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Meat Science 63 (2003) 533–541

MEAT SCIENCE

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Physicochemical characteristics of three muscles from free-range reared Iberian pigs slaughtered at 90 kg live weight

Ramón Cava*, Mario Estévez, Jorge Ruiz, David Morcuende

Tecnología de los Alimentos. Facultad de Veterinaria, Universidad de Extremadura, Campus Universitario, Cáceres 10071, Spain

Received 31 January 2002; received in revised form 28 June 2002; accepted 29 June 2002

Abstract

Three muscles from free-range reared pigs with different metabolic pattern were studied. *m. Masseter* (M), *m. Longissimus dorsi* (LD) and *m. Serratus ventralis* (SV) the first having an oxidative metabolism and the other two an intermediate and glycolytic metabolism. *m. Masseter* contained the highest content of myoglobin (M: 6.65 mg/g, LD: 3.00 mg/g and SV: 3.64 mg/g; $P<0.001$) and exhibited the highest CIE a^* (M:17.10, LD: 14.83, SV:15.34, $P<0.001$) and C* (M: 17.95, LD: 15.61, SV: 15.54, $P<0.001$) values. *m. L. dorsi* and *S. ventralis* contained a higher intramuscular fat content than *m. Masseter* (M: 2.26 g/100 g muscle, LD: 4.79 g/100 g muscle, SV: 3.52 g/100 g muscle, $P=0.001$) and lower amounts of phospholipids (M: 0.33 g/g imf, LD: 0.12 g/g imf, SV: 0.19 g/g imf; $P<0.001$). Fatty acid profiles from total intramuscular fat and lipid fractions, neutral lipids and polar lipids, significantly differed among muscles, there being a higher content of unsaturated fats (especially in the C18:2 and C20:4 percentages) in the *m. Masseter* than in the other two muscles analysed. Comparatively, muscles from 90 kg live weight Iberian pigs contained more fat and heme pigments and were redder than those from the commercial pig crosses usually produced.

Keywords: Iberian pig; Muscle; Lipid content; Meat colour; Free-range rearing

1. Introduction

The Iberian pig is a rustic pig breed reared in the south west of the Iberian Peninsula. In contrast with industrial pig breeds and their crosses, the Iberian pig production system involves a long period of time. Iberian pigs are slaughtered at greater ages (12–14 months) and live weights (150–160 kg live weight), the last 40–60 days previous to slaughter being the most important phase in the productive system due to characteristics of feed (acorn, grass or concentrate feeds) consumed by the pigs.

Traditionally, meat from Iberian pigs has been transformed into dry-cured meat products: dry-sausages, shoulders, loins and hams. Literature concerning the effect of fattening phase characteristics on lipid content and fatty acid composition of muscle, liver and subcutaneous adipose tissue lipids and the characteristics of dry cured products obtained is very abundant (Cava et al., 1997; Cava, Ruiz, Tejeda, Ventanas, & Antequera, 2000; Cava, Ruiz, Ventanas, & Antequera, 1999; Ruiz et al., 1998).

However, there is no information about characteristics of meat from free-range reared Iberian pig to fresh consumption. In recent years, interest by consumers in the so-called 'natural', 'bio' or 'organic' meats has been increasing. Therefore meat from pig production systems in which pigs are free-range reared, and fed on natural feeds with no growth promoters and antibiotics, begins to be an important field of interest. In some European countries like Denmark (Norgaard & Bennet, 1995), France (Coutron-Gambotti, Gandemer, & Casabianca, 1998; Dargon, Badouard, & Boulot, 1996), Germany (Hoges, 1988); Hungary (Dworschák et al., 1995), Sweden (Jonsäll, Johansson, & Lundström, 2001) and Netherlands (de Kleijn et al., 1991) free-range rearing pig production is beginning to have a sounder base from which to expand, and sales levels look likely to strongly increase (McIntyre, 1999).

Muscles are comprised of different type of fibres (αW, αR and βR) with different contractile and metabolic properties. The relative proportion of the three types of

* Corresponding author. Tel.: +34-927-257-169; fax: +34-927-257-110.

E-mail address: rcava@unex.es (R. Cava).

0309-1740/03/$ - see front matter © 2002 Elsevier Science Ltd. All rights reserved.
PII: S0309-1740(02)00180-8

fibres in each muscle largely determines its technological and sensory properties such as taste, juiciness or rate of lipid and myoglobin oxidation (Renerre & Labas, 1987; Valin, Touraille, Vigneron, & Ashmore, 1982). Depending on the types of fibre that constitute a muscle, it has a different trend to intramuscular fat deposition, a different heme pigment concentration and its phospholipid and fatty acid composition varies. Meats are more tasty and juicy, and total heme pigments and lipids oxidise faster in oxidative muscles than in glycolytic ones; this contributes to different textural properties (Wood, Wiseman, & Cole, 1994) and the formation of aroma compounds and thus the appearance of rancidity and warmed-over flavour during storage (Gray & Pearson, 1987).

