Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2010 8(3), 607-616
ISSN: 1695-971-X
eISSN: 2171-9292

The use of barley as single ingredient in the diet provided during the finishing period may improve the meat quality of heavy pigs from PO Teruel ham (Spain)

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Abstract

Thirty-two Duroc × (Large White × Landrace) barrows of 86.6 kg of body weight (BW) were used to investigate the effect of diet (control or granulated barley) provided during the finishing period on growth performance, meat quality and costs of production. The control diet consisted in a commercial feedstuff and the granulated barley diet consisted in the use of this cereal as only ingredient. The pigs were assigned to pens in groups of two (eight replicates per treatment) and were slaughtered at 130 kg BW. All the animals received the same feeding and management before the trial. No differences were observed for the growth performance and carcass traits between treatments. Pigs fed granulated barley had higher ($P < 0.01$) feed conversion ratio but lower production costs per kg of live ($P < 0.001$) and carcass ($P < 0.01$) weight than those on the control diet. The intramuscular fat (IMF) percentage in *Longissimus dorsi* muscle tended to be higher ($P = 0.07$) and had higher ($P < 0.01$) C18:1n-9 and total monounsaturated fatty acid (FA) percentages and lower ($P < 0.05$) C17:0, C17:1, C18:2n-6, C18:3n-3, C20:3n-9, Σn-6, Σn-3 and total polyunsaturated FA proportions in pigs fed granulated barley than in the control pigs. It is concluded that the use of barley as single ingredient in the diet provided during the finishing period of pigs may increase the IMF percentage, the C18:1n-9 proportion in IMF and some colour parameters of meat.

Additional key words: dry-cured meat product, fattening pigs, loin characteristics, protein/lysine deficiency.

Resumen

El uso de cebada como único ingrediente en la dieta durante el periodo de acabado puede mejorar la calidad de la carne de cerdos pesados de la DO Jamón de Teruel

Se usaron un total de 32 cerdos Duroc × (Large White × Landrace), todos machos castrados, de 86,6 kg de peso vivo (PV) para estudiar el efecto de la dieta de acabado (control o cebada granulada) sobre los rendimientos productivos, la calidad de la carne y los costes de producción. El pienso control consistía en una dieta comercial y la dieta con cebada granulada era un pienso compuesto únicamente por cebada granulada. Los animales se alojaron en departamentos en grupos de dos (ocho réplicas por tratamiento) y se sacrificaron cuando alcanzaron 130 kg PV. Todos los animales recibieron el mismo manejo y alimentación antes del comienzo del ensayo. Los cerdos que comieron cebada granulada tuvieron mayor ($P < 0,01$) conversión alimenticia pero menores costes por kg de PV ($P < 0,001$) y por kg de canal ($P < 0,01$) que los que comieron pienso control. El contenido en grasa intramuscular del músculo *Longissimus dorsi* tendió a ser mayor ($P = 0,07$) y mostró mayor contenido ($P < 0,01$) en C18:1n-9 y ácidos grasos monoinsaturados y menor ($P < 0,05$) en C17:0, C17:1, C18:2n-6, C18:3n-3, C20:3n-9, Σn-6, Σn-3 y ácidos grasos poliinsaturados en los cerdos que comieron cebada granulada que en los cerdos control. Se concluye que el uso de cebada granulada como único ingrediente en la dieta de cerdos en la fase de acabado puede incrementar el contenido en grasa intramuscular, de C18:1n-9 en dicha grasa y algunos parámetros relacionados con el color de la carne.

Palabras clave adicionales: características del lomo, cerdos grasos, deficiencia en proteína/lisina, producto cárnico curado.

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Received: 30-07-09; Accepted: 12-04-10.

Introduction

Spain is the world leader in dry-cured hams and shoulders with a total production of 46 million pieces in 2008. Currently, the only dry-cured ham trademark accepted by the Spanish government (Protected Origin, PO) from traditional heavy white pigs is «Teruel ham». The production of Teruel ham has increased greatly in recent decades from 2,000 pieces in 1985 to nearly 700,000 in 2008 (MARM, 2009).

