Animal (2014), **8:3**, pp 484–493 © The Animal Consortium 2014
doi:10.1017/S1751731113002292

The effect of immunocastration and a diet based on granulated barley on growth performance and carcass, meat and fat quality in heavy gilts

A. Daza[1], M. A. Latorre[2†], A. Olivares [3] and C. J. López-Bote[3]

[1]*Escuela Técnica Superior de Ingenieros Agrónomos, Universidad Politécnica de Madrid, Ciudad Universitaria, 28040 Madrid, Spain;* [2]*Facultad de Veterinaria, Universidad de Zaragoza, Avda, Miguel Servet, 177, 50013 Zaragoza, Spain;* [3]*Facultad de Veterinaria, Universidad Complutense de Madrid, Ciudad Universitaria, 28040 Madrid, Spain*

(Received 18 June 2013; Accepted 29 November 2013; First published online 7 January 2014)

A total of 48 Duroc × (Landrace × Large White) gilts of 33.2 kg BW were used to investigate the influence of immunocastration and diet on growth performance and carcass, meat and fat quality. Four treatments were arranged factorially (2 × 2) with two sexes (immunocastrated gilts: IG v. *entire gilts: EG) and two dietary treatments (a commercial feedstuff as control* v. *granulated barley as a single major ingredient) provided during the finishing period (from 103 to 126 kg BW). There were four replicates of three pigs per treatment. At the end of the trial, the IGs grew faster (*$P < 0.05$*) and ate more feed (*$P < 0.05$*) than the EGs. Carcasses from the IGs had thicker backfat depth than those from the EGs (*$P < 0.01$*) and carried out a lower percentage of rejected carcasses (*$P < 0.05$*) at slaughterhouse owing to lack of fat. Meat from the IGs tended to have higher intramuscular fat (IMF) content in the* Longissimus thoracis *(LT) muscle than that from the EGs (*$P = 0.09$*). In addition, immunocastration increased the total saturated fatty-acid proportion in subcutaneous fat and IMF (*$P < 0.001$*) and decreased the total monounsaturated fatty acid (MUFA) and total polyunsaturated fatty acid (PUFA) percentages in subcutaneous backfat (*$P < 0.05$* and $P < 0.001$*, respectively) and in IMF (*$P < 0.01$* and $P = 0.06$*, respectively). The use of a diet based on granulated barley during the finishing period had no effect on growth performance but tended to increase IMF content in the LT muscle (*$P < 0.06$*), and increased MUFA (*$P < 0.05$*) and decreased PUFA (*$P < 0.01$*) proportions in omental fat. It is concluded that immunocastration of gilts intended for dry-cured ham industry improved some aspects of growth performance and carcass and meat quality, whereas granulated barley had scarce effect on productive traits and fatty-acid profile but tended to improve IMF content.*

Keywords: gilt immunocastration, barley, performance, carcass quality, fat

Implications

In the Mediterranean area, fatter pigs are desirable to elaborate dry-cured products. Gilts generally exhibit lower carcass and muscle fat content in comparison with barrows. The surgical castration of gilts could resolve it, but it also has negative effects on animal welfare. Immunocastration thus appears as an interesting alternative. Besides, a barley-based diet inducing a reduction in the CP/energy ratio has been shown to increase carcass fatness. Therefore, immunocastration of gilts and the use of barley as a single major ingredient in the diet might be two strategies aiming to improve carcass fatness in gilts.

† E-mail: malatorr@unizar.es

Introduction

In Spain, the industry that manufactures dry-cured products (ham, shoulder and loin) requires heavy pigs (>100 kg BW), a minimum level of fat thickness over the *Gluteus medius* (GM) muscle (>16 mm), and a minimum C18:2n-6 proportion in subcutaneous backfat (<15%) to improve the uniformity and quality of the end-products. In several studies, Latorre *et al.* (2008 and 2009a) concluded that a significant proportion of gilt carcasses are rejected at slaughterhouse because they did not reach the minimum fat depth required, which carries out an important economic problem for producers.

Several management and nutritional strategies have been tried to increase carcass backfat depth in heavy gilts and also intramuscular fat (IMF) percentage in pork. According to

Peinado *et al*. (2011 and 2012), the surgical castration might be a strategy, but it also carries out negative consequences on animal welfare. For that, currently, the immunocastration against GnRH appears as an interesting chance. In Iberian pigs, which is a Spanish autochthonous fatty pig breed, Gómez-Fernández *et al.* (2013) observed that immunocastration provided better growth performance than surgical castration in gilts. However, although there are several reports on the influence of immunocastration in male pigs on productive results and meat quality (Pauly *et al*., 2009; Fábrega *et al*., 2010), the information about gilts is more scarce.

On the other hand, D'Souza *et al.* (2003) observed that pigs fed diets with 15% and 30% reduced CP : digestible energy ratio or with reduced vitamin A level had higher IMF content in the *Longissimus thoracis* (LT) muscle compared with pigs fed conventional diets. In addition, Daza *et al.* (2010 and 2012a) found that the replacement of the commercial feed by granulated barley as a single ingredient during the finishing period led to enhanced IMF content and its C18:1n-9 proportion. The use of barley in such a great proportion means a reduction in CP : energy ratio and a deficiency in vitamin A regarding the requirements for pigs of that BW.

Therefore, the aim of this study was to investigate the effect of immunocastration in gilts, the replacement of a conventional feed by granulated barley as the only main ingredient during the finishing phase, and their interaction on growth performance and carcass, meat and fat quality.

Material and methods

Animal husbandry and feeding management

All the experimental procedures used in this study were in compliance with the Spanish guidelines for the care and use of animals in research (Boletin Oficial Estado, 2007). A total of 48 Duroc × (Landrace × Large White) gilts of 33.2 kg BW (62 ± 3 days of age) were used. Before the trial, all pigs came from the same farm where they had the same feeding and management. On arrival at the experimental facilities (El Chantre, Teruel, Spain), gilts were individually weighed and were randomly allotted to 16 pens of three pigs each, according to the BW.