The aim of this experiment was to study the physicochemical characteristics of three muscles with different oxidative metabolism, *m. Masseter*, *m. Longissimus dorsi* and*m. Serratus ventralis*, from free-range reared Iberian pigs slaughtered at 85–90 kg live weight and to compare their characteristics with meat from lean pigs reported in the scientific literature.

2. Materials and methods

2.1. Animals

Ten Iberian pigs were free-range reared during the autumn season, being fed on grass and a concentrate feed based on cereals without incorporation of any animal source of protein or fat. Feed analysis (AOAC, 1984) showed a protein content of 16.21 g/100 g dry matter (d.m.) and a fat content of 2.68 g/100 g d.m. The fatty acid composition of feed (expressed as percentage of total fatty acids identified) was as follows: palmitic acid (C16): 14.16%; stearic acid (C18): 3.13%; oleic acid (C18:1, n-9): 26.56%, linoleic acid (C18:2, n-6): 51.30% and linolenic acid (C18:3, n-3): 1.65%.

Pigs were stunned and slaughtered at the end of the fattening period at a live weight of 85–90 kg. Muscles *m. Masseter*, *m. Longissimus dorsi* and *m. Serratus ventralis* were removed from the carcass, liberated of visible fat and vacuum packaged and kept frozen at −85 °C until analysed.

2.2. Analytical methods

2.2.1. Intramuscular fat isolation and fatty acid profiles

Lipids form subcutaneous tissue were extracted using a microwave oven according to the method described by De Pedro, Casillas, and Miranda (1997). Intramuscular total lipids from muscles were extracted according to the method described by Bligh and Dyer (1959). From the fat extracted, neutral lipids (NL) and polar lipids (PL) fractions of muscles were isolated according to the method developed by Garcia-Regueiro, Gilbert, and Diaz (1994). Fatty acid methyl esters (FAMEs) of total lipid extracts, muscle and subcutaneous tissue, neutral and polar lipid fractions were prepared by acidic sterification in presence of sulphuric acid (Cava et al., 1997). FAMEs were analysed using a Hewlett Packard, mod. HP-5890A, gas chromatograph, equipped with a flame ionisation detector (FID). FAMEs were separated on a 30 m FFAP-TPA fused-silica column (Hewlett Packard) with an i.d. of 0.53 mm and a 1.0 μm film thickness. The injector and detector were maintained at 230 °C. Column oven temperature was maintained at 220 °C. The carrier gas was nitrogen at a flow rate of 1.8 ml/min. Identification of FAMEs was based on retention times of reference compounds (Sigma). Unsaturation index and average chain length were calculated as follows:

Unsaturation index (UI):

$$\frac{\Sigma(\%\ \text{each of unsaturated fatty acids} \times \text{number of double bonds of the same fatty acid})}{\%\ \text{total fatty acids}}$$

Average chain length (ACL):

$$\frac{\Sigma(\%\ \text{each of fatty acids} \times \text{number of carbon atoms of this fatty acid})}{\%\ \text{total fatty acids}}$$

2.2.2. Phospholipid content

Muscle phospholipid contents were analysed according to Barlett (1959).

2.2.3. Myoglobin content

The concentration of heme pigments were assayed from the total content of heme pigment according to Hornsey (1956), and calculated by multiplying heme pigment concentration by the factor 0.026.

2.2.4. Objective colour measurements

Surface colour measurements of muscles were recorded on 45 min blooming time with a Chromameter (CR-300, Minolta Camera Co. Ltd Japan). The L^* (lightness), a^* (redness) and b^* (yellowness) values were recorded from the average of three random readings across each muscle surfaces. Chroma and hue angle values were obtained from the values a^* and b^* following equations described:

$$\text{Chroma } (C) = (a^*2 + b^*2)^{0.5}$$

$$\text{Hue angle } (H) = \text{arctg } (b^*/\text{a}^*)^*(360/2^\circ\pi;)$$

2.3. Statistical analysis

The effect of muscle on studied parameters was assessed by analysis of variance (ANOVA) using the General Linear Model of SPSS 10.0 (SPSS, 1999) and when was significant means were compared by Tukey's test at level of $P<0.05$.

3. Results and discussion

3.1. General parameters

Moisture, intramuscular fat (imf) and protein contents from the analysed muscles (*m. Masseter*, *m. Longissimus dorsi* and *m. Serratus ventralis*) are shown in Table 1. Moisture content varied between 71 and 75%, while protein contents were between 19.7 and 21.5 g/100 g. Intramuscular fat (imf) content ranged from 2.2 to 4.8 g/100 g, depending on the muscle analysed. *m. Longissimus dorsi* showed the highest imf content ($P<0.05$) (4.79 g/100 g muscle), while *m. Masseter* showed the lowest intramuscular fat content (2.2 g/100 g muscle) and the highest protein content ($P<0.05$) (21.5 g/100 g). *m. Serratus ventralis* exhibited intermediate levels of intramuscular fat (3.52 g/100 g muscle) and protein (20.16 g/100 g muscle) contents.