The pig crossbreeding used for Teruel ham production is Duroc × (Large White × Landrace) and the regulation of PO Teruel ham (BOA, 1993) establishes a minimum of 84 kg for carcass weight and of 16 mm for fat thickness over the *Gluteus medius* (GM) muscle to improve the uniformity and quality of the end product. Latorre *et al.* (2008a, 2009a,b) found that 130 kg of body weight (BW) optimized the production and quality of this type of ham. However, despite the known quality of Teruel ham and also of shoulder and loin, consumers judge that these products have a moderate score in flavour and aroma (6 on 10 points) suggesting that it could be due to the low content in intramuscular fat (IMF) (Calvo *et al.*, 2009). Certainly, IMF proportion and composition are important meat quality characteristics (Fernández *et al.*, 1999). Several dietary strategies have been carried out to enhance IMF content in swine production. For instance, it has been reported that reductions of protein/digestible energy ratio lead to a higher IMF percentage (D' Souza *et al.*, 2003). Also, the fatty acid profile of the IMF changes with the use of different dietary fat sources (rape seed oil, soya bean oil and tallow) (Wiseman and Agunbiade, 1998). Nevertheless, available data shows little repeatability (Ruusunen *et al.*, 2007). In addition, a negative association between dietary vitamin A and IMF proportion has been found in cattle (Siebert *et al.*, 2006) and pigs (D'Souza *et al.*, 2003).

Barley is the largest cereal crop in the province of Teruel with a yearly production of around 500,000 t (MARM, 2009). Its acceptable price and nutritional composition (FEDNA, 2003) make interesting to revalue this cereal as a local natural product and to use it as single ingredient in diets for pigs during the finishing period (from 90 to 130 kg BW). A diet based on barley means a reduction of the protein:energy ratio in the ration and a deficiency in vitamin A in relation with the requirements for pigs of that age. Both aspects may have a positive effect on IMF content.

Therefore, the aim of this study was to investigate the influence of the use of barley as single ingredient in the diet provided from 86 kg BW to slaughter on production results, carcass characteristics and meat and fat quality in heavy pigs intended for PO Teruel ham.

Material and methods

Animal welfare and husbandry

All the experimental procedures used in this study were in compliance with the Spanish guidelines for the care and use of animals in research (BOE, 2005). A total of thirty-two crossbred barrows of 86.6 kg BW were used for the study. All pigs were the progeny of Duroc sires (Asociación Turolenses de Industrias Agroalimentarias, Teruel, Spain) and Large White × Landrace dams (Hypor España G.P., Barcelona, Spain). Males were castrated at 5 ± 3 d of age. Before the experiment, all pigs had the same feeding and management. On arrival at the experimental farm (El Chantre, Teruel, Spain), pigs were randomly allotted to sixteen pens (two pigs per pen). There were two treatments, one group following the control diet and the other following the granulated barley diet (eight pens per treatment). The control feedstuff consisted in a commercial diet and the granulated barley feedstuff consisted in the use of this cereal as only ingredient in the diet. Pigs were housed in 30% slotted floor pens (2.30 × 2.60 m) in a controlled environment barn and had free access to pelleted diets and water throughout the trial. Ingredients, nutrients and fatty acid composition of experimental diets are shown in Table 1. Dietary chemical analysis was carried out according to the international procedures of the AOAC (2000).

Growth performance, carcass traits and production cost

Individual BW and feed consumption per pen were recorded at the beginning and at the end of the trial and

Abbreviations used: a* (redness), ADFI (average daily feed intake), ADG (average daily gain), b* (yellowness), BW (body weight), c* (chroma), FA (fatty acid), FC (feed conversion ratio), GM (*Gluteus medius*), Hº (hue angle), IMF (intramuscular fat), L* (lightness), LD (*Longissimus dorsi*), MUFA (monounsaturated fatty acid), *P* (statistical significance level), PO (Protected Origin), PUFA (polyunsaturated fatty acid), *r* (Pearson correlation), R^2 (coefficient of determination), RSD (residual standard deviation, SE (standard error of the mean), SFA (saturated fatty acid).

