The influence of dietary lysine restriction during the finishing period on growth performance and carcass, meat, and fat characteristics of barrows and gilts intended for dry-cured ham production

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ABSTRACT: A total of 120 pigs [Duroc × (Landrace × Large White); initial average BW: 100.3 ± 2.5 kg] were used to investigate the effects of sex (barrows and gilts) and dietary total Lys restriction (7.0, 6.5, and 6.0 g·kg⁻¹) on growth performance and carcass, meat, and fat characteristics. Pigs were intended for high-quality dry-cured ham from Spain (called Teruel ham), and a minimum fat thickness at the gluteus medius muscle (GM) is required (16 mm) for carcasses to be acceptable. Animals were slaughtered when they reached 129.0 ± 3.6 kg of BW. There were 6 treatments arranged factorially (2 sexes × 3 dietary Lys concentrations) and 4 replicates of 5 pigs per treatment. Barrows consumed more feed (P = 0.001) and tended to have less G:F (P = 0.06) than gilts. Carcasses from barrows were fatter (P = 0.001) and had heavier main trimmed lean cuts (P = 0.008) than gilts. A greater proportion of final acceptable carcasses for Teruel ham (P = 0.001) was observed in barrows than in gilts because of the greater percentage of carcasses that fulfill the minimum fat depth at GM required (P = 0.001). Meat from barrows had greater content of intramuscular fat (P = 0.02) than meat from gilts. Also, subcutaneous fat from barrows had less proportion of PUFA than fat from gilts (P = 0.02). A reduction in dietary Lys concentration decreased ADG (P = 0.004) and ADFI (P = 0.001) in pigs. In addition, backfat depth (P = 0.007) and fat at GM (P = 0.07) increased as dietary Lys decreased. The proportion of carcasses that fulfilled the minimum fat depth at GM required for Teruel ham increased as dietary Lys decreased in feed, but this effect was greater in gilts than in barrows (sex × Lys, P = 0.02). Meat and fat quality was not influenced by dietary treatment. We conclude that different feeding programs with different dietary Lys concentrations may be needed for barrows and gilts intended for production of dry-cured hams where a minimum carcass fat depth is required.

Key words: dietary lysine restriction, dry-cured ham production, pig, sex


INTRODUCTION

Spain is the world leader in production of dry-cured hams and shoulders with a total production of 46 million pieces in 2009 (MARM, 2010). One of the main Spanish dry-cured hams with Denomination of Protected Origin is called Teruel ham. Its regulation established the crossbreeding required (Duroc sires mated to Landrace × Large White sows) and the minimum requirement for carcass weight (84 kg), fat thickness over the gluteus medius muscle (GM; 16 mm), and fresh ham weight (11.3 kg) to improve the uniformity and quality of the end product (Boletín Oficial Aragón, 2009). In a recent study, Latorre et al. (2008a) concluded that pigs intended for Denomination of Protected Origin Teruel ham should be slaughtered at 130 kg of BW to optimize productive performance and carcass quality traits, but a considerable proportion of carcasses from gilts were rejected due to the lack of cover fat depth. Therefore,
feeding strategies are being studied, especially in gilts, to avoid that problem. This may be accomplished by reducing the Lys concentration in the diet because increasing dietary Lys increases carcass leanness (Fabian et al., 2002; Kill et al., 2003). In fact, Cisneros et al. (1996) reported that a decrease in Lys in pig diets increased the intramuscular fat (IMF) content in meat. However, it also might impair productive performance traits (Castell et al., 1994). This work was carried out with pigs from 20 to 100 kg of BW, but there is limited information about the influence of dietary Lys in diets fed to pigs greater than 100 kg of BW. Main et al. (2008) reported that the biological and resulting economic effects of increasing dietary Lys concentration in pig diets are relatively modest in magnitude when considering the responses of pigs during the late finishing period. Therefore, the aim of this study was to investigate the effect of reducing the dietary Lys concentration during the finishing period on productive performance and carcass, meat, and fat quality of barrows and gilts intended for Spanish dry-cured ham production.

**MATERIALS AND METHODS**

All the experimental procedures used in this study were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial Est.ado, 2005).

**Animal Husbandry and Experimental Diets**

A total of 120 crossbred pigs (100.3 ± 2.5 kg of BW; 161 ± 3 d of age) were used. All pigs were the progeny of Duroc sires (Asociación Turolesa de Industrias Agroalimentarias, Teruel, Spain) and Landrace × Large White dams (Hypor España G.P., Barcelona, Spain). Males were castrated at 5 ± 3 d of age. At the arrival to the experimental farm, pigs were housed in 80% slatted floor pens (2.50 × 2.50 m) in a natural environment and were allotted within sex to 24 pens based on the initial BW. There were 6 treatments with 2 sexes (barrows and gilts) and 3 total Lys concentrations in the diet (7.0, 6.5, and 6.0 g·kg⁻¹), and each treatment was replicated 4 times. The diets were formulated to be isenergetic and to meet or exceed the quantity recommended by Fundación Española Desarrollo Nutrición Animal (2006) for pigs of that age. The diet with greatest Lys content (7.0 g·kg⁻¹) was used as the control group, and the remaining diets (with 6.5 or 6.0 g of Lys·kg⁻¹) were formulated mainly by reducing the synthetic Lys proportion. Other AA amounts were determined using an ideal AA ratio (NRC, 1998) to ensure that Lys was the first-limiting AA. The composition and the estimated nutrient value (AOAC, 2000) of the diets are shown in Table 1. Pigs had free access to pelleted feed and water throughout the trial.