3.2. Myoglobin content and objective colour assessment

Myoglobin (Mb) content, expressed as mg myoglobin/g muscle, and Cie $L^*a^*b^*$ colour co-ordinates (Lightness, redness, yellowness, chroma and hue angle) are shown in Table 1. Myoglobin content significantly increased ($P<0.001$) in the order *L. dorsi* = *S. ventralis* < *Masseter* (3.00, 3.64 and 6.65 mg Mb/g muscle, respectively). Myoglobin content is an indicator of the redness of the muscle and is closely related to oxidative activity (Leseigneur-Meynier & Gandemer, 1991). These authors studying different pig muscles with different metabolic type of fibre found higher contents of heme pigments and lower lactate dehydrogenase activities in oxidative muscles—*m. Masseter*—than in glycolytic ones—*m. Longissimus dorsi* and *m. Biceps femoris*.

Objective colour measurements were significantly affected by type of muscle. In this sense, the redness value (a^*) increased as myoglobin content increased ($P<0.001$) in the order *m. L. dorsi* = *m. S. ventralis* > *m. Masseter* (14.8, 15.5 and 17.1, respectively). In contrast, lightness (L^*) increased in a significant extent ($p<0.001$) in the order *m. Masseter* < *m. S. ventralis* < *m. L. dorsi*. Chroma (C) increased ($P<0.001$) in the same way than redness did, *m. S. ventralis* = *m. L. dorsi* > *m. Masseter* (15.61, 15.88 and 17.95, respectively). Results show a close relationship between muscle type, myoglobin content and objective colour measurement co-ordinates, being in agreement with previous work (Fernandez, Monin, Talmant, Mourot, & Lebret, 1999; Leseigneur-Meynier & Gandemer, 1991).

3.3. Intramuscular, neutral lipid and phospholipid contents

Results from analysis of raw muscles revealed an important effect of the metabolic type of the muscle on intramuscular fat (imf), neutral lipid and phospholipid contents and fatty acid profiles. Imf content was significantly higher ($P<0.001$) in *m. L. dorsi* and *m. S. ventralis* than in *m. Masseter* (4.79, 3.52 and 2.26 g/100 g muscle, respectively) (Table 2). Phospholipid contents were significantly higher ($P<0.001$) in *m. Masseter* than in *m. L. dorsi* and *m. S. ventralis* (0.33 g/g imf for the *m. Masseter*, 0.12 g/g imf for the *m. L. dorsi* and 0.19 g/g imf for the *m. S. ventralis*) being in agreement with results previously published by Leseigneur-Meynier and Gandemer (1991) in lean pigs. The higher

Table 1
Moisture, intramuscular fat, myoglobin contents and lightness (L^*), redness (a^*), yellowness (b^*), chroma (C) and hue angle (H°) values of three muscles from Iberian pigs slaughtered at 90 kg live weight

	Muscles			*P*-value
	Masseter	*Longissimus dorsi*	*Serratus ventralis*	
Moisture	72.69b±0.95	71.28b±3.20	74.92a±1.61	0.008
IMF[a]	2.26b±0.78	4.79a±1.62	3.52ab±1.23	0.001
Protein[a]	21.31a±0.40	19.76b±1.79	20.16b±1.00	0.024
L^*	40.70c±1.55	46.36a±2.12	43.98b±1.69	0.000
a^*	17.10a±1.15	14.83b±1.15	15.34b±0.99	0.000
b^*	5.41a±0.95	4.73b±1.24	4.05b±0.70	0.015
C	17.95a±1.34	15.61b±1.20	16.54b±1.59	0.000
H°	17.44±2.09	17.68±4.38	14.68±1.86	0.570
Myoglobin content[b]	6.65a±0.54	3.00b±0.45	3.64b±0.50	0.000

Means with different letters differ significantly.
[a] g/100 g muscle.
[b] mg myoglobin/g muscle.

Table 2
Intramuscular fat, neutral lipid and phospholipid contents from *m. Masseter*, *m. Longissimus dorsi* and *m. Serratus ventralis* of Iberian pigs slaughtered at 90 kg live weight[a]

Muscles	Total lipids	Lipid fractions	
		Neutral lipids[a]	Phospholipids
Masseter	2.3b±0.8	1.5b±0.0 (0.67b±0.00)	0.77±0.4 (0.33a±0.1)
Longissimus dorsi	4.8a±1.7	4.3a±0.0 (0.88a±0.00)	0.53±0.2 (0.12b±0.0)
Serratus ventralis	3.5a,b±1.2	2.9a,b±0.0 (0.81a,b±0.00)	0.60±0.1 (0.19b±0.1)
P-value	0.001	0.125 (0.000)	0.128 (0.000)