Table 1. Composition and nutrient content of the experimental diets (g kg^{-1}, as-fed basis unless otherwise indicated)

	Control diet	Granulated barley
Ingredients		
Barley	431.0	1,000
Wheat	300.0	
Full fat-soybean-toasted	69.1	
Rapeseed meal	80.0	
Sunflower meal	55.0	
Fat	30.0	
Calcium carbonate	11.3	
Sepiolite	10.0	
Lysine supplement 50%	5.6	
Sodium chloride	4.0	
Vitamin and mineral premix[1]	4.0	
Calculated composition		
Digestible energy (MJ kg^{-1})	13.67	13.18
Analysed composition		
Dry matter	890.3	875.6
Crude protein	155.7	102.2
Crude fat	59.9	18.0
Fatty acids		
C14:0	0.68	0.20
C16:0	2.14	3.10
C18:0	0.81	0.21
C18:1n-9	6.28	1.61
C18:2n-6	10.91	7.65
C18:3n-3	0.53	0.08

[1] Provided the following (per kilogram of complete diet): 7,000 IU retinyl acetate, 1,500 IU cholecalciferol, 15 IU α-tocopherol acetate and 10 mg Cu (copper sulphate).

were used to calculate average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FC) per replicate. Animals were slaughtered when the average of each group achieved around 130 kg BW (191 and 196 days of average age for pigs fed control or granulated barley, respectively). The day before slaughter, feed was withheld for 7 h and pigs were weighed and transported 30 km to a commercial abattoir (Jamones y Embutidos Altomijares SL, Teruel, Spain), where they were kept in lairage for 10 h with full access to water but not to feed. Pigs were electrically stunned (225 to 380 V/0.5 amps for 5 to 6 s), exsanguinated, scalded, skinned, eviscerated, and split down the midline according to standard commercial procedures. Hot carcass weight was individually recorded and used to calculate dressing percentage.

At 45 min *postmortem*, carcass length from the posterior edge of the *Symphysis pubis* to the anterior edge of the first rib, ham length from the anterior edge of the *Symphysis pubis* to the hock joint, and ham circumference at its widest side were measured on the left side of each carcass. Carcass compactness was then calculated as carcass weight/carcass length. Fat depth over the GM muscle, and backfat thickness at the 10th rib on the midline of the carcass (skin included) were also measured.

The head was removed at the atlanto-occipital junction and carcasses were suspended in the air and refrigerated at 2°C (1 m s^{-1}; 90% relative humidity) for 2 h. Carcasses were then processed according to the simplified EC reference method (Branscheid *et al.*, 1990). Afterwards, hams, shoulders and loins were trimmed of external fat and weighed to calculate trimmed ham, shoulder and loin yields. The trimming consisted in eliminating part of the external fat and skin to fit commercial requirements and the process was performed by qualified personnel of the abattoir.

After the carcass had been processed, a section of liver and a section of 500 ± 20 g of the *Longissimus dorsi* (LD) muscle at the level of the last rib from each left loin were excised. Subcutaneous fat samples, including fat layers, skin and lean at the tail insertion in the coxal region of the left side were also taken from each carcass. All the meat, fat and liver samples were stored in individual plastic bags, vacuum-packaged and stored at –20°C until subsequent analyses.

The costs of production per kg of live and carcass weight were calculated by the method described by Alonso and Serrano (2004). The total cost of production was calculated as the sum of the following costs: pig purchase, housing and equipment amortization, housing and equipment maintenance, feeding, hygiene and health, energy, water, tax and insurances. The prices considered of concentrate and barley were € 0.32 and 0.25 kg^{-1}, respectively.

