Fat, meat quality and sensory attributes of Large White × Landrace barrows fed with crude glycerine

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Abstract

The use of alternative raw materials like crude glycerine in animal feed to reduce final costs could be of interest as the sector seeks to increase its competitiveness. The aims of the present work were to evaluate the effect of crude glycerine on back-fat thickness and the proximate composition of pork and to examine the effect on pork quality of using growing-finishing feeds with different percentages of crude glycerine added. For this purpose 60 crossbreed (Large White × Landrace) barrows were subdivided into three groups according to the crude glycerine concentration administered in feed: C, control diet, no crude glycerine; and G2.5 and G5 with 2.5% and 5% added crude glycerine, respectively. This study evaluated proximate composition, pH, cooking losses, texture, colour coordinates, fatty acid profile, and sensorial analysis. No differences were found in any of the three groups studied (C, G2.5, G5) for measurements performed both before (with ultrasound equipment) and after slaughter (millimetre ruler). The proximate composition and the physical-chemical parameters of longissimus dorsi were similar between groups. There were no differences detected (p > 0.05) between the three groups as regards the CIELab coordinates, textural profile and sensory attributes. Therefore, 5% crude glycerine to replace corn could be used as an ingredient in pig feed without appreciably affecting the back-fat and meat quality characteristics.

Additional key words: pig; pork quality; glycerol; by-product; stearic acid.

Introduction

In recent years the decreased availability of the raw materials traditionally used in feed production (cereals, soybean, etc) and their high prices have had a substantial impact on the animal production sector where feeding accounts for about 70% of total costs (Tible et al., 2007). It is for this reason that the use of alternative raw materials in animal feed to reduce final costs could be of interest as the sector seeks to increase its competitiveness. Among such alternatives, crude glycerine, a by-product of biodiesel production, might be considered a useful source of energy. The global annual biodiesel production is projected to be about 41 billion litres in 2019 according to report by OECD-FAO (2012). Furthermore it seems that biodiesel production capacities are growing all over the world (Kovacs et al., 2011). For example, the European Union produced 5,140 million liters in 2005 and its production capacity was close to 10,850 million litters in 2012 (USDA, 2012). Biodiesel can be produced from different seeds (e.g. rapeseed, soybean, sunflowers, canola), palm oil, frying oils and fat. The esterification process produces glycerol as subproduct. One tonne of biodiesel gives about 100 kg of crude glycerine, which can be used as an energy source under oxidizing conditions since one mol glycerol yields 22 moles of ATP. Despite the fact that this by-product is extensively used in the food, cosmetic and pharmaceutical industries, its generalised use is limited due
to the possible presence of impurities (e.g. methanol, salts, fatty acids), so that the development of other uses, as in animal feed, could be important for the sustainability of biodiesel industries (Nitayavardhana & Khanal, 2011). In this respect some authors (Alexandre et al., 2012; Quispe et al., 2013) have confirmed the economic advantages of using crude glycerine, obtained from biodiesel, as a component of animal feed, since any reduction in feeding costs should lead to a reduction in meat and meat product prices.

Glycerol is a sweet-tasting product and so it is well-accepted by animals (Kerr et al., 2007). In addition, it can be converted into glucose in the liver and provide energy through the gluconeogenic pathway. It also has osmotic properties that can affect muscle quality through the use of crude glycerine as a substitute for more expensive raw materials, further research in this area is required.

The objectives of the present work were: (1) to evaluate the effect of crude glycerine on back-fat thickness and the proximate composition of pork and (2) to examine the effect on pork quality (pH, water losses, textural profile, colour, fatty acid profile and sensorial attributes) of using growing-finishing feeds with different percentages of crude glycerine added.

Material and methods

Animals and diets

All procedures involving animals were approved by the Ethics Committee of the University of Murcia, according to EU Directive 86/609 (OJEU, 1986) as modified by Directive 2003/65 (OJEU, 2003), which regulates the welfare of animals used in research and for scientific purposes. Sixty castrated crossbreed males (Large White × Landrace) were blocked by initial body weight (BW) (30.7 ± 0.02 kg; 80 ± 3.5 days of age) and assigned to 12 pen (5 pigs per pen, 1.5 m² space per pig) to evaluate the crude glycerine inclusion (Abengoa Bioenergía San Roque Cádiz, Spain) in the pig’s diet on fat and loin thickness (LT), proximal composition, pH, water holding capacity (WHC), cooking losses (CL), texture, colour and sensory quality. All piglets were castrated before weaning.