Means with different letters differ significantly.
[a] Results expressed as g/100 g muscle. Results between parentheses are expressed as g/g of imf.

phospholipid content in the oxidative muscle—*m. Masseter*—than in the other two muscles (with glycolytic metabolism)-*m. L. dorsi* and *m. S. ventralis*- can be explained by the type of fibre that compose red muscles. βR fibres are rich in mitochondria and with a great amount of sub-cellular membranes rich in phospholipids. On the other hand, neutral lipid content followed an inverse tendency to phospholipids, being significantly lower ($P<0.001$) in the oxidative muscle than in the two glycolytic ones (0.67, 0.88 and 0.81 g/g imf for *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) (Table 1). These findings contradict the idea that oxidative muscles contain a higher intramuscular fat content than glycolytic muscles because of the different substrates that muscles use to produce energy (glucose in glycolytic muscles and fatty acids in oxidative ones). This controversy can be explained considering muscles with a pure metabolism and low fat infiltration like the rabbit muscles (Alasnier, Rémignon, & Gandemer, 1996) very different to the trend observed in this experiment. In this animal specie, intramuscular fat in the oxidative muscles are allocated in droplets inside the muscle cell; while in the glycolytic muscles imf are allocated in specialised cells—adipocites—between muscle fibres, constituting the marbling fat. These variations between our results and others previously cited are due to a different trend of the muscles to accumulate fat cells in the extrafasciculllar area as a result of distinct genetic and/or environmental factors (Kauffman & Saffani, 1967). The fact that Iberian pigs show an anabolic metabolism tending to a high fat accumulation in tissues support our results and explain the higher amounts of total intramuscular fat and neutral lipids in *m. L. dorsi* and *S. ventralis*—glycolytic muscles—than in *m. Masseter*—oxidative muscle.

3.4. Fatty acid composition of subcutaneous fat, intramuscular fat and lipid fractions

Fatty acid composition of subcutaneous fat and total intramuscular fat from *m. L. dorsi*, *m. S. ventralis* and *m. Masseter* is shown in Tables 3 and 4, respectively.

In general, oleic acid (C18:1) was the most common fatty acid in the two studied locations, subcutaneous fat and muscle, representing ~39.1–45.5% of the total analysed fatty acids, followed by palmitic acid (C16) (~20.1–24.2%) and stearic acid (C18) (~11.5–13.8%). Linoleic acid (C18:2 n-6) was found in *m. Longissimus dorsi* (~9.8%) and *m. Masseter* (~16.6%). A low percentage of arachidonic acid (C20:4) was found in subcutaneous fat (~0.21%), in contrast to the three studied muscles (~4.36, ~1.15 and ~1.85%, for *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively).

Table 3
Fatty acid composition (% methyl esters listed) of subcutaneous adipose tissue from Iberian pigs slaughtered at 90kg live weight

Fatty acid	Mean±SD
C12	0.07±0.01
C14	1.22±0.09
C15	0.05±0.01
C16	21.26±0.68
C17	0.32±0.05
C18	11.51±0.79
C20	0.26±0.03
Σ SFA	34.69±0.65
C16:1	2.28±0.21
C17:1	0.29±0.04
C18:1	45.50±1.12
C20:1	1.33±0.16
Σ MUFA	49.40±0.93
C18:2	14.17±0.55
C18:3	0.67±0.03
C20:2	0.84±0.10
C20:4	0.21±0.02
Σ PUFA	15.89±0.08

Values are the mean of 10 animals.

Fatty acid profiles of the intramuscular fat from muscles studied were markedly affected by type of muscle metabolism. In this sense, intramuscular fat from *m. Masseter* contained more polyunsaturated fatty acids (C18:2, C20:2 and C20:4) than the other two muscles, *m. L. dorsi* and *m. S. ventralis*. On the other hand, the intramuscular fat of *m. L. dorsi* was richer in oleic acid and saturated fatty acids (C18 and C16) than those from *m. Masseter* and *m. S. ventralis*. *m. S. ventralis* showed a fatty acid profile intermediate to *m. Masseter* and *m. L. dorsi* (Table 3). Differences between tissues

Table 4
Fatty acid profiles (% methyl esters listed) of intramuscular fat of three muscles from Iberian pigs slaughtered at 90 kg live weight