Meat analyses

The LD samples were thawed in vacuum-package bags for 24 h at 4°C, removed from the packages, blotted dry for 20 min, and weighed. Thawing losses were calculated by dividing the difference in weight between the fresh and thawed samples by the initial fresh weight. Meat colour was evaluated with a colorimeter (Model CM 2002; Minolta Camera, Osaka, Japan)

using objective measurements (CIE, 1976) with illuminant D65, 10º Standard Observer. The colorimeter was previously calibrated against a white tile according to manufacturer recommendations. The average of three random readings was used to measure lightness (L*, a higher value is indicative of a lighter colour), redness (a*, a higher value is indicative of a redder colour) and yellowness (b*, a higher value is indicative of a yellower colour). Additionally, chroma (c*) and hue angle (Hº) were calculated as $c^* = \sqrt{(a^{*2} + b^{*2})}$ and as H° = arctg (b*/a*), respectively, being indicative of the intensity of the colour (Wyszcecki and Stiles, 1982).

Cooking losses were determined by the method described by Honikel (1998). Briefly, a LD slice (200 ± 20 g) was taken from each chop, weighed, placed in a plastic bag, and cooked to an internal temperature of 70ºC in a 75ºC water bath (Precisterm J.P., Selecta S.A., Barcelona, Spain). Internal temperature was monitored during cooking with a handheld temperature probe (model HI 9063, Hanna Instruments, Woonsocket, RI). Cooked samples were allowed to cool at 15ºC for 30 min, blotted dry, and weighed. The difference between pre- and post-cooking weights was divided by the pre-cooked weight to calculate cooking losses percentage. To determinate shear force value, samples were cut parallel to the long axis of the muscle fibres into rectangular cross-section slices, 10 × 10-mm and 30-mm length. Afterwards, slices (8/chop) were sheared perpendicular to the fibre orientation, with a Warner-Bratzler device attached to an Instron Universal testing machine attached to a PC (Model 5543, Instron Ltd, Buckinghamshire, UK), and equipped with a 5-kg load cell and a crosshead speed of 150 mm min^{-1}.

Intramuscular fat and fatty acid analyses

The fatty acids (FA) of the diet were quantified by the one-step procedure described by Sukhija and Palmquist (1988) in lyophilized samples. Pentadecenoic acid (C15:1) (Sigma, Alcobendas, Madrid, Spain) was used as internal standard. Previously methylated fatty acid samples were identified according to Rey *et al.* (1997) using a gas chromatograph (Model HP6890; Hewlett Packard Co., Avondale, PA, USA) and a 30 m × 0.32mm × 0.25 µm cross-linked polyethylene glycol capillary column (Hewlett Packard Innowax). A temperature program of 170-245°C was used. The injector and detector were maintained at 250°C. The carrier gas (helium) flow rate was 3 mL min^{-1}. Fat from the LD muscle and the liver samples was obtained according to method developed by Marmer and Maxwell (1981). Fat extracts were methylated in the presence of sulphuric acid and analysed as described above. From individual FA percentages, the saturated FA (SFA), monounsaturated FA (MUFA), and polyunsaturated FA (PUFA) proportions were calculated.

Statistical analyses

The pen was the experimental unit for analysis of ADFI, FC, cost per kg of live weight and cost per kg of carcass weight, whereas the pig was the experimental unit for the remaining dependent variables. Data were analysed using the GLM procedure of SAS (1990). The model included the dietary treatment as main effect and the initial weight of pigs as covariate when $P < 0.05$ for the growth performance variables. Shaphiro and Wilk (1965) test was used to evaluate the normal distribution of the data carrying out the transformation arc sin $(x/100)^{0.5}$ for those whose distribution was not normal. Data in tables are presented as means. In order to estimate the relationships between IMF in LD muscle and the major FA proportion, regression analysis was carried out. Pearson correlations (r) were calculated between LD muscle traits and IMF in LD and main FA proportion in IMF of LD using the CORR procedure of SAS (1990).