The trial lasted 82 days and was conducted from October to December. Three experimental treatments were established according to the crude glycerine concentrations administered in the growing and finishing feed: C, control diet (no crude glycerine), G2.5 and G5 with 2.5% and 5% of crude glycerine, respectively. Twenty animals per treatment were used (four pen per treatment). The maximum crude glycerine levels included (5%) were established considering the manufacture feed technology capacity. The crude glycerine partially replaced corn in the diets which were formulated to be isoenergetic. The digestible lysine and the metabolizable energy (ME) ratio was similar in all the diets, for each phase. The amino acid diets were formulated according to ideal protein concept according to the recommendations of FEDNA (2006). The composition of the diet and the crude glycerine is summarized in Table 1.

Grower diet was fed from 30.7 to 64.2 kg BW (80 to 125 days of age) and finisher diet from 64.2 to 97.3 kg BW (125 to 162 days of age). Feeds and water were provided ad libitum.

The day before slaughter, the back-fat thickness (BFT) was measured by ultrasound (Prosound 2) using a 172 mm linear probe applied between the 10th and 11th ribs; the image site was determined by palpation. In order to establish a correct contact between animal hide and transducer, the area was thoroughly clipped and oiled. The following measurements were made: BFT and LT.

Two batches of 30 animals (10 per treatment each one) were randomly selected to be slaughtered in two consecutive days. The transport from the farm to the slaughter-house was approximately half an hour (20 km located in Lorca, Murcia, Spain). Pigs were slaughtered according to Directive 1009/2009 (OJEU, 2009). The carcasses were chilled at 4°C for 24 h, and then longissimus dorsi muscle was obtained.
Fat and meat quality of pigs fed crude glycerine

Table 1. Composition of the diets used in the experiment

| Feed            | Grower diet a | Finisher diet b |
|-----------------|---------------|-----------------|
|                 | Crude glycerine, % | Crude glycerine, % |
|                 | 0 2.5 5  | 0 2.5 5 |
| Ingredients (g/100 g as feed) | | |
| Barley          | 30.8 30.8 30.5 | 38.5 38.1 37.4 |
| Wheat           | 30.0 30.0 30.0 | 25.0 25.0 25.0 |
| Soybean meal, 47% CP c | 17.0 17.4 18.1 | 15.0 15.5 16.1 |
| Corn            | 15.0 12.5 10.0 | 15.0 12.5 10.0 |
| Lard            | 3.70 3.59 3.51 | 3.02 3.05 3.10 |
| Crude glycerined d | — 2.50 5.00 | — 2.50 5.00 |
| Calcium carbonate | 1.16 1.15 1.15 | 1.31 1.55 1.54 |
| Monocalcium phosphate | 0.46 0.46 0.46 | 0.49 0.49 0.49 |
| Sodium bicarbonate | 0.39 0.20 — | 0.38 0.18 — |
| Sodium chloride | 0.30 0.20 0.15 | 0.40 0.20 0.40 |
| VTM premixe | 1.10 1.10 0.11 | 0.90 0.90 0.90 |

Calculated composition (g/100 g as feed) f

| Ingredient                  | Grower diet | Finisher diet |
|-----------------------------|-------------|---------------|
| ME, MJ kg⁻¹                 | 13.5 13.5 13.5 | 13.5 13.5 13.5 |
| Dry matter                  | 88.6 88.7 88.8 | 89.0 89.1 89.2 |
| Ash                         | 4.68 4.63 4.62 | 4.92 5.01 5.24 |
| Ether extract               | 5.75 5.36 5.39 | 5.00 5.00 5.00 |
| Neutral detergent fiber     | 11.7 11.5 11.3 | 12.0 11.8 11.5 |
| Linoleic acid               | 1.24 1.18 1.13 | 1.14 1.10 1.06 |
| Ileal digestible Lys, g kg⁻¹| 0.95 0.95 0.95 | 0.79 0.79 0.79 |

a Grower diet: 80-125 d. b Finisher diet: 125-162 d. c CP: crude protein. d Chemical composition: total glycerol, 86.66%; methanol, 0.0038%; moisture, 7.50%; ash, 5.88%; chloride, 3.06%; calcium, 0.0040%; sodium, 2.005%; potassium, 0.0526%. e VTM: vitamin and trace mineral; Provided (per kg of complete diet): 6.0 and 4.9 g of L-lysine, 0.9 and 0.2 g of L-threonine and 0.7 and 0.3 g of DL-methionine for growing and finishing feed, respectively; 8,000 IU of vitamin A; 1,100 IU of vitamin D3; 20 IU of vitamin E; 1 mg of vitamin K₃; 1 mg of vitamin B₁; 3 mg of vitamin B₂; 1 mg of vitamin B₆; 0.015 mg of vitamin B₁₂; 17 mg of niacin; 10 mg of pantothenic acid; 0.08 mg of biotin; 0.02 mg of folic acid; 50 mg of manganese; 50 mg of Mn; 0.5 mg of I; 90 mg of Zn; 10 mg of Cu; 90 mg of Fe, and 0.3 mg of Se; 10 IU of endo-1,4-beta-xylanase (CE 3.2.1.8) from Bacillus subtilis (LMG s-15136). f According to FEDNA (2003). g ME: metabolizable energy.

