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# Effects of inclusion of sorghum distillers dried grains with solubles (DDGS) in diets for growing and finishing pigs

A. Cerisuelo[1, *], V. Moset[1], J. Bonet[2], J. Coma[2] and M. Lainez[1]

[1] *Centro de Investigación y Tecnología Animal (CITA-IVIA). Pol. Ind. La Esperanza, 100. 12400 Segorbe, Castellón. Spain*

[2] *Grupo Vall Companys. Pol. Ind. El Segre, Parc 410. 25191 Lleida. Spain*

## Abstract

The effects of sorghum distillers dried grains with solubles (sorghum-DDGS) in growing pig diets on growth performance and carcass quality were investigated. A total of 204 animals of 13.9 ± 2.60 kg body weight (BW) were allocated into two dietary treatments, a conventional diet (C) and a diet containing sorghum-DDGS (DDGS). DDGS inclusion levels used were 150 g kg$^{-1}$ in pigs from 14-40 kg BW, 300 g kg$^{-1}$ from 40-80 kg BW and 350 g kg$^{-1}$ from 80 kg BW to slaughter. Animals' body weight, feed intake, backfat thickness (BF) and loin depth (LD) were measured throughout the study. Protein, fibre and fat content of sorghum-DDGS were approximately three times-fold those of the whole grain. During the nursery period, feed intake and final BW tended to be lower in the group of pigs fed DDGS compared to the piglets fed C diet (871.4 g d$^{-1}$ and 30 kg *vs* 951.1 g d$^{-1}$ and 31 kg). During the growing period no differences were found on growth performance between treatments. Pigs fed sorghum-DDGS showed higher BF than pigs fed C diet (10.96 mm *vs* 9.80 mm, $p < 0.001$). No differences were found on LD and carcass weight and yield between treatments. Thus, although 150 g kg$^{-1}$ of sorghum-DDGS in nursery diets tended to reduce growth performance, inclusion rates up to 300-350 g kg$^{-1}$ during the finishing phase did not affect it, but led to fatter carcasses.

**Additional key words:** carcass characteristics; growth performance; pigs; *Sorghum bicolor*.

## Resumen

**Efectos de la inclusión de granos secos de destilería con solubles de sorgo (DDGS) en dietas de transición y cebo en porcino**

Los efectos de la inclusión de granos de sorgo secos de destilería con solubles (DDGS-sorgo) en dietas de cerdos sobre el rendimiento productivo y la calidad de la canal fueron investigados. Un total de 204 animales de 13,9 ± 2,60 kg de peso vivo (PV) se dividieron en dos tratamientos, unos alimentados con un pienso convencional (C) y otros con un pienso con DDGS-sorgo (DDGS). Los niveles de inclusión de DDGS fueron: 150 g kg$^{-1}$ en cerdos de 14-40 kg PV; 300 g kg$^{-1}$ de 40-80 kg PV y 350 g kg$^{-1}$ de 80 kg PV hasta sacrificio. Durante el estudio se midió el peso, consumo, espesor de grasa dorsal (EGD) y la profundidad de lomo (PL) de los animales. El contenido en proteína, fibra y grasa de los DDGS-sorgo fue alrededor de tres veces superior al del grano. Durante la transición, el consumo de pienso y el peso final tendió a ser menor en el grupo DDGS que en el grupo C (871,4 g d$^{-1}$ y 30 kg *vs* 951,1 g d$^{-1}$ y 31 kg). En cebo no se encontraron diferencias entre tratamientos. Los animales alimentados con DDGS-sorgo mostraron mayor EGD que los del grupo C (10,96 *vs* 9,80 mm, $p < 0,001$). La PL y el peso y rendimiento de la canal fueron similares entre tratamientos. Por lo tanto, si bien concentraciones de 150 g kg$^{-1}$ de DDGS-sorgo redujeron los rendimientos productivos en transición, niveles de 300-350 g kg$^{-1}$ durante el cebo no los afectaron, aunque produjeron canales más grasas.