From the beginning of the trial (day 0) to 72 days later, all animals received a commercial cereal–soya bean meal diet containing 14.02 MJ of digestible energy/kg, 15.8% CP and 1.02% of total lysine. During that period, a total of 24 gilts, from eight pens, were vaccinated twice against GnRH with Improvac (Pfizer, Madrid, Spain), at days 0 and 28 (with 33.2 and 57.4 kg BW, respectively). The vaccination protocol followed the recommendations of Pfizer Company.

From day 72 of the trial up to slaughter at day 97, two feeding treatments (control diet *v.* granulated barley: GB) were provided. The control feedstuff was a commercial diet based on cereals and vegetable meals and the GB feedstuff consisted of barley as the only main ingredient in the diet. Therefore, there were four treatments including two sexes (entire gilts: EG *v.* immunocastrated gilts: IG) and two diets (control *v.* GB). Each treatment was replicated four times and the replicate was a pen with three pigs.

Table 1 *Composition of experimental diets used for heavy gilts from 103 to 126 kg BW (g/kg as fed, unless otherwise indicated)*

	Control diet	Granulated barley diet
Ingredient composition		
Barley	536.8	986.0
Wheat	200.0	–
Rapeseed meal	130.0	–
Sunflower meal	40.0	–
Wheat flour	40.0	–
Blended fat[a]	12.5	–
Molasses sugarcane	10.0	–
Sepiolite	–	10.0
Calcium carbonate	13.34	2.00
Dicalcium phosphate	2.66	–
Sodium chloride	4.50	2.00
L-Lysine 50%	0.55	–
DL-Methionine 99%	0.58	–
L-Threonine	7.07	–
Vitamin and mineral premix[b]	2.00	–
Estimated nutrient composition[c]		
Digestible energy (MJ/kg)	13.74	12.10
Chemical nutrient composition[d]		
Dry matter	883.3	899.9
CP (N × 6.25)	139.1	115.6
Crude fat	32.1	18.7
Crude fibre	51.3	44.9
Fatty acids (g/100g total fatty acids)		
C14:0	0.29	0.18
C16:0	4.14	3.15
C18:0	1.31	0.24
C18:1n-9	4.98	1.75
C18:2n-6	16.34	7.71
C18:3n-3	2.99	0.71

[a]Mixture of fat from cattle and pig.
[b]Supplying per kg diet: 8000 IU of vitamin A, 1000 IU of vitamin D_3, 15 IU of α-tocopherol acetate and 10 mg of copper sulphate.
[c]According to Fundación Española Desarrollo Nutrición Animal (2010).
[d]According to Association of Official Analytical Chemists (2000).

Pigs were housed in 30% slatted floor pens (2.30 × 2.60 m) in a controlled environment barn and had free access to pelleted diets and water throughout the trial. Composition of the experimental diets is shown in Table 1. Chemical analysis of feeds was carried out according to Association of Official Analytical Chemists (2000) procedures.

Growth performance

Individual BW and feed consumption per pen were recorded at day 0 (beginning of the trial and 1st Improvac vaccine), at day 28 (2nd Improvac vaccine), at day 72 (beginning of dietary treatment) and at day 97 (end of the trial). Those data were used to calculate average daily gain (ADG), average daily feed intake (ADFI), and feed conversion ratio (FCR) per period and replicate. In addition, ultrasonic measurements of fat thickness were taken at days 28, 72 and 97 on the right

side of all animals at the last rib level by the same operator, measuring over the skin without clipping the fleece using an ultrasound RTU apparatus (600V-V2.232; Kretz Technick Inc., Sonovet, Austria). Animals were slaughtered at heavy BW (around 126 kg BW and 159 ± 3 days of age) for processing into dry-cured products.

Slaughter, carcass measures, and meat and fat sampling
The day before slaughter, feed was withdrawn 7 h before weighing and transportation of pigs to a commercial abattoir. There, animals were kept in lairage for 10 h with full access to water but not to feed and were slaughtered 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 1st 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. In addition, backfat thickness was measured at the levels of the 10th rib and over the GM muscle. Carcass compactness was then calculated as carcass weight/carcass length and the proportion of rejected carcasses was calculated using the fat thickness at GM level (<16 mm) as the criterion. After those measures, omental fat samples (53 ± 5 g) were collected from the left side of each carcass for posterior analyses.

After refrigeration at 2°C (1 m/s; 90% relative humidity) for 2 h, carcasses were processed according to commercial standards. The ham, shoulder and loin from the right side of each carcass were trimmed to fit commercial requirements, and individually weighed to calculate their yields. After the carcass had been processed, a section of 500 ± 20 g of the LT muscle excised at the level of the last rib from each left loin was excised. Subcutaneous fat samples (58 ± 7 g) including the fat layers, skin and lean were also taken at the tail insertion in the coxal region. All the meat and fat samples were vacuum-packaged in individual bags and stored at −20°C until subsequent analyses.

Colour of subcutaneous fat and LT muscle
Just after muscle sampling at slaughterhouse, the colour of subcutaneous backfat and LT muscle was measured as described by Latorre *et al.* (2009b) using objective measurements (L^*, a^*, b^*, C^* and h^o), according to Commission International de l'Eclairage (1976). Measurements were taken using a colourimeter (Model CM 2002; Minolta Camera, Osaka, Japan), with illuminant D65 and 10° Standard Observer, which was previously calibrated against a white tile according to the manufacturer's recommendations.

Fatty-acid analyses of feeds and fat
The fatty acids (FA) of diets were extracted and 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 FA 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 × 0.32 mm × 0.25 μm cross-linked polyethylene glycol capillary column (Hewlett Packard Innowax, Avondale, PA, USA). A temperature programme of 170°C to 245°C was used. The injector and detector were maintained at 250ºC. The carrier gas (helium) flow rate was 3 ml/min.

Lipids from subcutaneous and omental fat were extracted by the procedure proposed by Bligh and Dyer (1959), whereas lipids from the LT muscle were obtained, according to the method developed by Marmer and Maxwell (1981). Fat extracts were methylated in the presence of sulphuric acid and analysed as described above.