Back-fat thickness

At 24 h post-mortem, the BFT was measured in the carcasses in three points using a millimetre ruler: BFT₁ (measured in the back, at the first rib), BFT₂ (measured between the 9th and 10th ribs) and BFT₃ (measured in the thinnest layer of the gluteus medius muscle).

Sampling and physico-chemical analyses

Instrumental meat quality was assessed in the longissimus dorsi muscle. Each loin was then cut into different pieces to evaluate the following meat quality parameters:

— Proximate composition (moisture, total protein, intramuscular fat content) was assessed by AOAC (1990) procedures.

— The pH was measured using a portable Crison GLP21 equipment with a penetrating electrode (ISO 2917:1999). It was calibrated using two different potassium chloride standard (pH 4 and 7). The meat pH measurements were taken at 45 minutes (pH 45) and 24 hours (pH 24) post-mortem.

— Water-holding capacity (WHC) was expressed in percentage (Grau & Hamm, 1953). To determine CL, each sample (fillet 50 g weight, 20 mm thickness) was placed in polyethylene bag and cooked in a water bath at 75°C for 15 min until an internal temperature of 72°C. The differences in the weight of raw and cooked samples were used to calculate percentage of cooking losses (Honikel, 1998). These cooked meat samples were cut into 20 × 20 mm cubes, using a stainless steel cutter. A texture profile analysis (TPA) was made using a QTS-25 texture analyzer (Brookfield).
CNS Farnell, Borehamwood, Hertfordshire, England) equipped with a load cell of 25 kg and Texture Pro V. 2.1 software. Two consecutive cycles of 50% compression, with the cross-head moved at a constant speed of 30 mm min⁻¹ were carried out. Texture variables, hardness (expressed as N), cohesiveness (no units), springiness (expressed as mm), gumminess (expressed as N) and chewiness (expressed as N-mm) were calculated as described by Bourne (2002). Six measurements per sample were made.

— Colour measurements ($L^*$, $a^*$, $b^*$ coordinates) were made using a Minolta CR400 colorimeter calibrated against a standard white tile. Measurements were taken on the surface of the longissimus dorsi (8-mm diameter aperture, d/0 illumination system, D65 illuminant and a 2° standard observer). Chroma and hue value were calculated as $C^* = (a^2 + b^2)^{1/2}$ and $H = (\arctg b^*/a^*) \times 57.32$.

— Fatty acid profile in intramuscular fat was analyzed according to Granados (2001). Methylated samples were injected in an Agilent 6890 N Network GC System equipped with a flame ionisation detector and a phenyl-methyl-xyloxane capillary column (HP5), 30 m long and with an interior diameter of 0.32 mm and 0.25 m film thickness. The detector and injector were maintained at a temperature of 300°C and 280°C, respectively. Helium was used as carrier gas, at a flow of 3.2 mL min⁻¹ and a division ratio of 1:50. The methyl esters of fatty acids were quantified using undecanoic acid methyl ester as an internal standard.

All these analyses mentioned above (pH, proximate composition, WHC, colour coordinates and CL) were evaluated by duplicate at 24 h post-mortem. For the rest of the meat quality parameters (protein content, TPA, fatty acid profile and sensory analysis) the samples were frozen at −18°C until further analysis.

Sensorial evaluation

For the sensory analysis the pork loins were thawed in a conventional chiller at 4°C overnight. For cooking, the samples were placed between two heating plates covered with aluminium foil (Silanos, Liscia Average, Lavastoviglie Industriali, Italy) at 150°C for 6 min to reach an internal temperature of 72°C, as measured by a portable T200 thermometer (Digitron Instrumentation Ltd., Merd Lane, Hertford, UK). Rectangular pieces of approximately 15 × 20 mm from the loin centre were obtained and covered instantly with aluminium foil. Samples were kept at 60°C in sand baths (Braun, Esplugues de Llobregat, Barcelona, Spain) until they were presented to the panelists in a balanced order (Macfie et al., 1989). The panel was formed of eight assessors chosen from the staff of the University of Murcia with ages ranging between 24 and 45 years; five women and three men; all experienced in the profile assessment of different meat products and trained according to ISO 8586-2 (2008). Seven training sessions were carried out: in the first three, descriptors of raw/cooked pork loins were studied and the following four sessions were concerned with identifying, selecting and quantifying attributes to evaluate the meat. In both the training and assessment sessions, the samples were coded with random three digit numbers. Mineral water was provided for rinsing between samples. Sensorial analysis was carried out according to ISO 4121 (2003) using an unstructured scale of 10 cm. The descriptors used were: aroma intensity (AI), off-odour (OO), flavour intensity (FI), persistence (PER), meat colour (MC), juiciness (JUI), tenderness (TEN), chewiness (CHE) and fibrousness (FIB).