**Palabras clave adicionales:** características de la canal; cerdos; rendimiento productivo; *Sorghum bicolor*.

*Corresponding author: cerisuelo_alb@gva.es
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Abbreviations used: AA (amino acid); ADF (acid detergent fibre); ADFI (average daily feed intake); ADG (average daily gain); ADL (lignin); BF (backfat); BW (body weight); C (control diet); CF (crude fibre); CP (crude protein); DDGS (distiller dried grains with solubles); DM (dry matter); EE (ether extract); FCR (feed conversion ratio); LD (loin depth); NDF (neutral detergent fibre); NDSF (neutral detergent soluble fibre).

# Introduction

Distiller dried grains with solubles (DDGS) are produced as a co-product from ethanol production from grain. It is expected that in the near future, the number of ethanol industries will grow importantly. Consequently, there will be an over-supply of distillers grains that will need to be eliminated. Spain ranked third in in the list of countries producing fuel bioethanol in the European Union in 2011 with 400 million of litres of bioethanol (EurObserv'Er 2012) and the production of biofuels is also expected to continuously expand.

Currently, there is no other industry than the livestock sector to absorb the DDGS, thus it is necessary to increase research on their value and use in livestock feeds. The interest of DDGS in animal feeding is mainly due to the three-fold increase in the concentration of nutrients compared to the original grain. However, DDGS composition is highly variable depending on the variety and quality of the grains used, as well as the efficiency of starch conversion by the industry (Spiehs *et al.*, 2002; Cozannet *et al.*, 2010).

Maize (*Zea mays* L.) is the primary grain used in wet mills and dry-grind ethanol plants because of its high fermentable starch content compared to other feedstuffs. Among the main cereals used for animal nutrition sorghum (*Sorghum bicolor* L., Moench) is comparable in composition to maize. Sorghum grain ranks the 5$^{th}$ place in cereals for global production (Faostat, 2008; available in http://faostat.fao.org) and is a viable feedstock for ethanol production (Wang *et al.*, 2008). It contains 96% the energy content of maize (NRC, 1998; INRA, 2004), therefore, it is expected that sorghum-based DDGS have a similar composition and implications on animal performance than maize-based DDGS. Additionally, sorghum grains require less rainfall during the growing season than maize and it is therefore cheaper to produce (Klopfenstein *et al.*, 2008). Moreover, its use is less competitive with human feeding than other cereals, an issue of global relevance since many countries in the world base their diets on cereals such as maize, wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.). All this makes sorghum-DDGS a reliable alternative feedstuff for pig feeding.

However, sorghum-DDGS may contain higher fibre content and lower fat levels than maize-DDGS, and this may result on lower amino acid (AA) digestibility (Stein & Shurson, 2009; Urriola *et al.*, 2009) and animal performance. Additionally, some varieties of sorghum contain elevated levels of tannins, which might decrease feed palatability and reduce performance (Hastad, 2005). All this have discouraged nutritionists from using substantial amounts of sorghum-DDGS in swine diets and decrease its recommended inclusion levels compared to other cereals based DDGS. Although the number of studies with sorghum-DDGS in pigs is low, some of them reported inclusion levels of sorghum-DDGS from 150 to 200 g kg$^{-1}$ in weanling pigs and up to 300 g kg$^{-1}$ in growing pig diets with no negative effects on growth (reviewed by Stein & Shurson, 2009).

A study was conducted to evaluate the consequences of feeding pigs high levels of DDGS from sorghum grains to pigs on growth performance (14 to 107 kg), estimated body composition and carcass yield and its relation with DDGS chemical composition.