Statistical analyses
Data were analysed as a completely randomized design with treatments arranged factorially (2 × 2) using the SPSS-14 statistical package. The model included the sex (IG *v.* EG) and dietary treatment (control *v.* GB) as main effects, the interaction sex × diet, and the initial BW of pigs, initial backfat depth by ultrasound or carcass weight as covariates when $P < 0.05$, for growth performance, backfat depth measures or carcass characteristics, respectively. The least significant difference test was used to compare means or lsmeans. The pen was the experimental unit for the statistical analysis of productive performance traits, whereas the pig was the experimental unit for the remaining dependent 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 (ham, shoulder and loin yields, as well as percentage of rejected carcasses because of low fatness).

Results

One pig died at the beginning of the trial, but it was not related to experimental treatments (data not shown). No relevant interaction was detected for the variables studied and then, except for the FA profile of omental fat, only main effects of sex and diet are presented.

Growth performance
From day 0 (1st Improvac vaccine) to day 28 of the trial, no influence of immunocastration was observed ($P > 0.10$; Table 2). However, from day 28 (2nd Improvac vaccine) to day 72 of the trial, the IGs grew faster ($P < 0.01$), ate more feed ($P < 0.05$) and were more efficient ($P < 0.01$) than EGs. Therefore, at the end of that period, IGs were heavier ($P < 0.01$) and fatter ($P < 0.05$). From day 72 (beginning of the experimental diets) to day 97 of the trial, the IGs had higher FCR than EGs ($P < 0.05$) because they had higher ADFI ($P < 0.05$) and similar ADG ($P > 0.10$). During that time, the dietary treatment had no effect on daily growth but gilts fed GB diet tended to show higher ADFI ($P = 0.07$) and FCR ($P = 0.09$) and had thicker fat depth ($P < 0.05$) than those fed control diet. At the end of the trial, the experimental diet did not modify any variable studied ($P > 0.10$) but the IGs had

Table 2 *The effect of sex and diet on productive performance traits and subcutaneous fat depth*

	Sex		Diet			*P*-value[b]	
	EG	IG	Control	GB	s.e.m.[a]	Sex	Diet
BW (kg)							
At day 0 (vaccination 1)	32.8	33.5	34.1	32.3	0.63	ns	+
At day 28 (vaccination 2)	57.3	57.6	57.2	57.7	0.73	ns	ns
At day 72 (beginning of experimental diet)	100.4	105.9	102.8	103.5	1.19	**	ns
At day 97 (slaughter)	123.7	129.5	126.2	127.0	1.51	*	ns
From 33 to 57 kg BW (0 to 28 days of trial)							
ADG (g/day)	859	875	865	869	23.2	ns	ns
ADFI (kg/day)	2.06	2.05	2.12	1.99	0.028	ns	**
FCR	2.41	2.35	2.45	2.30	0.062	ns	ns
From 57 to 103 kg BW (28 to 72 days of trial)							
ADG (g/day)	990	1.088	1.012	1.066	21.4	**	ns
ADFI (kg/day)	2.71	2.91	2.78	2.85	0.053	*	ns
FCR	2.77	2.65	2.74	2.68	0.029	**	ns
From 103 to 126 kg BW (72 to 97 days of trial)							
ADG (g/day)	932	942	936	939	20.7	ns	ns
ADFI (kg/day)	3.25	3.55	3.29	3.51	0.083	*	+
FCR	3.49	3.77	3.52	3.75	0.093	*	+
From 33 to 126 kg BW (0 to 97 days of trial)							
ADG (g/day)	937	989	950	976	15.3	*	ns
ADFI (kg/day)	2.67	2.83	2.72	2.77	0.051	*	ns
FCR	2.84	2.86	2.86	2.84	0.038	ns	ns
Subcutaneous fat depth (mm)[c]							
At day 28	9.17	9.58	9.54	9.20	0.324	ns	ns
At day 72	14.9	16.0	15.0	15.9	0.39	*	ns
At day 97	20.6	24.5	21.5	23.7	0.65	***	ns

EG = entire gilts; IG = immunocastrated gilts; control = commercial diet; GB = granulated barley as only main ingredient; ADG = average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio.
Data presented are lsmeans.
[a]Standard error of the mean, calculated using $n = 8$ pens as experimental units per main effect of sex or diet.
[b]ns: not significant ($P > 0.10$); $^{+}P < 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$. No significant interaction (sex × diet) was found.
[c]Measures taken *in vivo* by ultrasounds.

higher ADG (+5.5%, $P < 0.05$) and ADFI (+6.0%, $P < 0.05$) than the EGs. The IGs were also heavier (+5.8 kg, $P < 0.05$) and fatter (+19% backfat depth, $P < 0.001$) at slaughter than the EGs.

Carcass quality

The carcasses from IGs were heavier than those from EGs ($P < 0.05$); however, no effect of immunocastration was detected on dressing percentage and dimensions of carcass and ham ($P > 0.10$; Table 3). A lower proportion of carcasses were rejected at slaughterhouse owing to lack of fat depth in the IG group (4.2% *v.* 26.2%; $P < 0.05$). In fact, the IGs had fatter carcasses than the EGs at both the 10th rib ($P < 0.05$) and GM muscle level ($P < 0.01$). In addition, the IGs had lower loin weight and yield ($P < 0.05$ and 0.01, respectively) than the EGs.

The carcasses from gilts fed GB diet tended to be longer ($P = 0.06$) and had lower compactness ($P < 0.05$) than those from gilts fed control diet. The yield of total main lean joints (ham + shoulder + loin) was lower when GB was consumed ($P < 0.05$) and it was because of the lower ham ($P = 0.07$) and loin ($P < 0.05$) proportions.