The standard National Pork Producer Council (NPPC, 1991) scale was used to determine the marbling (1 minimal infiltration, up to 6, maximal infiltration).

Statistical analysis

Data were analyzed with the statistical package SPSS 15.0 (Statistical Package for the Social Science). Animal was used as experimental unit. The effect of the different dietary treatments on meat quality was analysed using an analysis of variance (ANOVA). When the differences among groups were significant ($p < 0.05$), Tukey’s test at a significance level of $p < 0.05$ was carried out to evaluate the differences between the treatments. Pearson correlation coefficients were evaluated for the back-fat and LT.

Results

Back-fat and loin thickness

Table 2 shows that back-fat and LT measurements by ultrasound and with a millimeter ruler (BTF1, BF2
and BTF 3). No differences were found in any of the three groups studied (C, G2.5, G5) for measurements performed both before (with ultrasound equipment) and after slaughter (millimetre ruler). Significant Pearson correlation between BFT with BFT2 and BFT3 were found ($R^2 = 0.487$ and $0.581$; $p < 0.05$).

**Meat quality**

Proximate composition, pH and water content. Table 3 shows meat proximate composition, pH, WHC and CL from pigs fed different crude glycerine levels. These parameters did not vary by effect of crude glycerine inclusion in diets ($p > 0.05$).

Texture (textural profile analysis), colour coordinates ($L^*$, $a^*$ and $b^*$) and marbling. Meat texture results are shown in Table 4. The inclusion of crude glycerine in the feed did not have any effect ($p > 0.05$) on the meat texture parameters. Table 4 also shows the results of the objective instrumental evaluation of colour ($L^*$, $a^*$, $b^*$ and $C^*$). The coordinate means values were 49.85, 10.3 and –1.8 for $L^*$, $a^*$ and $b^*$ respectively, with no treatment effects ($p > 0.05$).

Fatty acid profile. Table 5 shows the fatty acid profile of intramuscular fat obtained from the longissimus dorsi muscle. No significant differences were observed in the pork fatty acid composition when crude glycerine was added in growing and finishing feeds.

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**Table 2.** Back-fat thickness (mean in mm) measured with millimetre ruler (BFT1, BFT2 and BFT3) and ultrasound (BFT and LT) in pigs fed with 0, 2.5 or 5% of crude glycerine

| Item | Control | G2.5 | G5 | SE | Significance |
|------|---------|------|----|----|--------------|
| n    | 20      | 20   | 20 | 0.06 | ns           |
| BFT1 | 39.6    | 43.9 | 40.5 | 0.05 | ns           |
| BFT2 | 26.4    | 26.8 | 26.2 | 0.08 | ns           |
| BFT3 | 23.1    | 26.3 | 25.8 | 0.57 | ns           |
| BFT  | 18.2    | 19.2 | 19.0 | 0.84 | ns           |
| LT   | 41.6    | 39.7 | 41.9 |      |              |

* Back-fat thickness: 1 (BFT1), measured at the first rib with the millimetre ruler; 2 (BFT2), measured between the 9th and 10th ribs with the millimetre ruler; 3 (BFT3), measured in the Gluteus medius muscle, at the lowest fat thickness area with the millimetre ruler; BFT, measured from the first hyperecogenic layer (skin) to the hyperecogenic layer above muscle (hypoeocogenic); Loin thickness (LT), measured from where the back-fat terminates to the bottom of the muscle (end of the hypoeocogenic layer). * Control, G2.5, G5: pigs fed with 0%, 2.5%, 5% crude glycerine in diet, respectively. * SE: standard error of the mean. * ns: non-significant ($p > 0.05$).

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**Table 3.** Proximate composition (%) (mean), pH (at 45 minutes and 24 hours post-mortem), water holding capacity (WHC, % free water) and cooking losses (CL, %) in longissimus dorsi from pigs fed with 0, 2.5 or 5% of crude glycerine

| Item          | Control | G2.5 | G5 | SE   | Significance |
|---------------|---------|------|----|------|--------------|
| Fat           | 3.45    | 4.30 | 3.80 | 0.246 | ns           |
| Moisture      | 73.24   | 72.26| 72.65| 0.492 | ns           |
| Protein       | 23.00   | 22.86| 22.74| 0.882 | ns           |
| Ash           | 1.45    | 1.46 | 1.40 | 0.130 | ns           |
| pH 45         | 6.09    | 6.11 | 6.17 | 0.042 | ns           |
| pH 24         | 5.35    | 5.31 | 5.39 | 0.020 | ns           |
| WHC*          | 71.46   | 73.70| 72.45| 0.508 | ns           |
| Cooking loss  | 26.49   | 27.12| 25.86| 0.442 | ns           |

* Control, G2.5, G5: pigs fed with 0%, 2.5%, 5% crude glycerine in diet, respectively. * SE: standard error of the mean. * ns: non-significant ($p > 0.05$). * WHC: water holding capacity.
Sensory analysis. Fig. 1 shows the sensory attributes of meat from pigs fed different crude glycerine levels. There were no differences among treatments groups for AI, OO, FI, PER, MC, JUI, TEN, CHE and FIB.