# Material and methods

## Animals and experimental design

The experimental procedures were approved by the Instituto Valenciano de Investigaciones Agrarias Animal Ethics Committee and fulfilled the European regulations for the Care and Use of Animals for Scientific Purposes. Two hundred and four nursery ([Landrace × Large White] × Pietrain) pigs were weaned at 28 ± 3 days of age. After weaning, animals were distributed in a room different from that of the experiment for 21 days until they reached 13.9 ± 2.60 kg body weight (BW, 47 ± 3 days of age) and fed the same conventional prestarter feed. At the beginning of the study (day 0), animals were moved to the experimental facility. It was an environmentally controlled room with 16 pens and pigs were distributed according to BW and sex in 8 pens per treatment (4 pens per sex and treatment; 12-14 animals per pen and 102 pigs per dietary treatment). Additionally, from the 8 pens per dietary treatment 4 of them were constituted by light pigs (12.1 ± 0.71 kg BW in C and 12.5 ± 1.40 kg BW in DDGS) and the other 4 by heavy pigs (15.5 ± 1.63 kg BW in C and 15.5 ± 0.77 kg BW in DDGS). Pens were provided with a conventional nursery feeder with five feeding spaces and two nipple drinkers. Additionally, the pens had part-slatted, part-solid floors (plastic slat) and were provided with a central area of supplementary floor heating in panels integrated in the flooring system which assures a better meet of the individual pig needs. This first part of the study (nursery study) had a duration of 28 days. Mean ambient temperature was set at 30°C the first week post-weaning and decreased gradually until the end of the nursery period.

At 38.9 ± 6.33 kg BW, a total of 190 pigs from the initial 204 were separated in 38 growing-finishing pens (19 pens per treatment; 10 pens being of females and 9 pens of males) of five animals each distributed within three environmentally controlled rooms. Each nursery pen was divided in two fattening pens according to pig BW within the original pen (and thus, according to nursery treatment and sex). Additionally, with the remaining pigs, six pens were made according to BW, nursery treatment and sex. Thus, during the growing-finishing phase, pigs were maintained in the same feeding treatment than that of the nursery period. Animals were distributed among rooms in order to assure that all rooms had the same number of pens per treatment and sex. In this phase, pigs were fed using a conventional single-space feeder provided with a nipple drinker for growing pigs. Pigs were reared in these conditions until slaughter (106.7 kg BW and 166 ± 3 days of age).

Dietary treatments consisted on providing two different diets containing different sorghum-based DDGS levels during the nursery (14 to 30 kg BW), growing (40 to 80 kg BW) and finishing (80 to 107 kg BW) periods. The two diets used included 0% (C) and a fixed percentage of sorghum-DDGS (DDGS) which was different depending on the growing phase. The DDGS diets contained 150 g $kg^{-1}$ (15DDGS), 300 g $kg^{-1}$ (30DDGS) and 350 g $kg^{-1}$ (35DDGS) in the nursery, growing and finishing periods, respectively. From the end of the nursery period to the beginning of the growing period (2 weeks), all the pigs received a common feed in order to get adapted to the fattening feeds.

## Feeds

Table 1 shows ingredient and nutrient composition of the experimental diets. Dietary formulation was based on net energy and standardized ileal digestible (SID) lysine. Diets including sorghum-DDGS were formulated to be isoenergetic and isoproteic with C diets and all feeds were provided in a pelleted form.

All the sorghum-DDGS used in this trial were obtained from a single source. Feed and water were provided *ad libitum* during all the growing period (nursery and finishing phases) using pelleted diets.

## Laboratory analyses

Feeds used in this study were manufactured using two sorghum-DDGS batches. From each batch, one representative sample of sorghum-DDGS was taken and analysed (n = 2). Sorghum-DDGS were presented in a pelleted form thus increasing the homogeneity of the samples taken for analysis. Additionally one representative sample of each feed (nursery and growing-finishing feeds) was taken. The different feeds and the sorghum-DDGS were analyzed for dry matter, ash, crude fibre (CF), crude protein (CP) and ether extract (EE) following the AOAC (2005) methods (Tables 1 and 2). Additionally, the neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin (ADL) content were obtained following the methods of Van Soest *et al.* (1991) with a thermo-stable amylase pre-treatment (Tables 1 and 2). All feed analyses were carried out at the Animal Science Department of the Universitat Politècnica de València.

The AA profile of the DDGS (Table 3) was determined after acid hydrolysis with 6 N HCl at 110°C for 23 h as previously described Liu *et al.* (1995), using a Waters (Milford, MA, USA) HPLC system consisting of two pumps (Mod. 515, Waters), an autosampler (Mod. 717, Waters), a fluorescence detector (Mod. 474, Waters) and a temperature control module. Aminobutyric acid was added as internal standard after hydrolysation. The AA were derivatised with AQC (6-aminoquinolyl-N-hydroxysuccinimidyl carbamate) and separated with a C-18 reverse-phase column Waters AcQ. Tag (150 mm × 3.9 mm). Methionine and cystine were determined separately as methionine sulphone and cysteic acid respectively after performic acid oxidation followed by acid hydrolysis.

