Nutritive value of distillers dried grains with solubles from barley, corn and wheat for growing rabbits

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Abstract

Due to their fibrous nature, distillers dried grains with solubles (DDGS) from the bioethanol industry could be considered an interesting feedstuff for rabbit nutrition. To characterize the DDGS available in the Iberian Peninsula the chemical, amino acid and fatty acid composition of eight DDGS batches (2, 2 and 4 from barley, corn and wheat grains, respectively) was performed. Five diets were formulated to determine the nutritive value of DDGS in growing rabbits by the substitution method: a control diet and four experimental diets containing 200 g of the DDGS being evaluated kg^{-1} dry mater (DM) [DDGS from national barley, national corn, Brazilian corn and national wheat grains]. The digestibility trial was performed using 60 three-way crossbred fattening rabbits (12 per diet), aged 42 days with average live weight of 1.49 kg (S.E.: 0.033 kg). DDGS can be characterized as a raw material really rich in fibre (neutral detergent fibre and neutral detergent soluble fibre) and crude protein (CP, on av. 352, 208 and 318 g kg^{-1} DM, respectively). Barley DDGS had higher fibre and lower protein contents than wheat DDGS (+25 g of acid detergent fibre and –91 g of CP kg^{-1} DM, respectively; $P<0.05$), as well as the highest ash content (on av. +16 g kg^{-1} DM; $P<0.05$). Corn DDGS had intermediate fibre and protein values between barley and wheat DDGS, but were the richest in ether extract (on av. +70 g kg^{-1} DM). DDGS' protein was richer in proline, phenylalanine, valine and arginine for barley DDGS (107, 55, 54 and 51 g kg^{-1} CP, respectively), in leucine, alanine and histidine for corn DDGS (114, 75 and 27 g kg^{-1} CP, respectively), and in glutamic acid for wheat DDGS (290 g kg^{-1} CP). Barley DDGS was richer in saturated (236 g kg^{-1} total fatty acids), corn DDGS in monounsaturated (278 g kg^{-1} total fatty acids) and wheat DDGS in polyunsaturated fatty acids (615 g kg^{-1} total fatty acids). Barley DDGS was characterized by the lowest nutritive value traits of DDGS evaluated (11.9 MJ digestible energy (DE) and 168 g digestible protein (DP) kg^{-1} DM). In spite of higher protein and lower fibre content of the Brazilian corn (+1.7 g CP and –31 g neutral detergent fibre kg^{-1} DM), no significant differences for the nutritive value of both corn DDGS were observed (on av. 15.3 MJ DE and 208 g DP kg^{-1}

DM). Wheat DDGS might be considered as the DDGS with the highest nutritive value of those evaluated (15.7 MJ DE and 263 g DP kg^{-1} DM).

Keywords: distillers dried grains with soluble; chemical composition; amino acids; digestibility; rabbits.

Introduction

Distillers dried grains with solubles (DDGS), the most important by-products of the bioethanol manufacture industry (0.3 tones per ton processed cereal) composed mostly by mixing distillers grains (DDG) and solubles (DDS, thin stillage) at a 3:1 ratio (Erickson et al., 2005), are mainly used for animal nutrition (US Grains Council, 2007). However, DDGS are characterized by a relatively high variability in their chemical composition and nutritive value. Olantine (1986) even describes 35 causes for this variability, highlighting grain source (Reese and Lewis, 1989), technology used in manufacturing processes (Spiehs et al., 2002; Knott et al., 2004; Noll et al., 2006), efficiency in the ethanol manufacture process (Spiehs et al., 2002; Shurson and Alghamdi, 2008), mixing ratio of the final components obtained (Noll et al., 2006; Kim et al., 2008), and drying time and temperature (US Grains Council, 2007).