Results and discussion

The effect of dietary treatment on pig performance and carcass characteristics is shown in Table 2. No differences were observed for the growth performance or carcass traits between pigs fed control diet and those fed granulated barley except for FC, which was higher ($P < 0.01$) in pigs fed granulated barley. However, the production costs per kg of live ($P < 0.001$) and carcass ($P < 0.01$) weight were lower in pigs that consumed granulated barley than in those which consumed control diet. This result is especially interesting for pig producers because the cost in heavy pigs is very important during the finishing period, especially in feeding, and a diet based on barley would provide a cheaper feedstuff, taking account that a possible supplementation of vitamins and minerals could be required. The feeding

Table 2. Growth performance, carcass characteristics and cost of production according to dietary treatment

	Control diet	Granulated barley	SE[a]	*P*[b]
Growth performance				
Initial weight (kg)	84.6	88.5	2.22	
Slaughter weight (kg)	129.1	130.4	3.81	
Average daily gain (kg d^{-1})	0.71	0.67	0.030	
Average daily feed intake (kg d^{-1})	3.20	3.41	0.096	
Feed conversion ratio (kg kg^{-1})	4.52	5.11	0.142	**
Carcass traits				
Carcass weight (kg)	104.3	103.7	3.11	
Carcass yield (%)	80.8	79.5	0.55	
Fat thickness (mm)				
At tenth rib	25.6	27.1	1.16	
At Gluteus medius muscle	24.3	24.1	1.19	
Carcass size (cm)				
Carcass inner length	87.4	86.5	0.73	
Ham perimeter	75.8	76.1	0.10	
Ham length	39.1	39.1	0.32	
Carcass compactness[c]	1.20	1.20	0.032	
Primal lean cut weight (kg)				
Ham	13.3	12.9	0.38	
Shoulder	8.0	8.0	0.22	
Loin	3.1	3.0	0.10	
Total[d]	24.5	23.9	0.66	
Primal lean cut yield (% carcass)				
Ham	12.8	12.4	0.13	
Shoulder	7.7	7.7	0.12	
Loin	2.9	2.9	0.06	
Total[d]	23.5	23.1	0.23	
Production cost (€)				
Per kg of live weight	1.39	1.30	0.014	***
Per kg of carcass weight	1.73	1.63	0.018	**

[a] SE: standard error of the mean. [b] *P*: statistical significance. **: $P < 0.01$, *** $P < 0.001$. [c] Carcass weight (kg)/carcass inner length (cm). [d] Ham + Shoulder + Loin.

cost per kilo of live weight during the experimental period was € 1.44 and 1.27 for pigs that received control diet and granulated barley, respectively.

No differences were observed between treatments for the variables L*, shear force, and cooking losses (Table 3). However, meat from the pigs fed granulated barley had higher a* ($P < 0.001$), b* ($P < 0.05$) and c* ($P < 0.05$) values and lower H^0 value ($P < 0.001$) and thawing losses ($P < 0.05$) than meat from pigs fed control diet. This data would confirm results reported by Latorre *et al.* (2008b) who found that FC was positive correlated with a* and b* in three pig genotypes. Also, the IMF in LD muscle tended to be higher ($P = 0.07$) in pigs fed granulated barley than in pigs fed control diet. This result is important for consumers because a higher IMF has been associated with more juiciness and greater acceptability of the meat (Barton-Gade, 1987). The increase in IMF content in pigs fed diets with a reduced protein:digestible energy ratio was also observed in other studies. Thus, Kerr *et al.* (1995) reported that feeding pigs with reduced protein diets during the weaner-grower and finishing periods resulted in a higher marbling score compared with pigs fed a high protein diet. Cisneros *et al.* (1996) found that feeding pigs an aminoacid-deficient diet during the late finishing phase (3-5 weeks pre-slaughter) increased IMF level compared with the control pigs. Witte *et al.* (2000) also observed that protein-deficient diet during

Table 3. *Longissimus dorsi* muscle and liver traits according to dietary treatment