Meat characteristics and subcutaneous fat colour

The immunocastration had no influence on the colour of the LT muscle or subcutaneous fat ($P > 0.10$) (data not shown). Nevertheless, meat from IGs tended to have higher IMF proportion than meat from EGs ($P = 0.09$; Table 3). The dietary treatment did not modify LT muscle colour ($P > 0.10$) but loin from gilts fed GB diet tended to show the highest IMF content ($P = 0.06$). In addition, subcutaneous fat from gilts given diet based on GB tended to show higher b^* value ($P = 0.06$) than that from gilts fed control diet.

Fatty-acid profile of subcutaneous fat

The total saturated fatty acid (SFA) proportion in backfat was higher in the IGs than in the EGs ($P < 0.001$) owing to the higher C12:0 ($P = 0.07$), C16:0 ($P < 0.01$) and C18:0 ($P < 0.001$) contents (Table 4). The total monounsaturated fatty acid (MUFA) percentage was lower in IGs than in EGs ($P < 0.05$) owing to the lower C16:1n-9 ($P = 0.06$), C18:1n-9 ($P = 0.10$) and C18:1n-7 ($P < 0.05$) contents. The total polyunsaturated fatty acid (PUFA) proportion was also lower in IGs than in EGs ($P < 0.001$) owing to the lower C18:2n-6 ($P < 0.001$), C18:3n-3 ($P = 0.08$), C20:4n-6 ($P < 0.05$) and

Table 3 *The effect of sex and diet on carcass characteristics and meat intramuscular fat content of heavy pigs*

	Sex		Diet			*P*-value[b]	
	EG	IG	Control	GB	s.e.m.[a]	Sex	Diet
Carcass weight (kg)	94.9	100.1	97.3	97.6	1.68	*	ns
Dressing percentage (%)	76.6	77.6	77.3	76.9	0.54	ns	ns
Carcasses rejected owing to low backfat depth (%)[c]	26.2	4.2	17.9	12.5	7.20	*	ns
Carcass traits[d]							
Carcass length (cm)	85.7	85.6	84.9	86.4	0.52	ns	+
Ham length (cm)	38.0	37.6	37.9	37.7	0.22	ns	ns
Ham perimeter (cm)	76.4	76.6	76.8	76.2	0.35	ns	ns
Carcass compactness[e]	1.14	1.14	1.15	1.13	0.007	ns	*
Fat thickness (mm)							
At 10th rib (mm)	27.8	31.0	29.1	29.8	0.90	*	ns
At *Gluteus medius* muscle (mm)	20.8	24.6	22.6	22.9	0.91	**	ns
Main joint yield (% carcass)[f]							
Ham	13.17	13.19	13.34	13.02	0.124	ns	+
Shoulder	7.66	7.55	7.65	7.56	0.085	ns	ns
Loin	5.75	5.43	5.73	5.46	0.079	**	*
Total	26.55	26.22	26.72	26.05	0.216	ns	*
Intramuscular fat content (%)[g]	4.26	4.99	4.21	5.04	0.305	+	+

EG = entire gilts; IG = immunocastrated gilts; control = commercial diet; GB = granulated barley as the only main ingredient.
Data presented are lsmeans.
[a]Standard error of the mean, calculated using $n = 24$ pigs as experimental units per main effect of sex or diet.
[b]ns = not significant ($P > 0.10$); $^{+}P < 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$. No significant interaction (sex × diet) was found.
[c]A minimum of 16 mm of backfat depth is required in Spain.
[d]Carcass length was measured from the posterior edge of the *Symphysis pubis* to the anterior edge of the 1st rib, ham length from the anterior edge of the *Symphysis pubis* to the hock joint and ham circumference at its widest side.
[e]Carcass weight (kg)/carcass length (cm).
[f]Data recorded from the right side of each carcass.
[g]Measured at the *Longissimus thoracis* muscle.

C20:5n-3 ($P < 0.05$) contents. The backfat from the IGs had lower n-6 ($P < 0.001$) and n-3 ($P < 0.05$) and also lower PUFA/SFA ratio ($P < 0.001$) than that from the EGs. In addition, fat from gilts fed GB diet had lower C18:1n-7 proportion than fat from gilts fed control diet ($P < 0.01$).

Fatty-acid profile of omental fat

In omental fat, the immunocastration increased C20:0 ($P < 0.05$) and reduced C16:1n-9 ($P < 0.05$) and C16:1n-7 ($P = 0.06$) contents, although SFA and MUFA were not affected ($P < 0.10$; Table 5). In addition, the C18:2n-6 and PUFA percentages and the PUFA/SFA ratio were lower in fat from IGs than that from EGs ($P < 0.05$). The use of barley as a major ingredient in finishing diet decreased C16:1n-9 ($P < 0.05$) and C17:1 ($P < 0.05$) contents and increased C18:1n-9 ($P < 0.01$), resulting in a higher MUFA proportion ($P < 0.05$). Some significant interactions sex × diet were detected ($P < 0.05$). In the EGs, the intake of GB diet reduced the proportions of C18:2n-6, C18:3n-3, n-6, n-3 and PUFA percentages and also the PUFA/SFA ratio ($P < 0.05$), whereas omental fat from the IGs was not affected by the dietary treatment.

Fatty-acid profile of IMF from the LT muscle

The SFA proportion in IMF of the LT muscle was higher in IGs than in EGs ($P < 0.001$) owing to the higher C12:0 ($P = 0.08$), C14:0 ($P = 0.09$), C16:0 ($P < 0.001$), C18:0 ($P < 0.001$) and C20:0 ($P < 0.05$) contents (Table 6). The MUFA and PUFA proportions in IMF were lower in IGs than in EGs ($P < 0.01$ and $P = 0.06$, respectively) owing to the lower C18:1n-9 ($P < 0.01$), C18:2n-6 ($P = 0.09$), C20:2n-9 ($P < 0.01$) and C20:4n-6 ($P < 0.05$). The IMF of the LT muscle from IGs had lower PUFA/SFA ratio ($P < 0.05$) than that from EGs. The dietary treatment had no effect on FA profile of IMF of loin ($P > 0.10$).