Literature about chemical composition and nutritive value of corn DDGS is extensive. However, the available knowledge about DDGS from other cereal grains, such as wheat (Nyachoti et al., 2005; Widyaratne and Zijlstra, 2007; Nuez Ortín and Yu, 2009; Avelar et al., 2010) and especially barley and sorghum (Waller, 2004), is more limited.

De Blas and Mateos (2010), describing the usual range of ingredients composition of feeds for rabbits in Spain, indicated that rabbit diets usually include even 350 g kg^{-1} of cereal co-products (mainly wheat bran, maize gluten feed and DDGS). Considering the fibrous nature of DDGS and that their availability has exponentially increased in the last decade (Renewable Fuel Association, 2012), DDGS inclusion in rabbit diets could have been promoted. However, the nutritive value of corn DGGS for rabbits has been poorly studied (Villamide et al., 1989), and as far as the author is aware there is no scientific knowledge about the nutritive value of other cereal grains DDGS for rabbit, such as those from wheat and barley grains whose production in rabbit production areas is not negligible.

Therefore, this study has been addressed to characterize the chemical composition of the barley, corn and wheat DDGS available in the Iberian Peninsula, as well as their nutritive value for growing rabbits.

2. Materials and methods

2.1. Samples of DDGS

Eight batches of DDGS from the three major bioethanol plants in Spain were used in the present study. These factories process the cereal grains by dry grind technology, rendering ethanol and DDGS as product and co-product, respectively (Abengoa, 2011). Batches were obtained during the last quarter of 2010, differing in their cereal source (both type and origin: two from national barley grains, one from national and one from Brazilian corn grains, and three from British and one from national wheat grains). A total of 200 kg, in pellets of 0.86 ± 0.04 cm in diameter, were harvested from each DDGS. Representative samples of 1 kg of each DDGS were milled with a 1–mm sieve and stored for their subsequent chemical, amino acid and fatty acids analyses.

2.2. Digestibility trial

Four of the eight DDGS analyzed were selected, considering the grain source and within–grain source composition variability (mainly protein and fibre), for their subsequent nutritive evaluation by the substitution method. Five diets were formulated from a basal mixture (Table 1). The control diet (C) contained 982.4 g of the basal mixture kg^{-1} dry matter (DM) and 17.6 g of a vitamin–mineral premix kg^{-1} DM, and the four experimental diets (D) contained 782.4 g of the basal mixture kg^{-1} DM, 17.6 g of a vitamin–mineral premix kg^{-1} DM and 200 g of the DDGS being evaluated kg^{-1} DM [Dnb, DDGS from national barley (nb) grains; Dnc, from national corn (nc) grains; Dbc, from Brazilian corn (bc) grains; Dnw, from national wheat (nw) grains]. Feed formulation (basal mixture and DDGS level of inclusion) was performed to avoid undesirable nutritional deviations from the recommendations for fattening rabbits (Blas and Mateos, 2010), and following the guidelines for the evaluation of raw materials by the substitution method described by Villamide et al. (2001).

The digestibility trial was performed using sixty three-way crossbred fattening rabbits, aged 42 days with average live weight of 1.49 kg (S.E.: 0.033 kg). Twelve rabbits per diet were randomly housed in metabolic cages of 52 × 44 × 32 cm, and feed and water were offered ad libitum during the experimental period. Following an adaptation period of 10 days the consumption control and faeces collection period was 4 days (Pérez *et al.*, 1995). Faeces were stored in identified sealed plastic bags and frozen at –20ºC until analysis. Apparent digestibility coefficients for DM, CP, gross energy (GE), neutral detergent fibre (aNFDom), acids detergent fibre (ADFom) and amino acids of diets were determined for each animal as:

$$dNutrient = 1 - \frac{Nutrient\ fecal\ excretion}{Nutrient\ intake}$$

The digestible contents and the apparent digestibility coefficients (d) of the main nutrients of each DDGS were calculated by differences, assuming additivity, e.g. for the digestible energy (DE) and dGE of the $DDGS_x$:

$$DE_{DDGS_x} = \frac{(DE_D - B\ DE_C)}{D} \quad and \quad dGE_{DDGS_x} = \frac{DE_{DDGS_x}}{GE_{DDGS_x}}$$

where DE_D is the DE of diet that includes the $DDGS_x$ being evaluated, B the substitution rate of the basal mixture in the diet (0.7824), DE_C the DE in the control diet and D the substitution rate of the $DDGS_x$ (0.200).