**Table 1. Composition and nutrient content of the experimental diets provided from 100 to 130 kg of BW (g·kg⁻¹, as-fed basis unless otherwise indicated)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary Lys content, g·kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.0</td>
</tr>
<tr>
<td>Ingredient</td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>450</td>
</tr>
<tr>
<td>Wheat</td>
<td>300</td>
</tr>
<tr>
<td>Maize</td>
<td>63</td>
</tr>
<tr>
<td>Canola meal</td>
<td>80</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>73</td>
</tr>
<tr>
<td>Blended animal-vegetable fat</td>
<td>11.2</td>
</tr>
<tr>
<td>Calcium carbonate</td>
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</tr>
<tr>
<td>Sodium chloride</td>
<td>4.5</td>
</tr>
<tr>
<td>l-Lys</td>
<td>2.4</td>
</tr>
<tr>
<td>Vitamin and mineral premix</td>
<td>4.0</td>
</tr>
<tr>
<td>NE, kcal·kg⁻¹</td>
<td>2,280</td>
</tr>
<tr>
<td>Total Lys</td>
<td>7.0</td>
</tr>
<tr>
<td>Analyzed nutrient composition³</td>
<td></td>
</tr>
<tr>
<td>CP (N × 6.25)</td>
<td>145</td>
</tr>
<tr>
<td>DM</td>
<td>894</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>43</td>
</tr>
<tr>
<td>Ash</td>
<td>52</td>
</tr>
<tr>
<td>Ether extract</td>
<td>39</td>
</tr>
<tr>
<td>Total Lys</td>
<td>7.1</td>
</tr>
</tbody>
</table>

¹Provided the following (per kilogram of complete diet): 6,000 IU of retinyl acetate; 1,200 IU of cholecalciferol; 11 IU of all-rac-c-tocopheryl acetate; 0.5 mg of menadione (menadione sodium bisulfite complex); 0.2 mg of thiamine (thiamine mononitrate); 2.5 mg of riboflavin; 0.2 mg of pyridoxine (pyridoxine·hydrochloride); 15 μg of cyanocobalamin; 8 mg of D-pantothenic acid (DL-calcium pantothenate); 15 mg of niacin; 350 mg of choline; 16 mg of Cu (copper sulfate); 75 mg of Fe (ferrous sulfate); 40 mg of Mn (manganese oxide); 110 mg of Zn (zinc oxide); 0.1 mg of Co (cobalt sulfate); 0.3 mg of Se (sodium selenite); and 0.8 mg of I (calcium iodate).


³According to AOAC (2000).

The reason to begin the trial with 100 kg of BW and finish at 130 kg of BW was to comply with Fundación Española Desarrollo Nutrición Animal (2006) recommendations. According to the recommendation, the requirements of growing-finishing pigs depend on the BW, from 20 to 60 kg, from 60 to 100 kg, and greater than 100 kg. The last range (>100 kg of BW) is included because the dry-cured product industry is important in the Mediterranean area (Spain and Italy), and heavy pigs are needed for this type of production. When the average BW was close to 130 kg (193 ± 3 d of age), all the animals were slaughtered on the same day.

**Growth Performance**

Individual BW and feed consumption per pen were recorded at 0 and 32 d of the trial and were used to calculate ADG, ADFI, and G:F for each replicate. The ADFI was adjusted for mortality. Pigs that died during the experiment were weighed, and the ADG was included in the calculations of G:F. Orts was recorded by replicate for each period.
Slaughtering and Carcass Quality Traits

On 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 Altimijares, S.L., Teruel, Spain), where they were kept in luirage for 10 h with full access to water but not to feed. Animals were electrically stunned (225 to 380 V/0.5 A for 5 to 6 s), exsanguinated, scaled, skinned, eviscerated, and split down the midline according to standard commercial procedures. Hot carcass weight was individually recorded and used to calculate dressing percentage. Carcass weight is the first criterion used to identify those carcasses that are acceptable for Teruel ham production. Consequently, carcasses that weighed less than 84 kg were not acceptable.

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 were measured on the left side of each carcass using a flexible ruler with a precision of 0.5 mm. In addition, fat depth over the GM at its thinnest point, and backfat thickness (BF) between the last 3rd and 4th ribs on the midline of the carcass (skin included) were measured. Fat depth over the GM is the second criterion used to identify those carcasses that are acceptable for Teruel ham production. Therefore, carcasses with fat depth less than 16 mm at that point were not acceptable.

