Iberian pigs and white pigs (Table 3). Compared to adipose tissues from Iberian pigs, those from white pigs showed significant higher percentages of saturated fatty acids and polyunsaturated fatty acids. On the contrary, Iberian pigs presented higher percentages of monounsaturated fatty acids.

The fatty acid composition of the animal tissues reflects the compositional characteristics of the fat from the feeds given to the animals (Miller, Shackelford, Hayden, & Reagan, 1990; Enser, Richardson, Wood, Gill, & Sheard, 2000). Consistently, raw material from Iberian pigs reflected the fatty acid composition of acorns (with high levels of oleic acid). Contrarily, tissues from white pigs reflected the general composition of the concentrated feed, with relative high proportion of linoleic acid and PUFA. According to previous studies, these results represent the general pattern of fatty acid composition of different tissues from Iberian pigs fed extensively with natural resources (Cava et al., 1997; Ruiz et al., 1998; Timón, Martín, Petrón, Jurado, & García, 2001) and white pigs fattened intensively with mixed diets (Flachowsky, Schöne, Schaarmann, Lübbe, & Böhme, 1997; Serra et al., 1998).

The livestock production system, the feed given to the animals and the genetic traits could had an influence on the different quality characteristics of the tissues from Iberian and white pigs. Furthermore, the large differences in the age and weight of the animals at slaughter might have influenced quality, since these factors surely affect the physiology and biochemical maturation of porcine tissues.

3.5. General composition of frankfurters

The general composition of the frankfurters is shown in Table 4. No differences for moisture, fat, protein or ash contents were detected. The values obtained for the proximate composition in this work are within the range considered as acceptable in frankfurters (Matulis, McKeith, Sutherland, & Brewer, 1995). In fact, the chemical composition of the experimental frankfurters from the present study is similar to that reported by González-Viñas, Caballero, Gallego, and García-Ruiz (2004) for commercial frankfurters obtained from Spanish supermarkets. Agreeing with the results for meat, IF had a significantly higher amount of iron compared with that from WP. Since the source of iron for the frankfurter is the meat, the HF had a similar iron content to white pigs. Red meats are an essential source of heme iron for humans and, in addition, enhance the absorption of non-heme iron from vegetables and other foods when included at the same time in the diet (Mulvihill & Morrissey, 1997). Meat from Iberian pigs has been previously described as a good source of high available iron and, based on the present results, the frankfurters produced with such raw material keep considerably high levels of iron, significantly higher than those from white pigs and other cooked meats (Miller et al., 1994; Kosse, Yeung, Gil, & Miller, 2001).

Table 4
Chemical composition and instrumental colour from experimental frankfurters

	IF	WF	HF	*p*
Moisture	63.4 ± 1.57	62.3 ± 1.51	61.7 ± 0.43	0.068
Fat	18.4 ± 0.50	18.7 ± 0.71	18.9 ± 1.02	0.611
Protein	11.4 ± 0.62	10.9 ± 0.58	10.7 ± 0.22	0.054
Ash	1.28 ± 0.11	1.36 ± 0.21	1.09 ± 0.42	0.302
Iron	$16.3^{a} \pm 1.11$	$11.7^{b} \pm 2.63$	$11.2^{b} \pm 1.07$	0.001
pH	$8.08^{a} \pm 0.02$	$7.91^{c} \pm 0.03$	$7.98^{b} \pm 0.01$	<0.001
*L**	$71.6^{c} \pm 0.63$	$73.1^{b} \pm 0.42$	$77.1^{a} \pm 0.62$	<0.001
*a**	$13.6^{a} \pm 0.17$	$11.7^{b} \pm 0.29$	$11.6^{b} \pm 0.97$	<0.001
*b**	9.21 ± 0.03	9.02 ± 0.15	9.21 ± 0.23	0.131
Chroma	$16.4^{a} \pm 0.15$	$14.7^{b} \pm 0.24$	$14.8^{b} \pm 0.35$	<0.001
Hue	$34.2^{b} \pm 0.30$	$37.8^{a} \pm 0.88$	$38.4^{a} \pm 0.29$	<0.001

See footnotes of Table 2.

3.6. Colour characteristics of frankfurters

Cie *L**, *a**, *b**, chroma and hue angle measured in frankfurters are shown in Table 4. IF presented different colour characteristics to WF and HF, as suggested by the parameters measured. IF exhibited a more intense, redder and darker colour compared to that from WF. The red colour in the frankfurters is caused by the presence of heme pigments supplied by the meat, which is the main ingredient. This explains the differences found between types of frankfurters since meat from Iberian pigs presented a higher *a** and chroma values than those from white pigs. Though WF and HF had similar colour characteristics, the latter were paler as a probably result of the colour traits of the raw material used for their manufacture. The meat from white pigs was paler than that from Iberian pigs whereas adipose tissues from Iberian pigs had also higher *L** values than those from white pigs. In conclusion, the colour traits of the frankfurters are influenced by the colour characteristics of the main ingredients as has been previously described in liver pâté and other liver and meat products (Estévez et al., 2004; Estévez, Ventanas, Cava, & Puolanne, 2005).