	Control diet	Granulated barley	SE[a]	*P*[b]
Longissimus dorsi traits				
Colour				
Lightness (L*)	50.9	52.2	0.25	
Redness (a*)	–1.7	-0.3	0.28	***
Yellowness (b*)	12.9	13.9	0.31	*
Chroma (c*)	13.1	14.0	0.30	*
Hue angle (H°)	97.8	91.8	1.22	***
Water holding capacity (%)				
Thawing losses	10.7	9.2	0.48	*
Cooking losses	16.3	15.5	0.78	
Shear force (kg)	2.7	2.7	0.13	
Intramuscular fat (%)	1.7	2.1	0.15	+
Liver traits				
Fat content (%)	2.9	2.6	0.22	

[a] SE: standard error of the mean. [b] *P*: statistical significance. +: $P < 0.10$, *: $P < 0.05$, *** $P < 0.001$.

the finishing period increased IMF percentage of meat and D'Souza *et al*. (2003) reported that pigs fed the 15 and 30% reduced protein:digestible energy diets had significantly higher IMF levels compared with pigs fed the conventional diet. At the same time, D'Souza *et al*. (2003) also found that the vitamin A restriction in the diet increased IMF percentage in the LD muscle, although Olivares *et al.* (2009a) did not observe any effect. It seems that the influence of vitamin A on IMF deposition is mediated by retinoic acid, a derivative of vitamin A, which regulates the adipogenic differentiation of fibroblasts inhibiting the terminal differentiation of intramuscular adipose tissue (Kuri-Harcuch, 1982). It has also been indicated that retinoic acid is related to the regulation of the growth hormone gene expression (Bedo *et al.*, 1989), which in turn decreases IMF deposition. Therefore, deficiencies in vitamin A in the diet might result in lower growth hormone concentrations and in an increased IMF percentage.

Correlation coefficients calculated between IMF in the LD muscle and carcass weight, fat thickness at the level of the tenth rib and fat thickness at the level of the GM muscle were $r = 0.31$ ($P = 0.09$), $r = 0.42$ ($P < 0.01$) and $r = 0.32$ ($P = 0.06$), respectively (data not shown). Latorre *et al.* (2009a) found that IMF of LD muscle increased linearly as BW increased in Duroc × (Large White × Landrace) pigs slaughtered from 120 to 140 kg BW. In the same muscle, Mayoral *et al.* (1999) observed a slight change in IMF in Iberian pigs from 120 to 150 kg BW, and Daza *et al*. (2005) did not observe a clear influence of backfat increase on the IMF content in heavy pigs. A study conducted by D'Souza *et al*. (2002) on loin characteristics reported that the IMF of gilts did not significantly change between 16 and 25 weeks of age, which suggests that the rate of IMF deposition to lean muscle tissue deposition in the LD muscle for the finishing period remained constant. In other experiments, D'Souza *et al*. (2003) and Latorre *et al.* (2004) observed no significant relation between backfat thickness and IMF whereas Huff-Lonergan *et al.* (2002) found a positive but moderate significant correlation between IMF and BF in Berkshire × Yorkshire pigs. The reason for the discrepancies among the authors could probably be related to the range of slaughter weight studied and the genotype of pigs.

The FA profile of IMF from LD muscle according to dietary treatment is shown in Table 4. No difference between treatments was found in ΣSFA ($P > 0.05$). The ΣMUFA percentage was higher ($P < 0.01$) in pigs that consumed granulated diet than in those that consumed control diet due to the higher ($P < 0.01$) content in C18:1n-9. The IMF of pigs fed granulated barley showed lower ($P < 0.05$) ΣPUFA than that from pigs fed control diet because of the lower proportions in C18:2n-6 ($P < 0.01$), C18:2n-3 ($P < 0.001$) and C20:3n-9 ($P < 0.01$). Therefore, Σn-6 and Σn-3 were lower ($P < 0.05$) and SFA/PUFA was higher ($P < 0.05$) in pigs fed barley than in pigs fed control diet. The higher

Table 4. Fatty acid profile (%) of intramuscular fat from *Longissimus dorsi* muscle according to dietary treatment[a]