The head was removed at the atlanto-occipital junction, and carcasses were suspended in the air and refrigerated at 2°C (1 m/s; 90% relative humidity) for 6 h. Then carcasses were processed according to the simplified European Community reference method (Branscheid et al., 1990). To fit commercial requirements (round shape), hams and shoulders were trimmed of external fat, and loins and sirloins were trimmed of intermuscular fat. They were then weighed to calculate trimmed ham, shoulder, loin, and sirloin yields. Fresh ham weight is the third criterion used to identify those carcasses that are acceptable for Teruel ham production. Thus, carcasses with fresh ham weight less than 11.3 kg were not acceptable.

Meat Quality Analyses

Muscle pH was measured in the left semimembranosus muscle of each carcass at 45 min and at 24 h postmortem using a portable pH meter equipped with a glass electrode (model No. 52-00, Crison Instruments S.A., Barcelona, Spain). After collection of carcass and pH data, a total of 72 carcasses were randomly selected (3 carcasses per pen) for the meat quality evaluation. A section of 400 ± 20 g of longissimus thoracis muscle (LT) was excised at the last rib from each left loin of carcass. Meat samples were placed in individual plastic bags and vacuum-packaged at −20°C until subsequent analyses. When required, the LT samples were thawed in vacuum-packaged bags for 24 h at 4°C, removed from packages, blotted dry for 20 min, and weighed. Thawing loss was calculated by dividing the difference in weight between the fresh and thawed samples by the initial fresh weight.

Meat color was evaluated with a chromameter (CM 2002, Minolta Camera, Osaka, Japan), previously calibrated against a white tile according to manufacturer recommendations, using objective measurements (CIE, 1976). The average of 3 random readings was used to measure lightness (L*, a greater value is indicative of a lighter color), redness (a*, a greater value is indicative of redder color), and yellowness (b*, a greater value is indicative of a more yellow color). Additionally, chroma (C*) and hue angle (H*) were calculated as $C^* = \sqrt{(a^*)^2 + (b^*)^2}$ and as $H^* = \tan^{-1}(b^*/a^*)$. 57.29, respectively. Chroma is related to the quantity of pigments, and greater values represent a more vivid color denoting lack of grayness, and hue is the attribute of a color perception denoted by blue, green, yellow, red, purple, and so on related to the state of pigments (Wyszecki and Styles, 1982).

The moisture, CP, and IMF contents of the meat samples were determined with a near infrared transmittance meat analyzer (Infratec 1265, Tecator, Höganäs, Sweden) by spectroscopy between 800 to 1,100 nm. The chops were trimmed free of intermuscular fat, minced, and distributed in the cup ring equipped with a plastic-bottom plate with 100-mm diameter and 15 mm deep. The monochromator contained a 50-W tungsten lamp and a diffraction grating that created monochromatic light.

Cooking loss was determined by the method described by Honikel (1998). Briefly, an LT slice (200 ± 20 g) was taken from each chop, weighed, placed in a plastic bag, and cooked to an internal temperature of 70°C in a 75°C 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 15°C for 30 min, blotted dry, and weighed. The difference between pre- and postcooking weights was divided by the precooked weight to calculate cooking loss percentage. Samples were then cut parallel to the long axis of the muscle fibers into rectangular cross-section slices of 10 x 10 mm and 30 mm length. Slices (8/chop) were sheared perpendicular to the fiber orientation, with a Warner-Bratzler device attached to an Instron Universal testing machine attached to a PC (Instron model 5543, Instron Ltd., Buckinghamshire, UK), and equipped with a 5-kg load cell and a crosshead speed of 150 mm/min.

Subcutaneous Fat Quality Analyses

From the same carcasses used for meat study, subcutaneous fat samples, including fat layers, skin, and
lean, were taken at the tail insertion in the coxal region of the left side, placed in individual plastic bags, and vacuum-packaged at −20°C until subsequent analysis. Briefly, a 200-mg sample of subcutaneous adipose tissue was homogenized and saponified, and the fatty acids (FA) were extracted, methylated, and analyzed with a gas chromatograph (Autosystem XL Agilent Technologies 6890N Net Work GC System, Perkin Elmer, Boston, MA) equipped with a flame-ionization detector, a Hamilton injector, and a capillary column (Omegawax 320, 30 m x 0.32 mm with a film thickness of 0.25 µm; Supelco, Bellefonte, PA) with 0.4 mL/min of He as the carrier gas. The temperature of the inlet detector was 260°C, and the initial temperature of the oven was 190°C for 2 min, increasing to 205°C at a rate of 5°C/min for 3 min. Total SFA, MUFA, PUFA, and unsaturated FA (UFA = MUFA + PUFA) were calculated.