Additionally, the neutral detergent soluble fibre (NDSF) content of the sorghum-DDGS was analyzed using a modification of the methods of Hall *et al.* (1997) described in Martínez-Vallespín *et al.* (2011). Briefly, NDSF includes soluble and insoluble pectins, soluble hemicelluloses (arabinoxylans and β-glucans), fructans and oligosaccharides and is calculated as the difference between the organic matter fraction and the starch, protein, and NDF (corrected by CP content) fractions, all included in the ether-ethanol insoluble residue.

## Measurements

Pigs were weighed at the beginning and at the end of each growing period. Also, the amount of feed of-

**Table 1.** Experimental diets composition and analyses (g kg$^{-1}$, as-fed basis unless otherwise indicated) in different periods

| | Nursery | | Growing | | Finishing | |
|---|---|---|---|---|---|---|
| | Control | 15DDGS | Control | 30DDGS | Control | 35DDGS |
| Ingredients | | | | | | |
| Maize | 351 | 290 | 285 | 200 | 302 | 229 |
| Soybean meal | 270 | 190 | 171 | 53 | 133 | 0 |
| Wheat | 150 | 150 | 0 | 0 | 0 | 0 |
| Barley | 100 | 86 | 200 | 0 | 169 | 79 |
| Sorghum DDGS | 0 | 150 | 0 | 300 | 0 | 350 |
| Sorghum | 0 | 0 | 141 | 268 | 0 | 0 |
| Hominy feed | 0 | 0 | 60 | 60 | 100 | 100 |
| Rice bran | 0 | 0 | 60 | 30 | 120 | 91 |
| Rapeseed meal | 0 | 0 | 0 | 0 | 80 | 50 |
| Lard | 43 | 48 | 20 | 30 | 20 | 30 |
| Sugarcane molasses | 20 | 15 | 25 | 25 | 50 | 40 |
| Calcium carbonate | 9.1 | 9.1 | 11.0 | 11.0 | 10.4 | 10.4 |
| Monocalcium phosphate | 11.4 | 11.4 | 2.0 | 2.0 | 0 | 0 |
| Lysine | 8.4 | 11.3 | 5.5 | 10.6 | 3.9 | 9.5 |
| Triptophan | 0.1 | 0.3 | 0 | 0.4 | 0 | 0.4 |
| Methinonine | 3.0 | 3.2 | 0.6 | 1.0 | 0.7 | 1.2 |
| Treonine | 2.4 | 2.7 | 0.7 | 1.2 | 0.5 | 1.0 |
| Salt | 4.3 | 3.0 | 3.7 | 1.0 | 3.0 | 1.3 |
| Liquid acid | 8.0 | 8.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Phytase | 0 | 0 | 0.2 | 0.2 | 0.2 | 0.2 |
| Vitamin-mineral premix[1, 2] | 15 | 15 | 5.0 | 5.0 | 5.0 | 5.0 |
| Nutrients | | | | | | |
| Dry matter | 899 | 906 | 903 | 906 | 907 | 912 |
| Net energy[3], MJ kg$^{-1}$ | 10.3 | 10.3 | 10.1 | 10.1 | 9.8 | 9.8 |
| Crude protein | 164 | 188 | 155 | 171 | 151 | 169 |
| SID Lysine[3] | 12.1 | 12.0 | 8.9 | 8.9 | 8.2 | 8.1 |
| Ether extract | 69 | 89 | 55 | 79 | 60 | 93 |
| Crude fibre | 2.4 | 2.6 | 3.9 | 3.2 | 5.9 | 4.4 |
| Neutral detergent fibre | 102 | 118 | 129 | 130 | 173 | 168 |
| Acid detergent fibre | 34 | 40 | 53 | 43 | 75 | 63 |
| Ash | 50 | 52 | 46 | 42 | 58 | 56 |