Table 4. Texture profile analysis, colour coordinates ($L^*$, $a^*$, $b^*$, $H^*$, $C^*$) and marbling in *longissimus dorsi* from pigs fed with 0, 2.5 or 5% of crude glycerine

| Item       | Treatment $^a$ | SE $^b$ | Significance $^c$ |
|------------|---------------|---------|-------------------|
|            | Control | G2.5 | G5     |             |
| Texture    |          |       |        |             |
| Gumminess  | 23.51   | 23.58 | 22.49  | 1.257   | ns     |
| Adhesiveness | −0.20  | −0.27 | −0.17  | 0.014   | ns     |
| Cohesiveness | 0.55   | 0.54  | 0.56   | 0.005   | ns     |
| Chewiness  | 99.44   | 90.38 | 80.55  | 4.942   | ns     |
| Springiness | 4.20   | 3.95  | 3.55   | 0.066   | ns     |
| Hardness   | 41.72   | 43.30 | 40.12  | 1.788   | ns     |
| Colour     |          |       |        |             |
| $L^*$      | 50.25   | 50.20 | 49.11  | 0.570   | ns     |
| $a^*$      | 10.51   | 9.97  | 10.38  | 0.166   | ns     |
| $b^*$      | −1.73   | −1.73 | −2.01  | 0.120   | ns     |
| $H^*$      | −9.78   | −10.32| −11.30 | 0.717   | ns     |
| $C^*$      | 10.17   | 10.16 | 10.61  | 0.154   | ns     |
| Marbling $^d$ | 1.22  | 1.28  | 1.16   | 0.053   | ns     |

$^a$ Control, G2.5, G5: pigs fed with 0%, 2.5%, 5% crude glycerine in diet, respectively. $^b$ SE: standard error of the mean. $^c$ ns, non-significant ($p > 0.05$). $^d$ Standard National Pork Producer Council (1991).

Table 5. Fatty acid composition (g/100 g) (mean) of intramuscular fat from pigs fed with 0, 2.5 or 5% of crude glycerine

| Fatty acid $^a$ | Treatment $^b$ | SE $^c$ | Significance $^d$ |
|----------------|---------------|---------|-------------------|
|                | Control | G2.5 | G5     |             |
| 10:0           | 0.09    | 0.09  | 0.10   | 0.003   | ns     |
| 12:0           | 1.38    | 1.14  | 1.36   | 0.095   | ns     |
| 14:0           | 1.30    | 1.41  | 1.34   | 0.023   | ns     |
| 16:0           | 24.56   | 24.75 | 24.59  | 0.326   | ns     |
| 16:1           | 2.08    | 2.16  | 2.26   | 0.052   | ns     |
| 18:0           | 11.84   | 10.88 | 11.56  | 0.166   | ns     |
| 18:1           | 40.45   | 41.06 | 41.16  | 0.338   | ns     |
| 18:2           | 17.08   | 17.51 | 17.28  | 0.263   | ns     |
| 18:3           | 0.16    | 0.08  | 0.10   | 0.027   | ns     |
| 20:0           | 0.70    | 0.72  | 0.66   | 0.012   | ns     |
| SFA            | 38.78   | 36.13 | 39.43  | 0.631   | ns     |
| TUFAs          | 61.22   | 63.87 | 60.58  | 0.631   | ns     |
| MUFA           | 43.98   | 46.28 | 43.19  | 0.736   | ns     |
| PUFA           | 17.24   | 17.59 | 17.38  | 0.263   | ns     |

$^a$ SFA: saturated fatty acid; TUFAs: total unsaturated fatty acid. MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid. $^b$ Control, G2.5, G5: pigs fed with 0%, 2.5%, and 5% crude glycerine in diet, respectively. $^c$ SE: standard error of the mean. $^d$ ns, non-significant ($p > 0.05$).

Discussion

Back-fat and loin thickness

In this work, crude glycerine had no effect on BFT, as confirm Lammers et al. (2008b), Hansen et al. (2009),

Table 5.
and Schieck et al. (2010), that found no significant differences in the meat from pigs fed with less than 15% crude glycerine added. In contrast, some authors like Hanczakowska et al. (2010) reported a decrease in adipose fat in animals (110 kg slaughter BW) fed with 10% crude crude glycerine (19.2 mm) compared with control pigs (21.6 mm) and those fed with 10% refined crude glycerine (20.9 mm). It is seems that more than 15% crude glycerine in the diet leads to a linear increase of fat depth at point BFT2 (tenth costal vertebra) and a lower percentage of fat free lean (Stevens et al., 2008).