	Muscles			*P*-value
	Masseter	*Longissimus dorsi*	*Serratus ventralis*	
Fatty acids (% methyl esters)				
C12	0.23a±0.14	0.08b±0.01	0.18a±0.03	0.004
C14	0.93b±0.15	1.25a±0.08	1.26a±0.08	0.000
C16	20.16c±0.54	24.27a±1.12	23.19b±0.66	0.000
C17	0.30a±0.04	0.23b±0.04	0.24b±0.03	0.002
C18	13.16±0.47	13.83±0.88	13.13±0.92	0.142
C20	0.20b±0.02	0.25a±0.03	0.23a±0.02	0.000
Σ SFA	34.98b±0.85	39.90a±1.70	38.23a±1.37	0.000
C16:1	2.47b±0.24	3.46a±0.60	3.35a±0.61	0.001
C17:1	0.20±0.02	0.20±0.03	0.21±0.03	0.719
C18:1	37.88b±3.19	43.66a±2.20	41.75a±2.46	0.001
C20:1	1.03a±0.08	0.86b±0.08	0.88b±0.08	0.000
Σ MUFA	41.59b±3.45	48.17a±2.70	46.18a±3.06	0.001
C18:2	17.34a±2.37	9.82c±1.03	12.71b±1.66	0.000
C18:3	0.41±0.02	0.38±0.04	0.40±0.04	0.164
C20:2	1.02a±0.31	0.58b±0.15	0.62b±0.20	0.001
C20:4	4.66a±1.01	1.15b±0.34	1.85b±0.53	0.000
Σ PUFA	23.44a±3.42	11.92c±1.41	15.59b±2.29	0.000
UI	0.98a±0.06	0.75c±0.02	0.81b±0.03	0.000
ACL	17.63a±0.04	17.44b±0.03	17.48b±0.03	0.000
Σ MUFA/Σ SFA	1.19±0.11	1.21±0.13	1.21±0.12	0.908
Σ PUFA/Σ SFA	0.67a±0.10	0.30c±0.03	0.41b±0.06	0.000
Σ MUFA/Σ PUFA	1.83c±0.43	4.12a±0.77	3.05b±0.73	0.000

Means with different letters differ significantly. Results are expressed as percentage of total fatty acid methylesters identified. UI, unsaturation index; ACL, average chain length; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids).

are a result of their different composition of lipid fractions, neutral lipids being the main component in subcutaneous fat, in which polyunsaturated fatty acids are represented by linoleic acid, while intramuscular fat is constituted by both neutral and polar lipids, the latter being rich in polyunsaturated fatty acids. Differences in fatty acid profiles of the three muscles reflect the type metabolic and compositional particularities of each one (Leseigneur-Meynier & Gandemer, 1991). *m. Masseter* contains a high amount of sub-cellular membranes rich in phospholipids with a high content of polyunsaturated fatty acids. In contrast, the *m. L. dorsi*—glycolytic muscle—has a lower amount of sub-cellular membranes, a higher content of intramuscular fat, and lower levels of polyunsaturated fatty acids.

The fatty acid composition of the neutral lipids and polar lipids of muscles from free-range reared Iberian pigs are given in Tables 5 and 6, respectively. In neutral lipids, the monounsaturated fatty acids were the most abundant (55.0–55.7% of the total fatty acids) followed by the saturated fatty acids. Oleic (C18:1) and palmitic (C16) acids were the main fatty acids of the glycerides (50.6–51.6 and 25.0–25.4%, respectively). Polyunsaturated fatty acids contained essentially linoleic (C18:2 n-6) acid (5.9–6.1%) and a small percentage of linolenic (C18:3 n-3) and arachydonic (C20:4 n-6) acids (0.6 and 1.3%, respectively). In the polar lipid fraction, polyunsaturated fatty acids were the most abundant (55.5–56.9%), followed by saturated fatty acids (27.7–28.8%). In general, results are in accordance to those reported by other researchers in lean pigs (Buscailhon, Gandemer, & Monin, 1994), Iberian pigs (Flores, Nieto, Bermell, & Alberola, 1987) and ourselves previously (Cava et al., 1997; 1999).

As for lipid fraction contents, the metabolic type of muscle affected the fatty acid profiles of neutral and polar lipids (Tables 5 and 6, respectively). Neutral lipids in the oxidative muscle exhibited a lower proportion of palmitic acid ($P<0.05$) (C16) (20.56, 24.61 and 23.45% for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) and the total of saturated fatty acids ($P<0.000$) (35.5, 40.3 and 38.7% for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively). Oleic acid percentages (C18:1) were significantly ($P<0.05$) lower in *m. Masseter* than in *m. L. dorsi* and *m. S. ventralis* (38.63, 43.82 and 42.00% for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively), the same as for the total of monounsaturated fatty acids ($P<0.05$) (42.8, 48.5 and 46.5% for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively). However, neutral lipids from the oxidative muscle—*m. Masseter*—contained higher percentages of linoleic acid (C18:2) ($P<0.05$) (16.79, 9.46 and 12.32% for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) and arachidonic acid

Table 5
Fatty acid profiles (% methyl esters listed) of the neutral lipids of three muscles from Iberian pigs slaughtered at 90 kg live weight