[1] Vitamin-mineral premix in nursery diets (provided per kilogram of feed): 10,050 IU of vitamin A; 2,000 IU of vitamin D3; 30 mg of vitamin E; 2.10 mg of vitamin K; 2.10 mg of vitamin B1; 4.08 mg of vitamin B2; 0.03 mg of vitamin B12; 24.9 mg of nicotinic acid; 14.7 mg of pantothenic acid; 0.11 mg of folic acid, 0.09 mg of biotin; 80 mg of Fe; 160 mg of Cu; 0.41 mg of Co; 100 mg of Zn; 43.20 mg of Mn; 2.25 mg of I and 0.23 mg of Se. [2] Vitamin-mineral premix in growing-finishing diets (provided per kilogram of feed): 10,000 IU of vitamin A; 2,000 IU of vitamin D3; 40 mg of vitamin E; 6 mg of vitamin K; 1 mg of vitamin B1; 6 mg of vitamin B2; 0.02 mg of vitamin B12; 29 mg of nicotinic acid; 11.71 mg of pantothenic acid; 0.5 mg of folic acid, 0.06 mg of biotin; 80 mg of Fe; 25 mg of Cu; 0.40 mg of Co; 100 mg of Zn; 43.20 mg of Mn; 2.25 mg of I and 0.09 mg of Se. [3] Calculated values based on FEDNA (2010) feed composition tables.

fered and feed refusals was controlled at this time. Feed intake was measured by pen by weighing the amount of feed offered over the experimental period and by weighing the amount of feed refused at the time of animal weighing.

Average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) were then calculated. Backfat (BF) and loin depth (LD) were measured at the P2 position (above the last rib at approximately 6.0-6.5 cm from midline), using a B-mode ultrasound device (Agroscan A16, Angoulême, France) at the end of the study. At slaughter, carcass weight and carcass yield were registered and calculated.

## Statistical analysis

Data were analyzed as a completely randomized design with treatments arranged factorially (2 × 2) using the GLM procedure of SAS (2002). The model

**Table 2.** Sorghum-based distillers dried grains with soluble (DDGS) and sorghum grain chemical composition (g kg$^{-1}$, as-fed basis)

| | Sorghum-based DDGS[1] | Sorghum grain[2] |
|---|---|---|
| Dry matter | 902 | 870-890 |
| Crude protein | 304 | 89-92 |
| Ether extract | 97 | 27-30 |
| Crude fibre | 49 | 21-24 |
| Neutral detergent fibre | 239 | 80-180 |
| Acid detergent fibre | 79 | 38-83 |
| Lignin | 66.7 | 7.0 |
| Neutral detergent soluble fibre | 79.4 | – |
| Ash | 44 | 14 |

[1] Two samples (from two different sorghum-DDGS batches) were analysed (n = 2). [2] Mean composition from NRC (1998) and FEDNA (2010).

included sex (males and females) and diet (C and DDGS) as main effects and also the interaction. For growth performance data, pen was considered the experimental unit; however for BF, LD and carcass weight the experimental unit was the animal. For final BW, initial BW was used as a covariate both in the nursery and the fattening period.

In all cases, statistical significance level was set at 5% (≤ 0.05), and an $\alpha$ of 0.05 > $p \leq 0.10$ was considered a trend.

# Results

## Sorghum-DDGS composition

The CP, CF and EE concentration of sorghum-based DDGS was approximately three times-fold than the concentrations for these nutrients expected for the sorghum grain (Table 2). Regarding other composition parameters such as NDF, ADF and ADL, the ratio with the original grain was more variable. The percentage of NDF, ADF and ADL was higher in the DDGS compared to the whole grain. The value of NDSF obtained for sorghum-DDGS in this study was 79.4 g NDSF g DM$^{-1}$.

Concerning the AA profile, the AA content of sorghum-DDGS expressed as the percentage of CP showed a similar profile to that reported for the sorghum grains (Table 3). When the AA content was expressed in grams per 100 grams of DDGS, results showed, as expected, a three-fold increase (from 3.1 to 3.4 times-fold) respect to those found in sorghum grains (Table 3).

## Growth performance and body composition

In the present study, inclusion rates of 15% sorghum-DDGS in the diet of nursery pigs (13.9 ± 2.60 kg to 30.4 ± 5.53 kg BW) led to non-significant differences on ADG but a tendency ($p < 0.10$) to a lower ADFI and BW the end of the nursery period in the DDGS group compared to the C group (Table 4). However, feed efficiency was similar between groups. During the nursery phase, no differences in growth performance were found between different sexes and also, the interaction between sex and treatment was not significant.