Significant Pearson correlation between BFT with BFT2 and BFT 3 may be suitable the validity of using real-time ultrasound in animals before slaughter to develop equations to predict the thickness of back-fat in the carcasses pigs as reported Velázquez (2000) for pigs body weighing between 80 and 120 kg.

**Meat quality**

*Proximate composition, pH and water content*

The mean values obtained were 3.8% fat, 72.7% moisture, 22.8% crude protein and 1.4% ash, which are similar to those reported by Della Casa et al. (2009) in Italian Duroc and Italian Large White cross heavy pigs fed with different crude glycerine percentages. Teixeira & Rodrigues (2013) found similar levels of fat in Large White and Landrace cross pigs, with a slaughter weight between 80 and 100 kg.

Crude glycerine did not affect pH of meat, which agrees with other researches (Della Casa et al., 2009; Hansen et al., 2009; Berenchtein et al., 2010; Mendoza et al., 2010; Schieck et al., 2010). In contrasts, Lammers et al. (2008b) observed a slight trend for the loins of Cambrough 22 and L337 cross pigs fed 5% and 10% crude glycerine to have a higher final pH than the loins from control animals.

Similar results were found for WHC and CL in previous studies (Kijora & Kupsch, 1996; Lammers et al., 2008b; Hansen et al., 2009; Berenchtein et al., 2010; Mendoza et al., 2010; Schieck et al., 2010). However, Mourot et al. (1993) emphasized a reduction in water losses and CL in Large White animals fed 5% crude glycerine from 30 to 100 kg of live weight. This was attributed to its action on cell osmotic pressure, what would increase the water content, and then, the WHC. The muscle fibers would be hyperhydrated, due to the increased water content of cells subjected to a lower degree of protein denaturation, especially during heat treatment. Similar results were described by Aihart et al. (2002), who found a trend towards a reduction in these parameters in meat from pigs fed glycerol. In addition, in a study with pigs fed 10% crude or refined glycerine, Hanczakowska et al. (2010) also found a higher WHC. The data regarding water losses in the literature vary substantially and Schieck et al. (2010) identified the NaCl content of feed as the main factor causing differences between groups. Sodium is often added as a catalyst in biodiesel production, which turns into NaCl after purification. The amount of NaCl in crude glycerine depends on the refining technique used, and should be taken into account when formulating diets (Kerr et al., 2007). An increased intake of NaCl would result in a higher salt content in the mus-
cle, which would result an increased WHC of meat due to myofibril edema. In our experiment, the Na+ and Cl− content of the crude glycerine used in feed was considered and similar electrolytic balance was formulated in feed for each phase.

Texture (Textural Profile Analysis), colour coordinates (L*, a* and b*) and marbling

Similar results were found by other authors as Duttlinger et al. (2008), Della Casa et al. (2009), Hansen et al. (2009) and Berenchttein et al. (2010) who evaluated the meat texture with a Warner-Bratzler cell (WB). Although different methodology was used (WB vs. TPA), Caine et al. (2003) found a positive correlation between the maximum force parameter obtained by the WB method and hardness (maximum force obtained during the first compression cycle) resulting from a TPA analysis. Others, including Gipe (2008), noted a tendency to greater hardness in the meat from pigs fed 2.5% crude glycerine than meat from a control group and a group fed 5% crude glycerine, which was attributed to the more apparent connective tissue in the meat samples. In the present study the absence of significant differences in texture parameters between the 2.5% and 5% crude glycerine groups suggests that about 5% crude glycerine could be included in pig diet without affecting meat tenderness.

There were no differences between treatments for the CIELab coordinates nor for the C* and H*, which agrees with the results obtained by other authors (Della Casa et al., 2009; Hanczakowska et al., 2010; Schieck et al., 2010). These values could be affected by numerous intrinsic and extrinsic factors that affect meat colour (Sañudo et al., 1998). Marbling, based on a subjective standard scale (NPPC, 1991), showed no significant differences between the different groups, as reported by Gipe (2008), Mendoza et al. (2010) and Schieck et al. (2010), in meat of pig fed glycerine.

Fatty acid profile

The fatty acid profile of intramuscular fat obtained from the longissimus dorsi muscle was not affected when crude glycerine was added in growing and finishing feeds. These results agree with the reports of other authors in pigs fed glycerine (Cerneau et al., 1994; Mourot et al., 1994; Kijora et al., 1997; Lammers et al., 2008c; Della Casa et al., 2009).