	Muscles			*P*-value
	Masseter	*Longissimus dorsi*	*Serratus ventralis*	
Fatty acids (% methyl esters)				
C12	0.25a±0.11	0.09b±0.01	0.19a±0.06	0.001
C14	1.02b±0.11	1.29a±0.11	1.32a±0.13	0.000
C16	20.56c±0.63	24.61a±0.96	23.45b±0.84	0.000
C17	0.29a±0.04	0.21b±0.03	0.24b±0.03	0.000
C18	13.24±0.51	13.90±1.01	13.26±1.02	0.237
C20	0.20b±0.02	0.24a±0.02	0.24a±0.02	0.001
Σ SFA	35.55b±0.69	40.34a±1.60	38.71a±1.54	0.000
C16:1	2.56b±0.27	3.50a±0.68	3.40a±0.62	0.003
C17:1	0.20±0.02	0.19±0.03	0.20±0.03	0.821
C18:1	38.63b±3.07	43.82a±1.78	42.00a±2.52	0.001
C20:1	0.97±0.11	1.00±0.12	0.93±0.11	0.399
Σ MUFA	42.36b±3.36	48.52a±2.43	46.52a±3.12	0.001
C18:2	16.79a±2.31	9.46c±1.07	12.32b±1.68	0.000
C18:3	0.41±0.04	0.37±0.05	0.40±0.05	0.269
C20:2	0.67a±0.23	0.35b±0.08	0.40b±0.05	0.000
C20:4	4.23a±0.94	0.96b±0.33	1.65b±0.45	0.000
Σ PUFA	22.09a±3.36	11.14c±1.39	14.77b±2.14	0.000
UI	0.95a±0.05	0.73c±0.02	0.80b±0.03	0.000
ACL	17.60a±0.03	17.43b±0.03	17.46b±0.03	0.000
ΣMUFA/ΣSFA	1.19±0.10	1.21±0.11	1.21±0.13	0.957
ΣPUFA/ΣSFA	0.62a±0.10	0.28c±0.03	0.38b±0.05	0.000
ΣMUFA/ΣPUFA	1.98c±0.47	4.44a±0.83	3.24b±0.76	0.000

Means with different letters differ significantly. Results are expressed as percentage of total fatty acid methylesters identified. UI, unsaturation index; ACL, average chain length; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

(C20:4) ($P<0.05$) (4.23, 0.96 and 1.65% for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) and the total of polyunsaturated fatty acids ($P<0.05$) (22.1, 11.2 and 14.8% for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) than the glycolytic muscles (Table 5). Contrarily to Leseigneur and Gandemer (1991), results from this work reflect a clear effect of type of muscle on the fatty acid profiles of neutral lipid fractions. The calculated unsaturation index (UI) significantly differed among muscles ($P<0.000$), being higher in *m. Masseter* (0.95) followed by *m. S. ventralis* (0.80) and lower in *m. L. dorsi* (0.73) as a result of the different polyunsaturated to saturated ratio and making neutral lipids from *m. Masseter* more susceptible to oxidative processes than those from the other two muscles.

Likewise, polar lipids from *m. Masseter* showed higher percentages of stearic acid (C18) ($P<0.05$) (18.43, 13.22 and 14.53% for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) and total saturated fatty acids ($P<0.05$) (36.4, 32.8 and 33.4% for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) and lower percentages of oleic acid (C18:1) ($P<0.05$) (12.01, 16.32 and 16.20%, for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) and the sum of monounsaturated fatty acids ($P<0.05$) (13.3, 17.9 and 17.8%, for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) (Table 6). *m. Masseter* contained higher percentages of arachidonic acid (C20:4) ($P<0.05$) (16.60, 12.75 and 11.88%, for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) and lower percentages of linoleic acid (C18:2) ($P<0.05$) (33.14, 36.14 and 36.41%, for the *m. Masseter*, *m. L. dorsi* and *m. S. ventralis*, respectively) than *m. L. dorsi* and *m. S. ventralis*. The unsaturation index (UI) for the three muscles was 1.48, 1.43 and 1.40. These results are in good agreement with previous work published on the pig (Cava et al., 1997; Leseigneur-Meynier & Gandemer, 1991), rabbit (Alasnier et al., 1996) and chicken muscles (Alasnier, Meynier, Viau, & Gandemer, 2000). Differences in fatty acid composition between oxidative and glycolytic muscles might be due to a higher number of cellular and sub-cellular membranes and the difference in the ratio of mitochondria to other membranes (plasma and reticulum membranes) between oxidative and glycolytic muscles (Alasnier et al., 1996, 2000; Leseigneur-Meynier & Gandemer, 1991). These authors in several experiments in which they studied the effect of muscle type on intramuscular fat content, phospholipid classes proportions and fatty acid profiles in different species, reported that red muscles contained more membrane structures, mainly due to the mitochondria content, and hence more phospholipids than glycolytic muscles. Furthermore, content

Table 6
Fatty acid profiles (% methyl esters listed) and fatty aldehydes of the polar lipids of three muscles from Iberian pigs slaughtered at 90 kg live weight