	Control diet	Granulated barley	SE[b]	*P*[c]
C10:0	0.09	0.10	0.020	
C12:0	0.08	0.07	0.005	
C14:0	1.37	1.32	0.037	
C16:0	24.11	24.03	0.262	
C16:1n-7	3.04	3.18	0.113	
C17:0	0.19	0.15	0.009	**
C17:1	0.19	0.15	0.007	***
C18:0	13.26	12.53	0.301	
C18:1n-9	45.79	48.38	0.562	**
C18:2n-6	8.39	6.86	0.363	**
C18:3n-3	0.41	0.31	0.017	***
C20:0	0.19	0.18	0.006	
C20:1n-9	0.80	0.78	0.017	
C20:3n-9	0.34	0.29	0.012	**
C20:4n-6	1.27	1.24	0.134	
C20:5n-3	0.21	0.19	0.015	
C22:5n-3	0.20	0.19	0.018	
ΣSFA	39.30	38.39	0.471	
ΣMUFA	49.82	52.49	0.562	**
ΣPUFA	10.83	9.08	0.533	*
Σn-6	9.66	8.10	0.474	*
Σn-3	0.83	0.69	0.043	*
ΣSFA/ΣPUFA	3.72	4.55	0.251	*
Σn-6/Σn-3	11.64	11.80	0.132	

[a] ΣSFA, ΣMUFA, ΣPUFA, Σn-6, Σn-3: addition of all saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), n-6 and n-3 fatty acids, respectively. [b] SE: standard error of the mean. [c] *P*: statistical significance. *: $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

C18:1n-9 and ΣMUFA proportion found in the LD muscle from pigs fed granulated barley could be explained because the activity of stearoyl-CoA-desaturase enzyme increased when they were administered rations with low fat content (Wirth *et al.*, 1980) or rich in carbohydrates (Enser, 1975). Moreover, according to a study by Olivares *et al*. (2009b), the vitamin A reduction in the ration led to an increase of C18:1n-9 and ΣMUFA proportions in IMF from the LD muscle of Duroc × (Large White × Landrace) pigs, which agrees with the results of the present experiment.

Table 5. Relationships between intramuscular fat percentage (IMF) and the major fatty acids proportion in *Longissimus dorsi* muscle

Regression equations	R^{2a}	RSD[b]	*P*[c]
IMF = – 4.432 + 0.262 · C16:0	0.18	0.60	**
IMF = + 2.963 – 0.0840 · C18:0	0.0027	0.66	
IMF = – 6.610 + 0.180 · C18:1n-9	0.51	0.47	***
IMF = + 6.990 – 2.541 · ln C18:2n-6	0.78	0.31	***

[a] R^2: coefficient of determination. [b] RSD: residual standard deviation. [c] *P*: statistical significance. ** $P < 0.01$, *** $P < 0.001$.

The relationships between IMF percentage in the LD muscle and the proportion of major FA in the same muscle were calculated using regression equations (Table 5). The IMF increased when C16:0 ($P < 0.01$) or C18:1n-9 ($P < 0.001$) proportions increased and when C18:2n-6 proportion decreased ($P < 0.001$). Olivares *et al*. (2009b) observed a positive and significant relationship between IMF and ΣSFA proportion in LD muscle from heavy Duroc × (Large white × Landrace) pigs, and Courbalay and Massabie (1996) found positive and negative relationships between backfat thickness and ΣSFA and ΣPUFA proportions, respectively.

In order to establish relationships between characteristics of meat and IMF and major FA proportion in IMF from the LD muscle, Pearson correlations were calculated (Table 6). A negative correlation ($P < 0.05$) was found between IMF and shear force indicating that meat with higher marbling is also tenderer. Negative correlation coefficients ($P < 0.05$) were also obtained between a* and C18:0 and C18:2n-6 proportions, while the correlation coefficients between a* and IMF

Table 6. Pearson's correlation coefficients between shear force and colour variables and intramuscular fat (IMF) percentage and major fatty acids proportion in *Longissimus dorsi* muscle

	IMF	C16:0	C18:0	C18:1n-9	C18:2n-6
Shear force	–0.34*	–0.28	–0.01	–0.04	0.18
Lightness (L*)	0.21	0.06	–0.13	0.17	–0.17
Redness (a*)	0.38*	0.08	–0.39*	0.46**	–0.42*
Yellowness (b*)	0.52**	0.34*	–0.11	0.35*	–0.53**
Chroma (c*)	0.52**	0.35*	–0.10	0.34*	–0.56**
Hue angle (H^0)	–0.39*	–0.10	0.37*	–0.44*	0.42*

* $P < 0.05$. ** $P < 0.01$.