During the growing period, the inclusion of 30% of sorghum-DDGS tended to decrease ($p = 0.064$) ADG with no significant effects on ADFI and feed efficiency. However, the inclusion of 35% of sorghum-DDGS during the finishing phase did not lead to differences on ADG, ADFI and FCR between treatment groups (Table 4). In both growing and finishing pigs productive performance was affected by sex being the feed efficiency and ADG higher for males than for females ($p < 0.05$). However, again, no Sex*Treatment interac-

**Table 3.** Amino acid composition of sorghum distillers dried grains with soluble (DDGS) and sorghum grain (as-fed basis)

| Amino acid | Sorghum DDGS[1], g kg$^{-1}$ of crude protein | Sorghum grain[2], g kg$^{-1}$ of crude protein | Sorghum DDGS[1], g/100 g | Sorghum grain[3], g/100 g |
|---|---|---|---|---|
| Lysine | 20.8 | 23.4 | 0.63 | 0.20-0.22 |
| Methionine | 18.3 | 17.2 | 0.55 | 0.15-0.17 |
| Methionine + Cystine | 35.5 | 35.6 | 1.08 | 0.31 |
| Threonine | 30.9 | 34.5 | 0.94 | 0.30-0.31 |
| Isoleucine | 37.0 | 41.4 | 1.13 | 0.36-0.37 |
| Valine | 47.2 | 51.8 | 1.43 | 0.45-0.46 |

[1] Two samples (from two different sorghum-DDGS batches) were analysed (n = 2). [2] Mean composition from FEDNA (2010). [3] Mean composition from NRC (1998) and FEDNA (2010).

**Table 4.** Growth performance (average daily gain, ADG; average daily feed intake, ADFI and feed conversion ratio, FCR) during the nursery and growing-finishing phases

| | Dietary treatment | | Sex | | SEM[1] | Significance[2] | | |
|---|---|---|---|---|---|---|---|---|
| | Control | DDGS | Males | Females | | Treatment | Sex | Treatment*Sex |
| Nursery[3] | | | | | | | | |
| Initial weight, kg | 13.8 | 14.0 | 13.9 | 13.9 | 0.76 | ns | ns | ns |
| Final weight, kg | 31.0 | 30.0 | 30.2 | 30.8 | 0.34 | 0.081 | ns | ns |
| ADG, g $d^{-1}$ | 597.5 | 578.7 | 573.6 | 602.7 | 23.86 | ns | ns | ns |
| ADFI, g $d^{-1}$ | 951.1 | 871.4 | 899.2 | 924.3 | 31.24 | 0.097 | ns | ns |
| FCR | 1.60 | 1.51 | 1.58 | 1.54 | 0.056 | ns | ns | ns |
| Growing phase[4] | | | | | | | | |
| Initial weight, kg | 39.0 | 38.9 | 39.1 | 39.9 | 1.48 | ns | ns | ns |
| Final weight, kg | 79.5 | 78.4 | 81.2 | 78.4 | 2.19 | ns | ns | ns |
| ADG, g $d^{-1}$ | 972.9 | 908.1 | 1,003.0 | 917.3 | 24.00 | 0.064 | 0.010 | ns |
| ADFI, g $d^{-1}$ | 1,247.8 | 1,202.8 | 1,285.0 | 1,266.9 | 34.45 | ns | ns | ns |
| FCR | 1.28 | 1.33 | 1.28 | 1.38 | 0.057 | ns | 0.020 | ns |
| Finishing phase[4] | | | | | | | | |
| Initial weight, kg | 79.5 | 78.4 | 81.2 | 78.4 | 2.19 | ns | ns | ns |
| Final weight, kg | 107.6 | 105.9 | 110.8 | 105.2 | 2.31 | ns | ns | ns |
| ADG, g $d^{-1}$ | 940.3 | 978.0 | 1057.2 | 920.6 | 25.72 | ns | < 0.001 | ns |
| ADFI, g $d^{-1}$ | 2,617.0 | 2,547.2 | 2,619.3 | 2567.7 | 39.83 | ns | ns | ns |
| FCR | 2.84 | 2.63 | 2.43 | 2.84 | 0.093 | ns | 0.001 | ns |