Statistical Analyses

Data were analyzed as a completely randomized design with treatments arranged factorially (2 x 3) using the REG procedure (SAS Inst. Inc., Cary, NC). The model included sex (barrows and gilts) and dietary Lys concentration (7.0, 6.5, and 6.0 g·kg⁻¹) as main effects. In addition, a GLM procedure (SAS Inst. Inc.) was used to detect possible interactions between main effects. The percentage of carcasses acceptable for Teruel dry-cured ham production was analyzed using a χ² test and means were separated by a t-test. The experimental unit was the pen with 5 pigs per pen for productive performance and carcass traits and by 3 pigs per pen randomly selected for meat and fat traits. A value of P < 0.05 was used to assess the significance, whereas a P-value between 0.05 and 0.10 was classified as a trend.

RESULTS

Growth Performance

Mortality was 1.66% and was not related to treatment (data not shown). No interactions between sex and Lys were detected for any productive performance criteria studied, and therefore only main effects and the linear response to dietary Lys concentration are reported (Table 2). Barrows were heavier than gilts at the beginning (103.2 vs. 97.5 kg; P = 0.01) and at the end (132.2 vs. 125.9 kg; P = 0.007) of the trial. The ADG was not different between sexes, but barrows consumed more feed (3.06 vs. 2.84 kg·d⁻¹; P = 0.001) and tended to have less G:F (0.296 vs. 0.313; P = 0.06) than gilts. No effect of dietary treatment was detected on final BW or G:F. However, there was a linear relationship between dietary Lys concentration and ADG (R² = 0.36; P = 0.004) and ADFI (R² = 0.77; P = 0.001), indicating reductions by 82 g·d⁻¹ and 0.18 kg·d⁻¹, respectively, as Lys decreased in the diet from 7.0 to 6.0 g·kg⁻¹.

Carcass Quality Traits

Carcasses from barrows were heavier (105.1 vs. 99.6 kg; P = 0.01) and fatter at the last 3rd and 4th ribs (28.0 vs. 23.1 mm; P = 0.001), and at GM (22.5 vs. 17.7 mm; P = 0.001) than carcasses from gilts (Table 3). However, no differences between sexes were detected in dressing percentage, carcass, and ham size. Barrows had heavier total main trimmed lean cuts (hams, shoulders, loins, and sirloins) than gilts (48.6 vs. 46.5 kg; P = 0.008) because of heavier hams (26.9 vs. 25.7 kg; P = 0.003) and shoulders (15.1 vs. 14.2 kg; P = 0.02). However, no effect of sex was detected on the total main trimmed lean yield, although loin proportion was less in carcasses from barrows than those from gilts (5.6 vs. 5.9%; P = 0.001). The BF increased linearly (R² = 0.68; P = 0.007) at a rate of 2.92 mm as dietary Lys concentration decreased in the diet from 7.0 to 6.0 g·kg⁻¹. Additionally, fat depth at GM tended to increase linearly (R² = 0.56; P = 0.07) with the Lys restriction in the diet. The total trimmed cut weight was not modified by dietary treatment, although loin weight tended to increase as Lys concentration decreased (R² = 0.14; P = 0.08). In spite of the lack of an effect of dietary Lys on total trimmed cut yield, a linear reduction in shoulder yield of 0.43 percentage units (R² = 0.25, P = 0.01) was observed as dietary Lys was reduced from 7.0 to 6.0 g·kg⁻¹.

Barrows had greater percentage of carcasses that fulfill the minimum requirement of fat depth at GM (92.5 vs. 61.8%; P = 0.001) than females (Table 4). However, no differences between sexes were detected on the proportion of carcasses that fulfill the minimum carcass and ham weight required. Therefore, barrows had a greater final percentage of acceptable carcasses for Teruel ham (carcasses that fulfill the 3 aforementioned requirements) than gilts (90.4 vs. 59.0%; P = 0.001). A reduction in dietary Lys concentration from 7.0 to 6.5 g·kg⁻¹ increased the final percentage of carcasses acceptable for Teruel ham (P = 0.04) because of a greater proportion of carcasses with ≥16 mm fat depth at GM (P = 0.001). However, an interaction between sex and dietary Lys was detected (P = 0.02) on the proportion of acceptable carcasses that fulfill the minimum carcass fat at GM required for Teruel ham. Whereas 7.0 g of Lys·kg⁻¹ of feed optimized the percentage of carcasses with fat depth ≥16 mm in barrows (87.5 vs. 90.0 vs. 100% for 7.0, 6.5, and 6.0 g of Lys·kg⁻¹, respectively), gilts needed less dietary Lys (≤6.5 g·kg⁻¹) to increase the proportion of carcasses that fulfill this fat depth level (35.8 vs. 70.8 vs. 78.7% for 7.0, 6.5, and 6.0 g of Lys·kg⁻¹, respectively).