2.3. Analytical methods

DDGS samples, diets and faeces were analyzed according to the methods of AOAC (2000): 934.01 for DM, 942.05 for ash, 976.06 for CP and 920.39 for EE. Previous acid–hydrolysis of samples was carried out in the analysis of EE. Starch content was determined according to Batey (1982). The aNDFom (assayed with a thermo–stable amylase and expressed exclusive of residual ash,), ADFom (expressed exclusive of residual ash) and lignin (determined by solubilisation of cellulose with sulfuric acid, sa) were analyzed sequentially (Van Soest et al., 1991). The NDSF content was determined according to Hall et al. (1997), adapting the method to the nylon filter bag system and with the modifications proposed by Martinez–Vallespín et al. (2011). Insoluble hemicelluloses and cellulose were determined by difference (aNDFom–ADFom and ADFom–Lignin (sa), respectively). Other fibre fraction (RES) that corresponds to a mix of soluble fibre, that includes that part of pectins not solubilized by the NDF solution and sugars, was estimated as (100–Ash–CP–EE–aNDFom–Starch) and used in the multivariate analyses performed with the literature data. Finally, GE was determined by adiabatic bomb calorimetry (Gallenkamp Autobomb, Loughborough, UK).

The content of fatty acid methyl esters and total amino acids were determined in the eight DDGS, the four experimental diets and the four pools of faeces obtained from each diet during the digestibility trial. The fatty acid methyl esters of the samples were analyzed in a gas chromatograph Focus Gas Chromatograph (Thermo, Milan, Italy) equipped with a split/splitless inlet and flame ionization detector. Separation was performed on a capillary column SPTM 2560 (Supelco, PA, USA) (100m×0.25mm×0.2mm film thickness) with a flow rate of 1.1 mL Helium min^{-1}, according to the following temperature gradient: 140°C initial temperature for 5 min, gradually increasing along a linear gradient of 4ºC min^{-1} to 240ºC, maintaining this temperature for 30 min, to finally return to the initial conditions. The injector and detector were maintained at 260ºC. Fatty acids were identified by comparing their retention times with those of a pattern of fatty acid methyl esters (47885–U) from Supelco® (Pennsylvania, USA) and quantified using C13:0 as internal standard (O'Fallon et al., 2007). Total saturated, monounsaturated and polyunsaturated fatty acids were calculated as [SFA: C14:0+C16:0+C17:0+C18:0+C20:0+C22:0, MUFA: C16:1+C18:1w9+C18:1w7+C20:1+ C22:1w9 and PUFA: C18:2+C18:3w6+C18:3w3+C20:2+C22:2, respectively].

The amino acid content was determined after acid hydrolysis with HCL 6N at 110 ºC for 23 h as previously described by Liu et al. (1995), using a Waters (Milford, Massachusetts, 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 hydrolyzation. The amino acids were derivatized with AQC (6–aminoquinolyl–N–hydroxysuccinimidyl carbamate) and separated with a C–18 reverse-phase column Waters AcQ Tag (150mm×3.9mm). Methionine and Cystine were determined separately as methionine sulphone and cysteic acid respectively after performic acid oxidation followed by acid hydrolysis.