3.7. Fatty acid composition of frankfurters

The fatty acid profile of frankfurters is shown in Table 5. Large differences among types of frankfurters were detected for most of the fatty acids analysed. IF had significantly smaller proportions of palmitic, stearic and SFA than WF. The differences for MUFA are particularly remarkable since IF had 10 percent more oleic acid than WF. The latter had larger percentages of PUFA such as linoleic acid. As expected, fatty acid composition of frankfurters reflected the fatty acid composition of the raw material used for their production. Large proportions of oleic acid have been considered as one of the main characteristics of Iberian pig products including meat, dry-cured products and liver pâtés (Timón et al., 2001; Estévez et al., 2003; Estévez et al., 2004). The HF had an intermediate fatty acid profile between IF and WF. Replacing 10% fat from white pigs with fat from Iberian pigs in the HF significantly influenced their fatty acid profile, significantly reducing the proportion of SFA (from 39.6% to 35.1%) and PUFA (from 11.8% to 11.0%) and increasing the percentages of oleic acid (from 44.5% to 49.6%) and MUFA (from 48.6% to 53.7%) compared to results from WF.

Focusing on nutritional and technological aspects, using raw material from extensively reared Iberian pigs improved the lipid characteristics of the frankfurters. Contrary to MUFA, PUFA are very prone to oxidation, leading to the generation of unpleasant odours and reducing nutritional value of meat and fat products (Morrissey, Sheehy, Galvin, Kerry, & Buckley, 1998). Compared to SFA, MUFA are hypocholesterolemic, but, unlike PUFA, they do not decrease high-density lipoproteins (HDL) cholesterol which protects against coronary heart disease (Mattson & Grundy, 1985). The nutritional ratio between SFA hypercholesterolemic fatty acids (C12, C14, C16) and the unsaturated hypocholesterolemic ones (C18:1 n-9; C18:2 n-6) was also lower in IF. Great importance has been given to long chain PUFA in meat products because of the role played by the ratio n-6/n-3 in the development of coronary heart diseases (CHD) (Okuyama & Ikemoto, 1999). The ratio n-6/n-3 was lower in IF than in WF as a result of the higher content of C18:2 (n-6) in those from white pigs. The content of long chain PUFA in tissues of pigs reared outdoors with access to pasture are thought to increase because of the intake of grass with high content of n-3 PUFA (Nilzén et al., 2001) though it was not generally detected in the present work. Using adipose tissue from Iberian pigs for the manufacture of frankfurters significantly improved the fatty acid profile of frankfurters since HF presented better nutritional and n-6/n-3 ratios than those from WF.

3.8. Texture profile of frankfurters

The range of values obtained for the texture profile of frankfurters in the present study (Table 6) are in agreement with those previously reported in similar cooked products

Table 5
Fatty acid composition (means ± standard deviation) from experimental frankfurters[a]

	IF	WF	HF	p[b]
12:0	0.04 ± 0.02	0.06 ± 0.00	0.06 ± 0.00	0.058
14:0	1.04[b] ± 0.02	1.13[a] ± 0.01	1.12[a] ± 0.01	<0.001
16:0	19.8[c] ± 0.09	23.4[a] ± 0.08	21.5[b] ± 0.17	<0.001
17:0	0.26[c] ± 0.01	0.46[a] ± 0.00	0.38[b] ± 0.01	<0.001
18:0	9.28[c] ± 0.02	14.3[a] ± 0.08	12.0[b] ± 0.38	<0.001
20:0	0.23 ± 0.09	0.29 ± 0.02	0.26 ± 0.02	0.365
Σ SFA	30.7[c] ± 0.10	39.6[a] ± 0.13	35.3[b] ± 0.56	<0.001
16:1 (n-7)	2.39[b] ± 0.01	2.44[a] ± 0.01	2.27[c] ± 0.03	<0.001
17:1 (n-7)	0.26[c] ± 0.00	0.43[a] ± 0.00	0.35[b] ± 0.00	<0.001
18:1 (n-9)	55.2[a] ± 0.14	44.5[c] ± 0.06	49.6[b] ± 0.57	<0.001
20:1 (n-9)	1.53[a] ± 0.09	1.16[c] ± 0.05	1.42[b] ± 0.02	<0.001
22:1 (n-9)	0.05[a] ± 0.00	0.04[b] ± 0.00	0.04[a] ± 0.00	<0.001
Σ MUFA	59.5[a] ± 0.09	48.6[c] ± 0.07	53.7[b] ± 0.59	<0.001
18:2 (n-6)	7.97[c] ± 0.02	9.79[a] ± 0.10	9.05[b] ± 0.04	<0.001
18:3 (n-6)	0.11[c] ± 0.01	0.16[a] ± 0.01	0.14[b] ± 0.01	<0.001
18:3 (n-3)	0.56 ± 0.01	0.57 ± 0.02	0.57 ± 0.01	0.795
20:2 (n-6)	0.47[b] ± 0.01	0.50[a] ± 0.01	0.51[a] ± 0.01	<0.001
20:3 (n-3)	0.06[a] ± 0.00	0.05[b] ± 0.00	0.05[ab] ± 0.01	0.028
20:3 (n-6)	0.08[b] ± 0.00	0.09[a] ± 0.00	0.08[ab] ± 0.01	0.007
20:4 (n-6)	0.28[b] ± 0.01	0.30[a] ± 0.01	0.26[c] ± 0.01	<0.001
20:5 (n-3)	0.14[a] ± 0.00	0.10[c] ± 0.00	0.13[b] ± 0.00	<0.001
22:2 (n-6)	0.03 ± 0.01	0.05 ± 0.02	0.04 ± 0.02	0.172
22:4 (n-6)	0.02 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.398
22:5 (n-3)	0.08[b] ± 0.00	0.10[a] ± 0.00	0.09[a] ± 0.00	<0.001
22:6 (n-3)	0.09[b] ± 0.01	0.10[a] ± 0.01	0.10[a] ± 0.01	0.013
Σ PUFA	9.88[c] ± 0.04	11.8[a] ± 0.11	11.0[b] ± 0.08	<0.001
n-6/n-3	9.66[c] ± 0.12	11.8[a] ± 0.27	10.7[b] ± 0.12	<0.001
Nutritional ratio[c]	0.33[c] ± 0.00	0.45[a] ± 0.00	0.39[b] ± 0.01	<0.001