Discussion

Growth performance

Over the whole experimental period, the gilt immunocastration had led to increased ADG and ADFI but had no effect on FCR. However, it is observed that these effects are shown after the 2nd Improvac vaccine because there was no influence from day 0 to 28 (between 1st and 2nd injections). There is scarce information in the literature about immunocastration in gilts or comparing immunocastrated and surgically castrated gilts. Oliver *et al.* (2003) found that immunocastration led to a reduction in ovary weight and an increase in daily BW gain and feed intake. In a recent study, Gómez-Fernández *et al.* (2013) observed that Duroc × Iberian IG had higher ADG, ADFI and FCR than EG. On the other hand, Peinado *et al.* (2012) reported in (Pietrain × Large White) × (Landrace × Large White) gilts,

Table 4 *The effect of sex and diet on fatty-acid profile (%) of subcutaneous fat*[a]

	Sex		Diet			*P*-value[c]	
	EG	IG	Control	GB	s.e.m.[b]	Sex	Diet
SFA							
C12:0	0.002	0.012	0.009	0.004	0.0037	+	ns
C14:0	1.16	1.21	1.18	1.19	0.020	ns	ns
C16:0	23.21	24.33	23.55	23.99	0.251	**	ns
C17:0	0.26	0.27	0.26	0.27	0.012	ns	ns
C18:0	13.80	15.29	14.39	14.69	0.304	***	ns
C20:0	0.24	0.26	0.24	0.26	0.013	ns	ns
Total SFA	38.7	41.4	39.6	40.4	0.507	***	ns
MUFA							
C16:1n-9	0.33	0.30	0.32	0.30	0.011	+	ns
C16:1n-7	1.91	1.81	1.90	1.82	0.050	ns	ns
C17:1	0.26	0.26	0.26	0.25	0.012	ns	ns
C18:1n-9	42.27	41.44	42.06	41.65	0.345	+	ns
C18:1n-7	2.50	2.34	2.51	2.32	0.047	*	**
C20:1	1.11	1.14	1.12	1.13	0.035	ns	ns
Total MUFA	48.4	47.3	48.2	47.5	0.383	*	ns
PUFA							
C18:2n-6	11.29	9.87	10.63	10.53	0.256	***	ns
C18:3n-3	0.83	0.75	0.78	0.79	0.030	+	ns
C20:4n-6	0.67	0.60	0.62	0.64	0.021	*	ns
C20:5n-3	0.17	0.12	0.15	0.14	0.015	*	ns
Total PUFA	13.0	11.3	12.2	12.1	0.295	***	ns
PUFA/SFA	0.34	0.27	0.31	0.30	0.010	***	ns
n-6[d]	11.96	10.46	11.24	11.17	0.262	***	ns
n-3[e]	1.00	0.87	0.94	0.93	0.039	*	ns

EG = entire gilts; IG = immunocastrated gilts; control = commercial diet; GB = granulated barley as the only main ingredient; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.
Data presented are means.
[a]Samples taken at the tail insertion in the coxal region (58 ±7 g).
[b]Standard error of the mean, calculated using $n = 24$ pigs as experimental units per main effect of sex or diet.
[c]ns = not significant ($P > 0.10$); $^{+}P < 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$. No significant interaction (sex × diet) was found.
[d]n-6 = C18:2n-6 + C20:4n-6.
[e]n-3 = C18:3n-3 + C20:5n-3.

from 60 to 114 or 122 kg BW, and in Duroc × (Landrace × Large White) gilts, from 28 to 119 or 132 kg BW, that surgical castration had no influence on BW gain and ADFI, but impaired FCR. In another study, Serrano *et al.* (2008) observed in Duroc × Iberian gilts reared indoor from 25 to 145 or 156 kg of BW that, although surgical castration did not affect ADG, it increased ADFI and tended to enhance FCR. All these results suggest that both kinds of castration might carry out different effects on the performance of gilts probably because of the start-up time (being younger animals in the case of surgical castration).

The replacement of the control by the GB diet during the finishing period did not modify growth performance variables. However, in previous studies (Daza *et al.*, 2010 and 2012a), the GB diet had a negative effect on ADG and FCR, probably because of the low CP content of barley (Fundación Española Desarrollo Nutrición Animal, 2010). In the present trial, the concentration of CP in the barley used for feedstuff fabrication was very high (more than 13%) and the CP/digestible energy ration was slightly lower (9.55 *v.* 10.12) in the GB diet in comparison with the control diet, which can explain the results obtained on productive performance. In agreement, D'Souza *et al.* (2003) observed in pigs that a reduction in 15% of CP/digestible energy ratio in the diet of pigs during their growing period had no influence on ADG, ADFI and FCR in the growing and finishing phases.

Carcass quality

It has been reported that immunocastration of gilts increased carcass fatness (Oliver *et al.*, 2003), which is confirmed by the present data. Serrano *et al.* (2008) also observed that surgical castration of gilts increased subcutaneous fat thickness. Similar to productive traits, the results obtained by ultrasounds show that the influence of immunocastration on backfat depth was clear after the 2nd Improvac vaccine. As a consequence, at slaughterhouse, the percentage of rejected carcasses to elaborate dry-cured products was higher in EGs owing to their thinner fat thickness at the level of GM muscle. According to Walstra (1974), the castration affects

Table 5 *The effect of sex and diet on fatty-acid profile (%) of omental fat*[a]