($P < 0.05$) and C18:1n-9 ($P < 0.01$) proportion were positive. These results agree with data from Ventanas *et al.* (2007). The correlation coefficients between b* or c* and IMF in the LD muscle ($P < 0.01$) and C16:0 and C18:1n-9 proportions ($P < 0.05$) were positive, whereas the correlation coefficients between C18:2n-6 proportion and b* and c* were negative ($P < 0.01$). The H° was negatively correlated with IMF percentage and C18:1n-9 proportion and positively correlated with C18:0 and C18:2n-6 proportions ($P < 0.05$). It indicates that meat with higher saturation of colour usually shows higher marbling in which stearic and linoleic acids are especially important.

A profile of FA of liver fat is presented in Table 7. The dietary treatment in this case had no significant influence on the fatty acid composition of liver fat. However, Otten *et al.* (1993) reported that the fatty acid profile of liver fat is related to the fatty acid pattern of plasma which depends in turn partially on the feeding given. Therefore, the pig liver had little capacity of fatty acid synthesis.

Table 7. Fatty acid profile (%) of liver fat according to dietary treatment[a]

	Control diet	Granulated barley	SE[b]	*P*[c]
C10:0	0.17	0.18	0.020	
C12:0	0.05	0.06	0.008	
C14:0	0.97	0.83	0.065	
C15:1	0.40	0.37	0.058	
C16:0	22.30	21.47	0.541	
C16:1n-7	2.61	2.42	0.162	
C17:0	0.54	0.58	0.036	
C17:1	0.31	0.27	0.016	
C18:0	21.41	23.36	1.303	
C18:1n-9	31.93	30.12	1.511	
C18:2n-6	11.64	11.62	0.662	
C18:3n-3	0.52	0.45	0.045	
C18:4n-3	0.11	0.08	0.023	
C20:0	0.16	0.17	0.013	
C20:1n-9	0.33	0.30	0.012	
C20:3n-9	0.25	0.24	0.015	
C20:4n-6	5.17	6.12	0.703	
C20:5n-3	0.31	0.37	0.043	
C22:5n-3	0.52	0.63	0.084	
C22:6n-3	0.28	0.31	0.047	
ΣSFA	45.61	46.66	1.171	
ΣMUFA	35.58	33.49	1.712	
ΣPUFA	18.81	19.85	1.503	
Σn-6	16.82	17.75	1.314	
Σn-3	1.75	1.86	0.185	
ΣSFA/ΣPUFA	2.76	2.61	0.262	
Σn-6/Σn-3	9.97	10.20	0.391	

[a] ΣSFA, ΣMUFA, ΣPUFA, Σn-6, Σn-3: addition of all saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), n-6 and n-3 fatty acids, respectively. [b] SE: standard error of the mean. [c] *P*: statistical significance.

It is concluded that the use of barley as single ingredient in the diet provided during the finishing period may increase the IMF percentage, the C18:1n-9 proportion in IMF and some variables of meat colour. Also, the production costs were lower in pigs that consumed granulated barley than in those which consumed control diet. Therefore, a diet based on barley would provide a cheaper feedstuff, although a possible supplementation of vitamins and minerals should be taken account. As this is very interesting for the producers, further studies would be desirable, for example with adequate calcium, phosphorus and/or vitamin A supplementations.

Acknowledgements

This research was supported by Project PET-2007-08C11-05 (INIA, Spain). Appreciation is expressed to Elifio Feliz de Vargas and Itziar Garitano (El Chantre, Teruel, Spain) for the care and control of experimental animals.

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