Meat Quality Traits

No interactions between sex and Lys were observed for meat quality traits, and therefore, only main effects and the linear response to dietary Lys are pre-
presented (Table 5). The LT from barrows had greater IMF (3.06 vs. 2.33%; \( P = 0.02 \)) content than that from gilts. No influence of dietary treatment on meat quality was observed except for shear force value, which tended to increase linearly (\( R^2 = 0.15; \ P = 0.07 \)) with the Lys restriction in the feed. An interaction between sex and dietary Lys was detected on the protein content in meat (\( P = 0.02 \)). Whereas a reduction in dietary Lys concentration from 6.5 to 6.0 g-kg\(^{-1}\) increased the protein proportion in LT from gilts (22.5, 22.4, and 22.9% for 7.0, 6.5, and 6.0 g of Lys-kg feed\(^{-1}\), respectively), no effect was observed in meat from barrows (22.5, 22.3, and 22.2% for 3 dietary Lys, respectively).

**Fat Quality Traits**

No interactions between sex and Lys were observed for any FA studied, and therefore only main effects and the linear response to dietary Lys are presented (Table 6). The subcutaneous fat from both sexes had similar SFA proportion in spite of the greater content of C10:0 (0.08 vs. 0.07%; \( P = 0.02 \)), C12:0 (0.08 vs. 0.07%; \( P = 0.02 \)), C14:0 (1.37 vs. 1.29%; \( P = 0.001 \)), and C16:0 (24.82 vs. 24.08%; \( P = 0.02 \)) in fat from barrows than gilts. The subcutaneous fat from barrows had less proportion of PUFA than that from gilts (12.90 vs. 13.63%; \( P = 0.02 \)) because of the reduced C18:2 (11.80 vs. 12.49%; \( P = 0.008 \)). The MUFA or UFA percentages were not influenced by sex. No effect of dietary treatment was observed on SFA proportion, although linear increases of C12:0 (\( R^2 = 0.38, \ P = 0.02 \)), C14:0 (\( R^2 = 0.56, \ P = 0.001 \)), and C16:0 (\( R^2 = 0.38, \ P = 0.03 \)) and a reduction trend of C20:0 (\( R^2 = 0.21, \ P = 0.07 \)) were detected with the dietary Lys restriction from 7.0 to 6.0 g-kg\(^{-1}\). Another trend for reduction with decreasing dietary Lys was observed for C20:1 (\( R^2 = 0.20, \ P = 0.06 \)), but there was no effect on MUFA concentration. Also, no influence of dietary treatment was detected on PUFA or UFA proportions of subcutaneous fat.

**DISCUSSION**

**Growth Performance**

At the beginning of the trial, barrows were heavier than gilts because pigs were allotted to treatments on the basis of age. Previous reports have reported that castrated males are heavier than females at similar age (Latorre et al., 2008a; Peinado et al., 2008). Both sexes had similar ADG throughout the trial; thus, the differences in initial BW were maintained at the end of the trial. In spite of the lack of differences in daily growth, barrows consumed more feed and were less efficient in converting feed into BW gain than gilts, which is consistent with the fatter carcasses observed in barrows at slaughter. This observation is in agreement with several authors (Ellis et al., 1996; Leach et al., 1996; Weatherup et al., 1998).

Different strategies to reduce the Lys concentration in the diet can be used. Loughmiller et al. (1998) for-
Table 3. The effect of sex and total dietary Lys content during the finishing period on carcass quality of heavy pigs intended for Spanish dry-cured ham

<table>
<thead>
<tr>
<th>Item</th>
<th>Sex</th>
<th>Total dietary Lys, g-kg⁻¹</th>
<th>Linear response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Barrows</td>
<td>Gilts</td>
<td>SEM</td>
</tr>
<tr>
<td>n¹</td>
<td>12</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Carcass weight, kg</td>
<td>105.1</td>
<td>99.6</td>
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</tr>
<tr>
<td>Carcass yield, %</td>
<td>79.5</td>
<td>79.1</td>
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</tr>
<tr>
<td>Carcass length, cm</td>
<td>88.7</td>
<td>88.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Ham length, cm</td>
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<td>40.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Ham circumference, cm</td>
<td>75.6</td>
<td>74.6</td>
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</tr>
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<td>Backfat depth, mm</td>
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<td>23.1</td>
<td>0.6</td>
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<tr>
<td>Fat depth at gluteus medius muscle, mm</td>
<td>22.5</td>
<td>17.7</td>
<td>0.8</td>
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<tr>
<td>Weight of main trimmed lean cuts, kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ham</td>
<td>26.9</td>
<td>25.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Shoulder</td>
<td>15.1</td>
<td>14.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Loin</td>
<td>5.8</td>
<td>5.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Sirloin</td>
<td>0.73</td>
<td>0.73</td>
<td>0.02</td>
</tr>
<tr>
<td>Total</td>
<td>48.6</td>
<td>46.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Yield of main trimmed lean cuts, % of carcass</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ham</td>
<td>25.7</td>
<td>25.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Shoulder</td>
<td>14.3</td>
<td>14.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Loin</td>
<td>5.6</td>
<td>5.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Sirloin</td>
<td>0.70</td>
<td>0.73</td>
<td>0.02</td>
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<tr>
<td>Total</td>
<td>46.3</td>
<td>46.7</td>
<td>0.3</td>
</tr>
</tbody>
</table>