	Sex		Diet			*P*-value[c]		
	EG	IG	Control	GB	s.e.m.[b]	Sex	Diet	Sex × diet
SFA								
C12:0	0.067	0.069	0.066	0.070	0.0026	ns	ns	ns
C14:0	1.27	1.28	1.27	1.28	0.023	ns	ns	ns
C16:0	27.23	27.52	27.13	27.62	0.212	ns	ns	ns
C17:0	0.26	0.26	0.28	0.24	0.009	ns	**	ns
C18:0	20.07	20.67	20.72	20.02	0.323	ns	ns	ns
C20:0	0.28	0.31	0.29	0.31	0.008	*	ns	ns
Total SFA	49.2	50.1	49.7	49.5	0.413	ns	ns	ns
MUFA								
C16:1n-9	0.25	0.21	0.25	0.21	0.012	*	*	ns
C16:1n-7	1.64	1.51	1.53	1.62	0.048	+	ns	ns
C17:1	0.19	0.18	0.20	0.17	0.006	ns	*	ns
C18:1n-9	35.59	35.81	34.98	36.43	0.374	ns	**	ns
C18:1n-7	1.56	1.44	1.55	1.46	0.052	ns	ns	ns
C20:1	0.82	0.89	0.83	0.88	0.027	ns	ns	ns
Total MUFA	40.1	40.0	39.3	40.8	0.414	ns	*	ns
PUFA								
C18:2n-6	9.44	8.58	9.56	8.46	0.285	*	**	*
C18:3n-3	0.75	0.69	0.77	0.67	0.024	ns	**	*
C20:4n-6	0.43	0.42	0.44	0.41	0.012	ns	ns	ns
C20:5n-3	0.15	0.14	0.15	0.14	0.009	ns	ns	ns
Total PUFA	10.8	9.8	10.9	9.7	0.315	*	**	*
PUFA/SFA	0.22	0.20	0.22	0.20	0.007	*	*	*
n-6[d]	9.87	9.00	10.00	8.87	0.296	*	**	*
n-3[e]	0.90	0.83	0.92	0.80	0.031	ns	*	*

EG = entire gilts; IG = immunocastrated gilts; control = commercial diet; GB = granulated barley as the only main ingredient; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.
Data presented are means.
[a]Samples taken covering intestines (53 ±5 g).
[b]Standard error of the mean, calculated using $n = 24$ pigs as experimental units per main effect of sex or diet.
[c]ns = not significant ($P > 0.10$); $^{+}P < 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$.
[d]n-6 = C18:2n-6 + C20:4n-6.
[e]n-3 = C18:3n-3 + C20:5n-3.

the physiology and metabolism of nutrients in pigs increasing the fat tissue and decreasing the lean tissue. It suggests that castration might also modify the proportion of major cuts of the carcass depending on its proportion of fat tissue. Gómez-Fernández *et al.* (2013) observed that immunocastration of Duroc × Iberian gilts had no effect on ham and shoulder weight but decreased loin weight and ham, shoulder and loin yield, whereas in the current study the immunocastration only reduced the loin weight and yield. Serrano *et al.* (2008) showed that gilt castration did not affect carcass weight and yield but reduced ham, shoulder and loin weights and yields. The different results obtained among experiments on carcass major joint weight and yield might be related to the higher subcutaneous fat proportion *per se* in the Iberian pigs than in commercial crossbreed pigs, to the differences in tissular composition among pieces and also to the amount removed in the trimming of carcass main joints.

In the present trial, the carcasses from gilts fed GB diet had lower compactness than those from gilts fed the control diet, owing to a tendency for longer carcasses in GB gilts, in agreement with data from Daza *et al.* (2012b). The substitution of the control feed by a diet based on GB had no effect on fat thickness at the GM muscle level, which is in agreement with results obtained in previous studies (Daza *et al.*, 2010, 2012a and 2012b). The increase in backfat depth at 97 days in pigs fed GB, compared with control diet, did not reach significance in the present study, but a higher backfat thickness has been previously reported in gilts fed a GB compared with a common diet (Daza *et al.*, 2012a). The discrepancies between studies may be explained by different points of measurements of backfat thickness on pigs. The slightly lower yields of loin and total main joints of gilts given the GB diet agree with the lower loin yield of pigs fed a barley-based diet compared with a control diet in a recent report (Daza *et al.*, 2012b), whereas in another study no significant difference was found between pigs fed a GB or a commercial diet on weight and yield of main lean joints (Daza *et al.*, 2010). Altogether, this indicates that feeding pigs with a GB instead of control diet may lead to fatter carcasses and lower yields of lean cuts.

Table 6 *The effect of sex and diet on fatty-acid profile (%) of intramuscular fat from the* Longissimus thoracis *muscle*[a]

	Sex		Diet			*P*-value[c]	
	EG	IG	Control	GB	s.e.m.[b]	Sex	Diet
SFA							
C12:0	0.074	0.077	0.075	0.075	0.0011	+	ns
C14:0	1.45	1.50	1.47	1.48	0.020	+	ns
C15:0	0.012	0.012	0.0091	0.016	0.0035	ns	ns
C16:0	23.81	25.01	24.19	24.64	0.192	***	ns
C17:0	0.15	0.15	0.16	0.15	0.005	ns	ns
C18:0	12.67	13.88	13.42	13.14	0.243	***	ns
C20:0	0.19	0.21	0.20	0.20	0.0051	*	ns
Total SFA	38.4	40.8	39.5	39.7	0.376	***	ns
MUFA							
C14:1	0.16	0.15	0.16	0.16	0.008	ns	ns
C15:1	0.25	0.24	0.27	0.22	0.034	ns	ns
C16:1n-9	0.090	0.087	0.095	0.082	0.0053	ns	ns
C16:1n-7	3.57	3.42	3.39	3.60	0.087	ns	ns
C17:1	0.19	0.18	0.19	0.18	0.006	ns	ns
C18:1n-9	43.70	42.42	42.86	43.25	0.284	**	ns
C18:1n-7	3.56	3.51	3.49	3.58	0.049	ns	ns
C20:1	0.82	0.81	0.81	0.82	0.018	ns	ns
Total MUFA	52.4	50.8	51.3	51.9	0.355	**	ns
PUFA							
C18:2n-6	7.02	6.40	6.99	6.43	0.255	+	ns
C18:3n-3	0.045	0.044	0.051	0.038	0.0063	ns	ns
C18:4n-3	0.042	0.040	0.042	0.040	0.0078	ns	ns
C20:2n-9	0.38	0.33	0.37	0.34	0.014	**	ns
C20:3n-9	1.31	1.12	1.28	1.14	0.083	ns	ns
C20:4n-6	0.15	0.13	0.15	0.14	0.0060	*	ns
C20:5n-3	0.30	0.27	0.29	0.28	0.024	ns	ns
Total PUFA	9.2	8.3	9.2	8.4	0.344	+	ns
PUFA/SFA	0.24	0.20	0.23	0.21	0.012	*	ns
n-6[d]	7.17	6.53	7.14	6.57	0.253	+	ns
n-3[e]	0.39	0.36	0.39	0.36	0.019	ns	ns