[1] SEM: standard error of least squares mean (n = 8 in the nursery period and n = 19 in the growing-finishing period). [2] ns: not significant. [3] Number of pigs per treatment = 53 females and 49 males in treatment C and 51 females and 51 males in treatment DDGS. [4] Number of pigs per treatment = 50 females and 45 males in treatment C and 50 females and 45 males in treatment DDGS.

tions were found indicating that the treatment effects were not affected by sex.

Regarding body composition measurements, LD was similar between treatments at the end of the study. However, pigs fed sorghum-DDGS showed greater BF levels compared to C pigs ($p < 0.001$; Table 5) at this time.

### Carcass quality

No differences were observed between treatments in carcass weight and carcass yield (Table 5). By sex, males showed a higher carcass weight compared to female (males = 92.7 kg and females = 89.1 kg, $p = 0.043$) according to their higher growth rates (Table 4), but females showed a higher carcass yield compared to males (males = 75.3% and females = 77.0%, $p \leq 0.001$).

## Discussion

During the bioethanol production process, fermentable sugars and starch are converted to ethanol by fermentation and thus, other components such as EE, CF, CP and also the different AA are increased near to 3-fold times their original concentration in the grain, as it also has been observed in the present study. Other studies also confirmed this nutrient concentration due to the ethanol production from cereals (Rasco *et al.*, 1987; Swiatkiewicz & Koreleski, 2008).

The protein and fat content of the sorghum-based DDGS used in the present study (30.4% and 9.7%, respectively) was similar to those obtained by Urriola *et al.* (2009) and Jones *et al.* (2010), although its protein content was higher to that obtained by Senne *et al.* (1998). However, NDF and ADF levels were lower than those reported in other studies (Feoli *et al.*, 2007a; Urriola *et al.*, 2009; Jones *et al.*, 2010). Concerning AA content of the sorghum-DDGS source used in the present study, this was within the levels obtained for this ingredient by other authors (Jenkins, 2003; Urriola *et al.*, 2009; Jones *et al.*, 2010). All this, together with the high content in soluble fibre might indicate that the feeding value of the sorghum-DDGS source used in this study for pigs is acceptable.

The value of NDSF obtained for sorghum-DDGS in this study was 79.4 g NDSF g $DM^{-1}$, which is in the range of the amount of soluble dietary fibre reported

**Table 5.** Backfat thickness and loin depth measured by ultrasounds at the end of the study and carcass weight and yield at slaughter[1]

| | Dietary treatment | | Sex | | SEM[2] | Significance[3] | | |
|---|---|---|---|---|---|---|---|---|
| | Control | DDGS | Males | Females | | Treatment | Sex | Treatment*Sex |
| Backfat, mm | 9.80 | 10.96 | 9.95 | 10.00 | 0.233 | < 0.001 | ns | ns |
| Loin depth, mm | 51.67 | 50.92 | 50.22 | 52.07 | 0.594 | ns | 0.006 | ns |
| Carcass weight, kg | 91.4 | 90.0 | 92.7 | 89.1 | 1.36 | ns | 0.043 | ns |
| Carcass yield, % | 76.5 | 76.0 | 75.3 | 77.0 | 0.41 | ns | 0.001 | ns |

[1] Number of pigs per treatment = 50 females and 45 males in treatment C and 50 females and 45 males in treatment DDGS. [2] SEM: standard error of least squares mean (n = 95). [3] ns: not significant.

by Stein & Shurson (2009) for maize-DDGS. This higher content in soluble fibre might be indicating a high nutritive value of the sorghum-based DDGS source used in this study, since it is known that this type of fibre is highly profitable by monogastrics by fermentation at the hindgut level (Noblet & Le Goff, 2001).

Additionally, in terms of DDGS quality, it is suggested that those sources of DDGS with a low lysine digestibility often show a low concentration of lysine (Cozannet *et al.*, 2010). Also, Stein (2007) observed that the lysine to CP ratio may give an estimate of the quality of the lysine and recommended that this ratio should be greater than 2.80% for good quality maize-DDGS. In the present study, sorghum-DDGS showed a lysine to CP ratio of 2.08% which indicate a decreased protein quality compared to corn DDGS.