	Muscles			*P*-value
	Masseter	*Longissimus dorsi*	*Serratus ventralis*	
Fatty acids (% methyl esters)				
C14	0.38±0.18	0.40±0.08	0.49±0.29	0.582
C16	16.95±1.41	18.47±1.07	17.63±1.70	0.107
C17	0.65±0.12	0.69±0.09	0.76±0.16	0.222
C18	18.43a±1.11	13.22b±1.52	14.53b±1.21	0.000
C20	tr	tr		
Σ SFA	36.41a±0.88	32.78b±1.11	33.40b±1.64	0.000
C16:1	0.72±0.17	0.99±0.25	1.00±0.26	0.037
C17:1	0.56±0.11	0.56±0.17	0.60±0.11	0.826
C18:1	12.01b±1.32	16.32a±1.40	16.20a±2.71	0.000
C20:1	tr	tr		
Σ MUFA	13.30b±1.49	17.87a±1.63	17.79a±2.77	0.000
C18:2	33.14b±1.41	36.14a±1.62	36.41a±2.64	0.003
C18:3	0.54±0.18	0.46±0.36	0.52±0.18	0.768
C20:2	tr	tr		
C20:4	16.60a±1.46	12.75b±1.18	11.88b±1.37	0.000
Σ PUFA	50.29±2.09	49.35±1.71	48.81±3.51	0.492
Aldehydes (% of DMA)				
C16AL	56.78a±1.41	50.35b±2.38	51.03b±1.82	0.000
C18AL	23.29b±1.14	25.59a±1.70	24.39a,b±1.57	0.015
C18:1AL	19.93b±1.49	24.06a±1.27	24.58a±1.37	0.000
UI	1.48a±0.05	1.43ab±0.04	1.40b±0.07	0.023
ACL	17.95a±0.06	17.84b±0.04	17.83b±0.06	0.000
ΣMUFA/ΣSFA	0.36b±0.04	0.55a±0.06	0.53a±0.08	0.000
ΣPUFA/ΣSFA	1.38±0.08	1.51±0.09	1.47±0.16	0.087
ΣMUFA/ΣPUFA	0.27b±0.04	0.36a±0.04	0.37a±0.09	0.002
DMA/FAME ×100	18.35±1.72	20.64±1.72	20.55±3.30	0.088

Means with different letters differ significantly. Results are expressed as percentage of total fatty acid methylesters identified. UI, unsaturation index; ACL, average chain length; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

of phosphatidilethanolamine and cardiolipin—major components of mitochondria—were higher in the oxidative muscle and lower in the glycolytic muscles. Fatty acid composition of these phospholipids significantly differed among muscles being more unsaturated oxidative ones than glycolytic ones as a result of their different phospholipid classes composition.

In all muscles, the proportion of dimethylacetals (DMA) from plasmalogens was between 18.3 and 20.6% of the total fatty acids and fatty aldehydes (Table 6). Metabolic type did not significantly affect ($P=0.088$) the proportion of DMA to FAME, however, proportions tended to be higher in the glycolytic muscles (20.64 for the *m. L. dorsi* and 20.55 for *m. S. ventralis*) than in the oxidative muscle (18.35 for the *m. Masseter*). The DMA component was mainly C16:0AL—hexadecanal—(50.35–56.78% of the total DMA), C18:0AL—octadecanal—(23.29–25.59% of the total DMA) and C18:1AL—octadecenal—(19.93–24.58% of the total DMA). The proportion of C16:0AL was significantly higher ($P<0.05$) in the oxidative muscle (*m. Masseter*) (56.78%) than in glycolytic ones (50.35% for the *m. L. dorsi* and 51.03% for the *m. S. ventralis*). The percentage of C18:1AL was significantly lower ($P<0.000$) in the oxidative muscle (19.93% for the *m. Masseter*) than in the two glycolytic muscles (24.06 for the *m. L. dorsi* and 24.58% for the *m. S. ventralis*). Alasnier et al. (1996) and Alasnier and Gandemer (1998) reported similar DMA derivatives in rabbit muscles.

3.5. Comparisons between meat characteristics from free-range reared Iberian pigs and industrial pig breeds

There are some differences in meat characteristics when those from 85–90 kg live weigh free-range reared Iberian pigs and industrial crosses are compared. Meat from Iberian pigs is richer in intramuscular fat than meat from Large-White×Pietrain or Duroc×Landrace pig crosses. In this sense, results from our work showed that *m. L. dorsi* from Iberian pigs contained ~1.9–3.2 fold times more intramuscular fat than industrial pig crosses (Leseigneur-Meynier & Gandemer, 1991). Intramuscular fat reduces the force used for chewing easing the separation of muscle fibres and causing a perception of higher tenderness of the meat. Furthermore, imf promotes saliva

secretion helping mastication and increasing juiciness perception (Wood et al., 1994). This higher intramuscular fat content might contribute to a higher sensory quality of meat from free-range reared Iberian pigs conferring higher juiciness and tenderness attributes. In recent years, pig productive methods have changed tending to a production of pigs with a higher content of intramuscular fat to provide to consumer meat with a higher sensory quality (Fernandez et al., 1999).