¹There was no significant sex × Lys interaction (P > 0.05).
²The experimental unit consisted of 5 carcasses belonging to the 5 pigs allocated to the same pen.
Table 4. The effect of sex and total dietary Lys content during the finishing period on proportion (%) of acceptable pig carcasses intended for Spanish dry-cured ham

<table>
<thead>
<tr>
<th>Item1</th>
<th>Sex</th>
<th>Total dietary Lys, g·kg⁻¹</th>
<th>P-value</th>
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</thead>
<tbody>
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<td></td>
<td>Barrows</td>
<td>Gilts</td>
<td>SEM</td>
</tr>
<tr>
<td>n²</td>
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<td>—</td>
</tr>
<tr>
<td>Carcass weight ≥84 kg</td>
<td>100</td>
<td>100</td>
<td>—</td>
</tr>
<tr>
<td>Fresh ham weight ≥11.3 kg</td>
<td>97.9</td>
<td>94.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Fat depth at gluteus medius ≥16 mm</td>
<td>92.5</td>
<td>61.8</td>
<td>3.1</td>
</tr>
<tr>
<td>All³</td>
<td>90.4</td>
<td>59.0</td>
<td>4.6</td>
</tr>
</tbody>
</table>

*Within a row, means without a common superscript letter differ (based on the χ² test; P < 0.05).

¹Required for Spanish dry-cured ham according to the Boletín Oficial Aragón (2009).

²The experimental unit consisted of 5 carcasses belonging to the 5 pigs allocated to the same pen.

³The means were 87.5, 90.0, and 100% (barrows) and 35.8, 70.8, and 78.7% (gilts) for 7.0, 6.5, and 6.0 g of Lys·kg⁻¹, respectively.

⁴Carcasses fulfilled the carcass, ham, and fat-depth requirements.

Dietary lysine restriction in diets for heavy pigs

Mulated diets by altering the dietary corn:soybean meal ratio without AA supplementation. However, Hahn et al. (1995) used low-protein corn:soybean meal diets supplemented with Met, Thr, Ile, Val, and Trp to meet or exceed an ideal AA pattern relative to Lys (Baker and Chung, 1992). In the current experiment, we used the same strategy as Hahn et al. (1995).

Several authors have reported an improvement in productive performance when dietary Lys proportion increases in the diet. Friesen et al. (1994) and Fabian et al. (2002) reported linear increases in ADG and G:F as dietary Lys increased from 5 to 11 g·kg⁻¹ in diets in 34 to 72 and 20 to 50 kg of BW pigs, respectively. Stahly et al. (1979) observed less ADG and G:F in pigs fed 7.5 g of Lys·kg⁻¹ than in those fed 9.0 g of Lys·kg⁻¹, but the magnitude of the effect was less at cold (10°C) than at a thermal neutral temperature (22.5°C) environment. Therefore, a reduction of growth performance in pigs might be expected in the current trial as Lys concentration decreased in the diet. In fact, Jin et al. (2010) provided 6.0 g of Lys·kg⁻¹ of the control diet and 15 or 30% of Lys restriction in the experimental treatments and reported reduced ADG and G:F in finishing gilts with Lys restriction. In the present study, the G:F was not affected by dietary treatment, but ADG and ADFI were reduced as dietary Lys concentration decreased. However, the Lys concentration in the control diet was greater and the Lys restriction was less severe than what has been used in other experiments, which may explain why we obtained different responses than those previously reported. Therefore, the effort in the current trial to avoid reduction in feed utilization by pigs, taking into account a Lys restriction, was successful.

Carcass Quality Traits

Barrows produced heavier carcasses than gilts because of the greater slaughter weight, but dressing percentage was similar, which agrees with Lo Fiego et al. (2005) and Latorre et al. (2008a). However, Ellis et al. (1996) and Latorre et al. (2009b) reported that carcass yield was greater in gilts than barrows. The discrepancies observed among authors could be related to differences of the method used for trimming the reproductive system at the slaughterhouse. Carcasses from barrows were fatter than carcasses from gilts, which is consistent with the greater IMF content in the LT of barrows in the posterior laboratory analysis. The difference between sexes was 17 and 21% in BF and fat depth at GM, respectively, which is similar to values reported by Correa et al. (2006) and Latorre et al. (2008a) with pigs slaughtered at heavy BW. On the other hand, carcass length was similar between sexes, in spite of castrates being heavier, which agrees with results of Hamilton et al. (2000). Although the weight of total trimmed primal cuts was greater in barrows than gilts, probably because of the heavier carcasses, the proportions of these pieces were not different, except for the weights of the loins that were greater in gilts than barrows. Peinado et al. (2008), working with crossbred pigs (Pietrain × Large sires × Landrace × Large White dams), also reported a greater percentage of loin in gilts than in barrows at 114 and 122 kg of BW. In the current study, the greater BF depth and the reduced yield of loin observed in barrows indicate that lean yield in carcass might be greater in gilts.