Other authors have found effects of glycerine in feeds on fatty acid profile. Thus, linoleic acid (18:2) remained unchanged by the effect of crude glycerine addition, in contrast to the findings of Mourot et al. (1993), Cerneau et al. (1994), Kijora et al. (1997), Lammers et al. (2008b) and Della Casa et al. (2009), who found this fatty acid to be reduced in pigs fed crude glycerine. Mourot et al. (1993) suggested that this change in the fatty acid profile could be related to a lower consumption of corn in the pig diet, which is rich in linoleic acid (FEDNA, 2003). In our study, the linoleic acid content in diet was also reduced by glycerol incorporation but differences between dietary treatments were very low (Table 1). The fact that linoleic acid is the most variable fatty acid as regards its concentration in meat is perhaps due to its being an essential fatty acid that cannot be synthesized de novo by animals, so that it must be taken from the diet (Granados, 2001). In addition, since fat composition closely depends on the fatty acid profile of the diet, the feed ingredients added will determine the fat quality, glycerol is an important structural component of triglycerides and phospholipids that can act as an intermediate in the lipogenesis pathway and yield energy through the citric acid cycle (Duttlinger et al., 2012). On the other hand, crude glycerine could also been source of fatty acid per se, as previous studies found that crude glycerine could contain 56% of fatty acids, mainly unsaturated (Chiloane et al., 2013). So the meat fatty acid profile could be influenced by a remainder of fatty acid in crude glycerine. In the present study, the crude glycerine fat content was negligible.

Sensory analysis

Crude glycerine included in feed had no effect on the sensory quality of pork. These results agree with those observed by Lammers et al. (2008a) and Schieck et al. (2010). In addition, Hanczakowska et al. (2010) found no significant differences in tenderness or juiciness, but a significant decrease in odour and taste-related parameters in pigs fed crude crude glycerine, that were attributed to the effect of certain substances present in the crude preparation rather than glycerol per se.

In conclusion, the crude glycerine from the elaboration of biodiesel can be used at up to 5% in growing-
finishing feed for pigs to replace corn without affecting pork meat quality, including the sensory characteristics of cooked pork.

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References

Airhart JC, Bidner TD, Southern LL, 2002. Effect of oral glycerol administration with and without betaine on carcass composition and meat quality of late-finishing barrows. J Anim Sci 80: 71 [Abstr].

Alexandre L, Aragao-Leoneti V, Borges SVW, 2012. Glycercol as a byproduct of biodiesel production in Brazil: alternatives for the use of unrefined glycerol. Renew Energ 45: 138-145.

AOAC, 1990. Official methods of analysis, 15th ed. Association of Official Agricultural Chemists. Washington DC, USA.

Berenchtein B, Batista Costa L, Barbosa Braz D, Vezzoni de Almeida V, Panhoza Tse ML, Shiguero Miyada V, 2010. Utilização de glicerol na dieta de suínos em crescimento e terminação. Rev Bras Zootecn 39(7): 1491-1496.

Bourne M, 2002. Food texture and viscosity. Concept and measurement. Academic Press, London. 427 pp.

Caine WR, Aalhus JL, Best DR, Dugan MER, Jeremiah LE, 2003. Relationship of texture profile analysis and Warner-Bratzler shear force with sensory characteristics of beef rib steaks. Meat Sci 64: 333-339.

Cerneau P, Mourot J, Peyronnet C, 1994. Effect du glycérol alimentaire sur la qualité de la viande de porc et le rendement technologique du jambon cuit. Journées de la Recherche Porcine en France 26: 193-198. [In French, English abstract].

Chiloane EK, Kanengoni AT, Siebrits FK, 2013. Effect of crude glycerol from South African biodiesel production on growth, carcass characteristics and pork quality of pigs. South Afr J Anim Sci 43(2): 159-166.

Della Casa G, Bochicchio D, Faeti V, Marchetto G, Poletti E, Garavaldi A, Pancirolli A, Brogna N, 2009. Use of pure glycerol in fattening heavy pigs. Meat Sci 81: 238-244.

Duttlinger W, Tokach MD, Dritz SS, Derouchez JM, Nelssen JL, Goodband RD, Prusa KJ, 2008. Effects of increasing dietary glycerol and dried distillers grains with solubles on growth performance of finishing pigs. J Anim Sci 86(2): 607. [Abstr].

FEDNA, 2003. Tablas FEDNA de composición y valor nutritivo de alimentos para la fabricación de piensos compuestos, 2nd ed. Fundación Española para el Desarrollo de la Nutrición Animal, Madrid, Spain.

FEDNA, 2006. Necesidades nutricionales para ganado porcino: Normas FEDNA. Fundación Española para el Desarrollo de la Nutrición Animal, Madrid, Spain.

Gipe A, 2008. Effects of dried distillers grains with soluble on pork loin quality and sow fat quality. Thesis, Kansas State University. 72 pp.