Meat from Iberian pigs contains a higher content of myoglobin than lean pigs. Pigment contents are higher than in meat from lean pigs. In this sense, in *m. L. dorsi* and *m. Masseter* from Iberian pigs myoglobin contents were ~5.5 and ~7.5-fold times higher than values referred in the literature for Large-White×Pietrain pigs (0.4 mg Mb/g vs 3.00 mg Mb/g and 2.00 mg Mb/g vs 6.65 mg Mb/g for the *m. L. dorsi* and *m. Masseter*, respectively) (Leseigneur-Meynier & Gandemer, 1991). Heme pigment content increases with animal age. Furthermore, physical exercise has a positive effect on heme pigment contents producing an increase in their concentration in muscle. Iberian pig production factors, with a higher slaughter age and physical exercise, means that meat from Iberian pigs contains a higher concentration of heme pigments than meat from lean pigs, intensively reared and slaughtered at early ages.

Instrumental colour co-ordinates reflected the marked differences in heme pigments in meat from free-range reared Iberian pigs and industrial pig breeds. In this way, CIE L^*, a^* and b^* values of meat markedly differ between industrial pig crosses and Iberian pigs. Colour co-ordinate a^* (redness) differs markedly between Iberian pig breed and other pig breeds in all the studied muscles. In this sense, in Iberian pigs the value of a^* for *m. L. dorsi* was 14.8, while this colour parameter value for the same muscle in Duroc×Landrace pigs was 6.9–2 fold time lower than in Iberian pigs. In the same way, the value of chroma (colour saturation) was much higher in the *m. L. dorsi* from Iberian pigs than in Duroc×Landrace (15.61 vs 8.23). Higher chroma and a^* values and lower L^* value in muscles from Iberian pigs indicate a redder colour of the meat, in contrast with paleness in meat from commercial pig crosses, which are perceived as more pale and pink meat by consumers (Fernandez et al., 1999).

Fatty acids profiles are affected by the level of fat in feeds and the fatty acid composition of dietary fat. In this sense, comparisons with others work is not very precise, due to the characteristics of feeds in each experiment being different. However, the high content of monounsaturated fatty acids of both subcutaneous and intramuscular fat from free-range reared Iberian pigs is remarkable. Free-range rearing provides a source of essential fatty acids, mainly linoleic (C18:3 n-3) acid, and tocopherols which originate in pasture. Muttetika and Mahan (1993) studied the effect of pasture on vitamin E levels in reproducing gilts and their progeny describing an increase in tissue tocopherol content in pigs fed on pasture. Recently, Cava et al. (2000) in Iberian pigs found a high content in linoleic acid (C18:3 n-3) (~449 g/100 g fatty acids) and alpha-tocopherol (~0.171 g/kg dry matter) in pasture that promote a rise in levels of these compounds in analysed muscles from free-range reared pigs compared to pigs fed on concentrate feed.

4. Conclusions

Muscle physicochemical characteristics significantly differed according to their respective metabolic patterns. These variations are of interest due to a presumably different behaviour of the muscles during refrigeration display, freezing or culinary practices on the oxidative and lipolytic changes and their shelf-lives.

Meat from free-range reared pigs slaughtered at 90 kg live weight shows some physicochemical characteristics that differ from that of lean pigs commonly found in the market. A higher intramuscular fat content and a higher intense red colour of muscles are the main characteristics which could contribute to different sensory characteristics. Composition of feeds together with a better utilisation of pasture should receive more attention from Iberian pig producers, with the objective of reducing polyunsaturated fatty acid percentages, principally linoleic acid (C18:2), and increasing oleic acid (C18:1) and in this way increase sensory quality and nutritive value. In general, consumers that like intensely coloured, tender, juicy and flavoured meat could consider meat from free-range reared Iberian light pigs as a red meat, having some distinctive sensory characteristics and with a presumably good acceptance. Nevertheless, more studies are necessary to provide a better knowledge about meat characteristics from free-range reared Iberian pigs including sensory analysis and technological aptitude, and also to clear up the role of free-range rearing on eating quality of this type of meat.

Acknowledgements

Funded by a grant from the I Plan Regional de Investigación. Junta de Extremadura (IPRD99001, "*Establecimiento de parámetros predictores de la calidad de carne fresca de cerdo Ibérico y Alentejano destinada a la elaboración de productos cárnicos curados y al consumo en fresco*"). The authors are grateful to AECERIBER and Miss Elena Diéguez and Mr. Pedro Cañuelo for providing us the animals. The authors also wish to thank Miss Ana Galaz and Miss Inmaculada Linares for their excellent technical assistance.

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