EG = entire gilts; IG = immunocastrated gilts; control = commercial diet; GB = granulated barley as the only main ingredient; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.
Data presented are means.
[a]Samples taken at the level of the last rib from each left loin (500 ±20 g).
[b]Standard error of the mean, calculated using $n = 24$ pigs as experimental units per main effect of sex or diet.
[c]ns = not significant ($P > 0.10$); $^{+}P < 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$. No significant interaction (sex × diet) was found.
[d]n-6 = C18:2n-6 + C20:4n-6.
[e]n-3 = C18:3n-3 + C18:4n-3 + C20:5n-3.

Meat characteristics

Muscle and fat colour are sensorial characteristics that have a great influence on consumers to choose pork. In the present trial, no influence of immunocastration was observed on colour variables of subcutaneous fat and LT muscle. Several authors (Serrano *et al.*, 2008; Peinado *et al.*, 2011 and 2012) neither detected differences between surgically castrated and intact gilts for meat colour. In addition, no significant effect of dietary treatment was observed on colour tissues in line with results reported by Daza *et al.* (2012a and 2012b).

In the present experiment, the immunocastration and the GB diet tended to increase the IMF content in the LT muscle. One could have expected an interaction effect of immunocastration and GB diet on IMF, but this was not achieved in the present study. Some studies reported that female castration led to a slight, although not significant, increase in IMF percentage (2.4 *v.* 2.0; Peinado *et al.*, 2011 and 2012). Previously, Daza *et al.* (2010 and 2012b) observed that the use of a diet based on GB led to an increase in IMF content. According to D'Souza *et al.* (2003), the high (30%) reduction of CP or lysine/energy ratio in the feed enhances IMF proportion. The positive effect observed in GB diet on loin chemical composition could be partly because of the lack of vitamin and mineral premix in that diet, especially vitamin A. Thus, D'Souza *et al.* (2003) observed a higher IMF content in the muscle when vitamin A was completely removed from the vitamin–mineral mixture.

However, the influence of dietary vitamin A on IMF content in meat is controversial, as other experiments (Olivares *et al*., 2009) did not find any influence. According to Brandebourg and Hu (2005), the retinoids, which are derivatives of vitamin A, have an inhibitory effect on cultured preadipocytes differentiation; therefore, it has been proposed that the influence of dietary vitamin A level on IMF is mediated by adipocyte differentiation (Dimaculangan *et al*., 1994).

Fatty-acid profile of tissues

In the current experiment, the immunocastration increased SFA and reduced MUFA and PUFA in subcutaneous backfat and in IMF and decreased PUFA in omental fat. It agrees with the previous studies that have reported on Durox × (Landrace × Large White) and (Pietrain × Large White) × (Landrace × Large White) gilts that surgical castration led to an increase of C16:0 and C18:0 and to a decrease of C18:2n-6 in IMF (Peinado *et al*., 2011 and 2012), although Serrano *et al*. (2008) did not report any significant influence of castration on concentration of these FA profiles in IMF from Duroc × Iberian gilts. This discrepancy could be because of the possible influence of genetic type. The results obtained in the current study are interesting as an increase in PUFA content reduces consistency of subcutaneous fat, impairs water migration and reduces the rate of moisture loss during the curing process (Ruíz Carrascal *et al*., 2000). Moreover, fat oxidation rate is positively related to PUFA content, and an increase in the oxidation rate of the fat might negatively affect the aroma and flavour of dry-cured products (Wood *et al*., 2008). In the present trial, PUFA/SFA ratio was lower in IGs than in EGs. Therefore, it would better fit for the technological processes of dry-cured products than EG, in base on the lower PUFA content, although the nutritional quality of their fat would be impaired, taking into account the higher SFA content.

The use of the GB feed during the finishing period only increased MUFA and decreased PUFA in omental fat but had no strong effect in subcutaneous fat or IMF. These results are not in agreement with those obtained in previous studies. Thus, Daza *et al.* (2010 and 2012b), in Duroc × (Landrace × Large White), found that granulated barley increased MUFA and reduced PUFA and did not affect SFA in IMF. However, as in the current experiment, Daza *et al.* (2012a and 2012b) did not observe any influence of granulated barley on FA composition of outer and inner layers of subcutaneous fat. These results suggest that lower CP content and the lack of vitamin–mineral premix in the GB diet had scarce influence on FA composition of subcutaneous backfat. In addition, Olivares *et al*. (2009) did not find any effect of dietary vitamin A level in finishing diets on FA composition of subcutaneous backfat. It is important to note that C18:2n-6 proportion found in the tissues, according to sexual status and dietary treatment given during the final period, was lower than 12%, which is a positive result because a higher value than 12% is not recommended for transformation and conservation processes of pork (Wood *et al*., 2008).

Conclusions

The immunization against GnRH in gilts improved ADG and reduced the percentage of carcasses rejected at slaughterhouse, both aspects being of importance for pig producers. In addition, gilt immunocastration tended to increase the IMF proportion of meat, which is desirable by consumers, although it resulted in higher SFA content in meat. The replacement of conventional feed by GB diet during the finishing period did not affect growth performance but tended to increase IMF content and affected the FA profile of omental fat with scarce influence on FA profile of subcutaneous fat and IMF.

Acknowledgements

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

References

Association of Official Analytical Chemists 2000. Official methods of analysis, 17th edition. AOAC, Arlington, VA, USA.

Bligh EG and Dyer WJ 1959. A rapid method of total lipid extraction and purification. Canadian Journal of Biochemistry and Physiology 37, 911–917.