Regarding the effects of high levels of DDGS in pig diets on growth performance, only recent research has been conducted with sorghum DDGS. The results of the present experiment indicate that the inclusion of sorghum-DDGS might reduce feed palatability in young pigs (nursery phase). In subsequent phases (growing and finishing periods) the impact of high levels of sorghum-DDGS on feed palatability might be less relevant. These results agree with many studies in which age is evidenced an important factor when deciding the DDGS inclusion rates in feeds for pigs due to palatability and digestibility aspects (Stein & Shurson, 2009). Whether this adaptation is due to age or to the gut adaptation to the feed itself is unknown.

The number of studies found in the literature in which sorghum-DDGS are included in pig diets is low and the results are often very variable. Some studies in the literature suggest that sorghum-based DDGS included up to 20% in nursery diets did not affect ADG, ADFI or FCR (Senne *et al.*, 1995) compared to pigs fed a typical maize-soybean meal diet. However, other studies show a linear reduction in feed intake when sorghum-DDGS are included at 15% (Senne *et al.*, 1996) or at 30% (Jones *et al.*, 2010) in nursery diets. Generally, reductions in performance when DDGS are included in this phase are due to differences in intake (Jones *et al.*, 2010), as it is the case in the present study. Moreover, the variability in the results among different studies may be attributed to the variability in quality of the different sorghum-DDGS sources used and also to the time postweaning when DDGS are introduced. In this regard, while some authors suggest that DDGS may be introduced immediately after weaning without compromising pig performance (Spencer *et al.*, 2007), others reported that the inclusion of DDGS in diets fed to pigs before day 21 postweaning resulted in a reduction in pig performance (Burkey *et al.*, 2008).

In growing-finishing pig diets higher inclusion levels of DDGS are reported due to its higher capacity for using fibre through fermentation. Inclusion levels up to 30% of sorghum-DDGS showed no differences in feed intake (Senne *et al.*, 1995) and pig performance (Senne *et al.*, 1996) compared to pigs fed a typical maize-soybean meal diet. However, greater inclusion levels might reduce ADG, ADFI and increase FCR (Feoli *et al.*, 2007b, 2008a).

In the literature, most of the studies show no effects of feeding sorghum-DDGS on LD or BF (Feoli *et al.*, 2007c, 2008b). In the present study, the greater EE levels found on sorghum- DDGS diets could have caused this greater BF values at the end of the study in the group of animals feed the DDGS diets.

Recent studies evaluated carcass traits when including high levels of DDGS in pig diets and most of them showed no effects or lower carcass yield in animals fed high levels of maize (Linneen *et al.*, 2008; Widmer *et al.*, 2008) and sorghum-DDGS (Feoli *et al.*, 2007c; 2008b). The inclusion of fibrous ingredients in pig diets might reduce the dressing percentage due to an increased weight and volume of the whole gut of animals (JØrensen *et al.*, 1996), thus reducing carcass yield. However, in the present study, no differences were observed between treatments in carcass weight and carcass yield (Table 5). The reason could be that, in the present study, sorghum-DDGS showed lower fibre content compared to other sorghum-DDGS (Feoli *et al.*, 2007a; Urriola *et al.*, 2009; Jones *et al.*, 2010) and also compared to other DDGS sources such as maize-DDGS.

In conclusion, the inclusion of 150 g $kg^{-1}$ sorghum-based DDGS in nursery diets (14 to 30 kg BW) tended to reduce voluntary feed intake of animals. However, inclusion levels as high as 300 g $kg^{-1}$ or 350 g $kg^{-1}$ of sorghum-DDGS in growing and finishing pig diets (80 to 110 kg BW) caused no negative effects on growth performance and carcass yield, but increased BF levels in pigs. Thus, sorghum-DDGS provide an excellent opportunity for swine producers or feed suppliers to lower feed costs in the growing-finishing period. However, it is necessary to continue the research on DDGS palatability and nutrient digestibility in order to optimize diet formulation with DDGS.

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