In spite of the differences in carcass weight, all carcasses (from both sexes) fulfilled the minimum carcass weight required and were acceptable for Teruel ham production. Also, hams were heavier for barrows than for gilts, but no differences were observed in the proportion of carcasses that fulfill the minimum ham weight required. Therefore, ham weight of both barrows and gilts is adequate for this type of dry-cured ham production. However, barrows had a greater proportion of carcasses that fulfill the minimum fat at GM required than gilts, which is probably because castrates were fatter at that point than females. Finally, barrows had a 31.4% greater proportion of final acceptable carcasses for Teruel ham (carcasses that fulfill the 3 aforementioned requirements) than gilts. The difference between sexes in the proportion of acceptable carcasses in the current
<table>
<thead>
<tr>
<th>Item</th>
<th>Sex</th>
<th>Total dietary Lys, g kg(^{-1})</th>
<th>Linear response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Barrows</td>
<td>Gilts</td>
<td>SEM</td>
</tr>
<tr>
<td>Sex</td>
<td>12</td>
<td>12</td>
<td><strong>SEM</strong></td>
</tr>
<tr>
<td>n(^1)</td>
<td>12</td>
<td>12</td>
<td><strong>SEM</strong></td>
</tr>
<tr>
<td>pH measured at semimembranosus muscle</td>
<td>45 min</td>
<td>6.13</td>
<td>6.14</td>
</tr>
<tr>
<td>24 h</td>
<td>5.85</td>
<td>5.84</td>
<td>0.03</td>
</tr>
<tr>
<td>Traits measured at longissimus thoracis muscle</td>
<td>Chemical composition, %</td>
<td>74.4</td>
<td>74.8</td>
</tr>
<tr>
<td>Moisture</td>
<td>3.06</td>
<td>2.33</td>
<td>0.23</td>
</tr>
<tr>
<td>Intramuscular fat</td>
<td>22.3</td>
<td>22.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Protein(^2)</td>
<td>53.5</td>
<td>53.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Redness (a(^*))</td>
<td>6.87</td>
<td>6.96</td>
<td>0.33</td>
</tr>
<tr>
<td>Yellowness (b(^*))</td>
<td>6.79</td>
<td>7.08</td>
<td>0.33</td>
</tr>
<tr>
<td>Chroma (C(^*))</td>
<td>87.1</td>
<td>84.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Hue angle (H(^*))</td>
<td>22.3</td>
<td>22.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Water-holding capacity, %</td>
<td>Thawing loss</td>
<td>11.3</td>
<td>11.8</td>
</tr>
<tr>
<td>Cooking loss</td>
<td>19.6</td>
<td>20.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Warner-Bratzler shear force, kg</td>
<td>2.49</td>
<td>2.54</td>
<td>0.07</td>
</tr>
</tbody>
</table>

\(^1\)The experimental unit consisted of 3 meat samples randomly selected from the 5 pigs allocated to the same pen.

\(^2\)There was a significant sex × Lys interaction (P = 0.02). The means were 22.5, 22.3, and 22.2% (barrows) and 22.5, 22.4, and 22.9% (gilts) for 7.0, 6.5, and 6.0 g of Lys kg\(^{-1}\), respectively.
The increase of fat depth in carcasses observed with dietary Lys concentration on acceptable carcasses indicate that, depending on sex, different feeding strategies should be used. In barrows, the greatest dietary Lys concentration (7.0 g·kg⁻¹) optimized the proportion of acceptable carcasses, and therefore a decrease in dietary Lys only resulted in a reduction in ADG. In gilts, the reduction of dietary Lys concentration from 7.0 to 6.5 g·kg⁻¹ improved the percentage of acceptable carcasses with fat depth at GM greater than 16 mm, and a greater Lys restriction (6.0 g·kg⁻¹) would not improve the results of acceptable carcasses and would impair the ADG. Loughmiller et al. (1998) worked with PIC gilts from 91 to 113 kg of BW and recommended 6.0 g of Lys·kg⁻¹, compared with 7.0 or 8.0 g of Lys·kg⁻¹, to maximize growth performance and carcass traits. In any case, the greatest proportion of acceptable carcasses shown by gilts (70.8 and 78.7% obtained with 6.5 and 6.0 g of Lys·kg⁻¹, respectively) was similar to the smallest proportion of acceptable carcasses found in barrows (87.5 and 90.0% obtained with 7.0 and 6.5 g of Lys·kg⁻¹, respectively).