Boletin Oficial Estado 2007. Ley 32/2007 de 7 de noviembre para el cuidado de los animales en su explotación, transporte, experimentación y sacrificio, vol. 268. BOE, Madrid, Spain, pp. 45914–45920.

Brandebourg TD and Hu CY 2005. Regulation of differentiating pig preadipocytes by retinoic acid. Journal of Animal Science 83, 98–107.

Commission International de l'Eclairage 1976. International Commission on Illumination, Colorimetry: Official Recommendations of the International Commission on Illumination. Publication CIE No. 15 (E-1.3.1). Bareau Central de la CIE, Paris, France.

Daza A, Latorre MA and López-Bote CJ 2010. 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). Spanish Journal of Agricultural Research 8, 607–616.

Daza A, Latorre MA and López-Bote CJ 2012a. The effect of granulated barley as only ingredient in the growing or finishing period may improve the meat quality of heavy pigs. Animal 6, 1543–1553.

Daza A, Latorre MA, Olivares A, Amazán D and López-Bote CJ 2012b. Effect of replacement of a conventional diet by granulated barley during finishing period on growth performance and carcass and meat characteristics in 130-kg gilts. Livestock Science 148, 196–200.

Dimaculangan DD, Chawla A, Boak A, Kagan HM and Lazar MA 1994. Retinoic acid prevents downregulation of RAS recision genelysy oxidase early in adipocyte differentiation. Differentiation 58, 47–52.

D'Souza DN, Pethick DW, Dunshea FR, Pluske JR and Mullan BP 2003. Nutritional manipulation increases intramuscular fat levels in the *Longissimus dorsi* muscle of female finisher pigs. Australasian Journal of Agricultural Research 54, 745–749.

Fábrega E, Velarde A, Cros J, Gispert M, Suárez P, Tibau J and Soler J 2010. Effect of vaccination against gonadotrophin-releasing hormone, using Improvac on growth performance body composition, behaviour and acute phase protein. Livestock Science 132, 53–59.

Fundación Española Desarrollo Nutrición Animal 2010. Tablas FEDNA para la formulación de piensos compuestos (ed. C De Blas, GG Mateos and P García Rebollar), p. 535. Fundación Española para el Desarrollo Nutrición Animal, Madrid, Spain.

Gómez-Fernández J, Horcajada S, Tomás C, Gómez-Izquierdo E and de Mercado E 2013. Efecto de la immunocastración y de la castración quirúrgica sobre los rendimientos productivos y la calidad de la canal en cerdas ibéricas de cebo. ITEA 109, 33–48.

Latorre MA, García-Belenguer E and Ariño L 2008. The effects of gender and slaughter weight on growth performance and carcass traits of pigs intended

for dry-cured hams from Teruel (Spain). Journal of Animal Science 86, 1933–1942.

Latorre MA, Ripoll G, García-Belenguer E and Ariño L 2009a. The increase of slaughter weight in gilts as strategy to optimize the production of Spanish high quality dry-cured ham. Journal of Animal Science 87, 1464–1471.

Latorre MA, Ripoll G, García-Belenguer E and Ariño L 2009b. The effect of gender and slaughter weight on loin and fat characteristics of pigs intended for Teruel dry-cured ham production. Spanish Journal of Agricultural Research 7, 407–416.

Marmer WN and Maxwell RJ 1981. Dry column method for the quantitative extraction and simultaneous class separation of lipids from muscle tissue. Lipids 16, 365–371.

Olivares A, Daza A, Rey AI and López Bote CJ 2009. Interaction between genotype, dietary fat saturation and vitamin A concentration on intramuscular fat content and fatty acid composition in pigs. Meat Science 81, 6–12.

Oliver WT, Mc Culey L, Harrel RJ, Suster D, Kerton DJ and Dunshea FR 2003. A gonadotropin-releasing factor vaccine (Improvac) and porcine somatotropin have synergistic and additive effects on growth performance in group-housed boars and gilts. Journal of Animal Science 81, 1959–1966.

Pauly C, Spring P, O'Doherty JV, Ampuero Kragten S and Bee G 2009. Growth performance, carcass characteristics and meat quality in group-penned surgically castrated, immunocastrated (Improvac) and entire male individually penned entire male pigs. Animal 3, 1057–1066.

Peinado J, Serrano MP, Medel P, Fuentetaja A and Mateos GG 2011. Productive performance, carcass and meat quality of intact and castrated gilts slaughtered at 106 or 122 kg BW. Animal 5, 1131–1140.

Peinado J, Serrano MP, Nieto M, Sánchez J, Medel P and Mateos GG 2012. The effect of gender and castration of females on performance and carcass and meat quality of heavy pigs destined to the dry-cured industry. Meat Science 90, 715–720.

Rey A, López-Bote CJ and Arias RS 1997. Effect of extensive feeding on alpha-tocopherol concentration and oxidative stability of muscle microsomes from Iberian pigs. Animal Science 65, 515–520.

Ruíz Carrascal J, Ventanas J, Cava R, Andrés AI and García C 2000. Texture and appareance of dry-cured ham as affected by fat content and fatty acid composition. Food Research International 33, 91–95.

Serrano MP, Valencia DG, Fuentetaja A, Lázaro R and Mateos GG 2008. Effect of gender and castration of females and slaughter weight on performance and carcass and meat quality of Iberian pigs reared under intensive management systems. Meat Science 80, 1122–1128.

Shapiro SS and Wilk MB 1965. An analysis of variance test for normality. Biometrika 52, 591–612.

Sukhija PS and Palmquist DL 1988. Rapid method for determination of total fatty acid content and composition of feedstuffs and feces. Journal of Agriculture & Food Chemistry 36, 1202–1206.

Walstra P 1974. Fattening of young boars: quantification of positive and negative aspects. Livestock Production Science 1, 187–196.

Wood JD, Enser M, Fisher AV, Nute GR, Sherad PR, Richardson RI, Hughes SI and Whittington FM 2008. Fat deposition fatty acid composition and meat quality: a review. Meat Science 78, 343–358.