Granados MV, 2001. Influencia del genotipo y la dieta sobre calidad de la canal y de la carne porcina. Efecto del α-tocoferol acetato sobre la estabilidad de la oxidación de la carne. Thesis. Universidad de Murcia, Murcia. 248 pp.

Grau R, Hamm R, 1953. Eine einfache Methode zur Bestimmung der Wasserbindung im Mukel. Naturwissenschaften 40: 29-30.

Hanczakowska E, W’glarz K, Szymczyk B, Hanczakowski P, 2010. Effect of adding crude or refined glycerol to pig diets on fattening performance, nutrient digestibility and carcass evaluation. Anim Sci 10(1): 67-73.

Hansen CF, Hernández A, Mullan BP, Moore K, Trezona-Murray M, King RH, Pluske JR, 2009. A chemical analysis of samples of crude glycerol from the production of biodiesel in Australia, and the effects of feeding crude glycerol to growing-finishing pigs on performance, plasma metabolites and meat quality at slaughter. Anim Prod Sci 49: 154-161.

Honikel KO, 1998. Reference methods for the assessment of physical characteristics of meat. Meat Sci 49: 447-457.

ISO, 1999. Meat and meat products. Determination for pH. International Organization for Standardization 2917.

ISO, 2003. Sensory analysis. Guidelines for the use of quantitative response scales. International Organization for Standardization 4121.

ISO, 2008. Sensory analysis. General guidance for the selection, training and monitoring of assessors, Part 2. Expert sensory assessors. International Organization for Standardization 8586-2.

Kerr BJ, Dozier WA, Bregendahl K, 2007. Nutritional value of crude glycerin for nonruminants. Proc 23rd Annual Carolina Swine Nutrition Conference, November 13, Raleigh, NC, USA. pp: 6-18.

Kijora C, Kupsch RD, BergnerH, Wenk C, Prabucki AL, 1997. Comparative investigations on the utilization of glycerol, free fatty acids, free fatty acids in combination with glycerol and vegetable oil in fattening pigs. J Anim Physiol Anim Nutr 77: 127-138.

Kijora C, Kupsch RD, 1996. Evaluation of technical glycerols from “biodiesel” production as a feed component in fattening pigs. Lipid/Fett 98: 240-245.
the protection of animals used for experimental and other scientific purposes. Official Journal of the European Communities L 358: 1-29.

OJEU, 2003. Directive 2003/65/EC of the European Parliament and of the Council of 22 July 2003 amending Council Directive 86/609/EEC on the approximation of laws, regulations and administrative provisions of the Member States regarding the protection of animals used for experimental and other scientific purposes. Official Journal of the European Communities L 230: 32-33.

OJEU, 2009. Council Directive 2009/2009/EC, on the protection of animals at the time of slaughter or killing. Official Journal of the European Communities L 303: 1-30.

Parker AJ, Dobson GP, Fitzpartrick LA, 2007. Physiological and metabolic effects of prophylactic treatment with the osmolytes glycerol and betaine on Bos indicus steers during long duration transportation. J Anim Sci 85: 2916-2923.

Quispe CsAG, Coronado CJR, Carvalho J, 2013. Glycerol: production, consumption, prices, characterization and new trends in combustion. Renew Sust Energ Rev 27: 475-493.

Sañudo C, Sánchez A, Alfonso M, 1998. Small ruminant production systems and factors affecting lamb meat quality. Meat Sci 49(1): 29-64.

Schieck GC, Shurson BJ, Kerr BJ, Johnston LJ, 2010. Evaluation of glycerol, a biodiesel co-product, in grow-finish pig diets to support growth and pork quality. J Anim Sci 88: 3927-3935.

Stevens JA, Schinckel M, Latour D, Kelly D, Sholly B, Legan B, Richert B, 2008. Effects of feeding increasing levels of glycerol with or without distillers dried grains with solubles in the diet on grow-finish pig growth performance and carcass quality. J Anim Sci 86: 606. [Abstr].

Teixeira A, Rodrigues, 2013. Pork meat quality of Preto Alentejano and Commercial Large White landrace cross. J Integrat Agr 12: 1961-1971.

Tible SJ, Cook DR, Balfagon A, Van Kempen T, 2007. Novedades en la alimentación de lechones. XXIII Curso de Especialización FEDNA, Fundación Española para el Desarrollo de la Nutrición Animal, Madrid.

USDA, 2012. EU Biofuels Annual 2012. United States Department of Agriculture. Available in http://www.usda-france.fr/media/Biofuels%20Annual_The%20Hague_EU-27_6-25-2012.pdf.

Velázquez PA, 2000. Predicción del contenido de cortez primarios en canales porcinos y en cerdos vivos. Available in http://www.disa.bi.ehu.es/spanish/asignaturas/17223/Alimentacion_Corte_Carne.pdf.