### Meat Quality

The effect of sex or dietary treatment on meat characteristics was limited. In agreement with other stud-
ies, no effect of sex was detected on pH at 45 min or at 24 h postmortem in the semimembranosus muscle (García-Macías et al., 1996; Leach et al., 1996). Several researchers have also indicated that meat color, determined by visual score, objective measurements, or myoglobin content, is independent of sex (Barton-Gade, 1987; Leach et al., 1996), which is confirmed by the present results. Water holding capacity and tenderness were not different between sexes, which agrees with previous observations by Weatherup et al. (1998) and Maiorano et al. (2007). It is generally accepted that the eating quality of pork, determined by tenderness, juiciness, and flavor, is similar for barrows and gilts (Cisneros et al., 1996; Leach et al., 1996). However, Gou et al. (1995) observed that hams from barrows had whiter subcutaneous fat, were more marbled, and had less loss during dry-curing than hams from gilts. These authors recommended the use of barrows for dry-curing. The LT from barrows had greater IMF and lesser CP content than from gilts, which is in line with the fatter carcasses observed. These results agree with those of Cisneros et al. (1996) and Weatherup et al. (1998). The meat chemical composition values in this study were similar to those reported by Latorre et al. (2009a,b) who worked with pigs of the same cross-breed, slaughtered at similar BW, and produced under similar management. A greater IMF concentration has been associated with more juiciness and greater acceptability of the meat (Barton-Gade, 1987; Ellis et al., 1996).

No effect of dietary Lys restriction was observed on meat traits. Friesen et al. (1994) and Bidner et al. (2004) also observed that ultimate pH, Hunter color, cooking loss, shear force, and firmness of muscle were not affected by dietary Lys concentration. An increase in IMF with the restriction in dietary Lys was expected because of the increase in carcass BF. In fact, Bidner et al. (2004) detected an increase in IMF as Lys concentration decreased, and Cisneros et al. (1996) reported also an increase of approximately 1.8 percentage units in IMF percentage of LT from feeding Lys-deficient diets (4.0 compared with 5.6 g of Lys·kg⁻¹ of diet). However, Huff-Lonergan et al. (2002) reported that the correlation between BF and IMF is positive but not very high (+0.80), and Latorre et al. (2008b) observed a negative correlation between IMF and ADG (−0.45), concluding that it was breed dependent. However, Witte et al. (2000) observed only a numerical increase in marbling score and a modest increase in IMF in the LT when Lys concentration decreased in the diet. Some reasons for the discrepancies among experiments may be differences in diet compositions and the extent of AA restriction.

**Subcutaneous Fat Quality**

Most authors reported greater SFA percentage in fat from barrows than in fat from gilts (Pieszka et al., 2006; Rodríguez-Sánchez et al., 2009). However, in the current work, the differences were not statistically significant in spite of the greater proportions in C10:0, C12:0, C14:0, and C16:0 reported in males. Latorre et al. (2009b) also found greater contents of these FA in fat from barrows. Lo Fiego et al. (2005) concluded that although sex had no statistically significant effect on lipid quality, gilts had a tendency toward a greater degree of unsaturation. In the present trial, fat from barrows contained relatively less PUFA than that from gilts, which agrees with Latorre et al. (2009a,b) who compared both sexes of pigs slaughtered at BW greater than 120 kg. The greater PUFA proportion in fat from gilts was due to the greater content of C18:2, which agrees with Piedrafita et al. (2001) and Peinado et al. (2008). All the C18:2 in the carcass is completely derived from the diet and thus would be related to feed intake. It plays an important role in human nutrition because it can reduce firmness and cohesiveness of adipose tissue and increase the fat oxidation rate (Wood et al., 2008).

The SFA proportion was not affected by dietary treatment although linear increases of some FA were detected (C12:0, C14:0, and C16:0). Also, no effect of Lys restriction was observed on MUFA, PUFA, or UFA proportions of subcutaneous fat. The lack of an effect of dietary Lys concentration on fat quality was expected because the influence of feeding Lys on carcass fat concentration depends on sex, BW, and environment (Campbell et al., 1988; Friesen et al., 1994; Jin et al., 2010), a greater or less effect. The influence of dietary Lys on fat quality has not been extensively studied, but results of this experiment indicated that dietary Lys has limited influence on carcass fat quality.

In conclusion, barrows tended to have less G:F, and had greater IMF content in meat and less PUFA proportion in subcutaneous fat than gilts. The restriction of dietary Lys from 7.0 to 6.0 g·kg⁻¹ reduced ADG without any effect on G:F, and increased the carcass fat thickness and the proportion of acceptable carcasses in gilts intended for dry-cured ham production. Different feeding programs (at least, based on Lys concentration in diet) might be needed for barrows and gilts to optimize the production of high quality dry-cured hams.

**LITERATURE CITED**


Bidner, B. S., M. Ellis, D. P. Witte, C. N. Carr, and F. K. McKeith. 2004. Influence of dietary lysine level, pre-slaughter fasting, and...
Dietary lysine restriction in diets for heavy pigs