See footnotes of Table 3.

Table 6
Texture profile from experimental frankfurters

	IF	WF	HF	p[a]
Hardness[a]	16.0 ± 0.97	15.1 ± 1.96	15.7 ± 2.39	0.732
Fracturability[a]	0.08 ± 0.01	0.09 ± 0.01	0.09 ± 0.01	0.435
Adhesiveness[b]	−0.17 ± 0.03	−0.13 ± 0.05	−0.14 ± 0.04	0.352
Springiness[c]	0.92 ± 0.02	0.87 ± 0.04	0.88 ± 0.02	0.105
Cohesiveness[d]	0.59[a] ± 0.00	0.59[ab] ± 0.01	0.58[b] ± 0.01	0.042
Gumminess[a]	10.0 ± 0.56	8.46 ± 1.44	9.09 ± 1.31	0.139
Chewiness[a]	9.44 ± 0.57	7.78 ± 1.94	8.03 ± 1.12	0.149
Resilience[d]	0.34 ± 0.01	0.33 ± 0.01	0.34 ± 0.01	0.051

[a] Newtons/cm^2.
[b] Newtons × s.
[c] cm.
[d] Dimensionless.

(Fernández-López, Sayas-Barberá, Navarro, Sendra, & Pérez-Álvarez, 2003; González-Viñas et al., 2004). The results suggest that the three types of frankfurters had similar texture characteristics since similar values of hardness, fracturability, adhesiveness, springiness, gumminess, chewiness and resilience were detected. Cavestany, Colmenero, Solas, and Carballo (1994) reported that differences in texture properties among meat products are influenced by a variety of factors such as difference in formulations, functionality of proteins and amount and characteristics of fat. There have been many studies of the effect of the reduction of fat and the addition of some particular fat replacers and additives on the texture characteristics of frankfurters-type sausages (Grigelmo-Miguel, Abadías-Serós, & Martín-Belloso, 1999; Crehan, Hughes, Troy, & Buckley, 2000; Pappa, Bloukas, & Arvanitoyannis, 2000). The fact that the experimental frankfurters in the present study were produced following the same recipe and had similar proximate composition could explain the lack of significant differences among them for the texture characteristics. Nevertheless, a clear trend was observed since IF tended to be harder and showed higher values of adhesiveness ($p > 0.05$), springiness ($p > 0.05$), cohesiveness ($p < 0.05$), gumminess ($p > 0.05$) and chewiness ($p > 0.05$) than WF. HF tended to present intermediate texture characteristics between IF and WF. These trends could be attributed to the different characteristics of the meat and particularly those related to the fatty acid composition of their lipids. The modification of the fatty acid composition of frankfurters, increasing monounsaturated fatty acids (MUFA) and reducing saturated (SFA) and polyunsaturated fatty acids (PUFA) levels through replacing pork back-fat with olive oil led to sausages with higher values of hardness, springiness, cohesiveness, gumminess and chewiness (Bloukas & Paneras, 1993). In addition, liver pâtés produced with tissues from Iberian pigs presented higher values of instrumental hardness than those produced with tissues from white pigs (Unpublished data). In the aforementioned work, pâtés from Iberian and white pigs had no different proximate composition but showed, however, significant different fatty acid composition (Estévez et al., 2004) which agrees with results obtained in the present work.

4. Conclusions

The large differences detected among tissues from Iberian and white pigs explain the differences found between types of frankfurters. Using meat and adipose tissue from Iberian pigs for the manufacture of frankfurters results in a high quality product, with higher iron content and different colour characteristics compared to frankfurters from white pigs. IF are characterized by large percentages of MUFA, a small proportion of hypercholesterolemic fatty acids and presented lower values of the ratio n-6/n-3 than WF. The quality characteristics and fatty acid composition of WF can be improved by replacing 10% fat with adipose tissue from Iberian pigs.

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