2.4. Statistical analysis

Data were analysed according to the general lineal model (GLM) procedure of SAS (Statistical Analysis System, 2002), as a completely randomised design with a model accounting for the fixed effect of the DDGS grain source (barley, corn or wheat) for DDGS' chemical composition data, the experimental diet (C, Dnb, Dnc, Dbc and Dnw) for the performance traits and apparent digestibility coefficients, or the DDGS type (nb, nc, bc and nw) for the DDGS' nutritive value data. Multivariate analyses were performed to determine the main parameters involved in the characterization and differentiation of DDGS. A principal component analysis including the chemical composition data [Ash, starch, EE, CP, aNDFom, ADFom, Lignin (sa), lysine, methionine, SFA, MUFA and PUFA] from the eight samples DDGS was done, using the PRINCOMP procedure of SAS (2002), to decrease information and determine the main parameters responsible for data variability. Finally, a discriminate analyse of chemical composition data [DM, ash, CP, EE, NDF, ADF and RES] from the DDGS available in the literature was performed (a total of 53 samples: 1, 4, 18 and 30 from sorghum, barley, wheat and corn DDGS, respectively; see Figure 1b), using the DISCRIM procedure of SAS (2002), to determine the main chemical parameters involved in the discrimination between DDGS by grain source.

Results

Chemical composition of the DDGS evaluated

Table 3 shows the main chemical composition of the DDGS by grain source. Barley DDGS had higher fibre and lower protein contents than wheat DDGS (+25 g of ADFom and –91 g of CP kg^{-1} DM, respectively; P<0.05), as well as the highest ash content (on av. +16 g kg^{-1} DM; P<0.05). Corn DDGS had intermediate fibre and protein values between barley and wheat DDGS, but were the richest in EE (on av. +70 g kg^{-1} DM).

DDGS' protein was richer in proline, phenylalanine, valine and arginine for barley DDGS (on av. +22, +10, +7 and +6 g kg^{-1} CP, respectively; P<0.05), in leucine, alanine and histidine for corn DDGS (on av. +44, +33 and +4 g kg^{-1} CP, respectively; P<0.05), and in glutamic acid for wheat DDGS (+107 and +46 g kg^{-1} CP respect to corn and barley DDGS, respectively; P<0.05). Protein of both barley and corn DDGS also had higher content of aspartic acid and threonine than that of wheat DDGS (on av. +13 and +7 g kg^{-1} CP, respectively; P<0.05).

In general, fat in DDGS was characterized by a high content in PUFA, especially C18:2 (on av. 578 and 550 g kg^{-1} total fatty acids), but grain source had a significant effect on fatty acid composition of DDGS. Therefore, barley DDGS was richer in SFA (+35 and +79 g kg^{-1} total fatty acids than wheat and corn DDGS, respectively; P<0.05), corn DDGS in MUFA (on av. +128 g kg^{-1} total fatty acids; P<0.05) and wheat DDGS in PUFA (on av. +55 g kg^{-1} total fatty acids; P<0.05). Fat in corn DDGS was characterized for a higher UFA/SFA ratio than barley and wheat DDGS (4.32 vs. 2.75 and 3.31 g g^{-1}, respectively; P<0.05).

Graphic representation of the first two principal components obtained from the main chemical composition of the analyzed DDGS samples (which explained 75.6% of total variability) clearly placed them according to grain source (Figure 1a). Thus, barley DDGS were placed in the area characterized for high fibre, ash and SFA contents, wheat DDGS in that with high CP, lignin (sa) and PUFA, and corn DDGS in that with high EE, starch and MUFA. In fact, the discriminate analysis by grain source, from the available common chemical composition of DDGS in the literature, allowed the right classification of 96.2 percent of the samples.

Representation of samples by their values for the first two discriminate functions clearly clustered them by grain source (Figure 1b).

Nutritive value of DDGS

Table 4 shows the daily performance and the apparent digestibility coefficients of the main nutrients in the experimental diets evaluated from the individual faeces analysis.

Inclusion of the national barley DDGS (Dnb) did not significantly affect dDM, dEE and dGE, but increased both dADF and dCellulose values (+4.0 points of percentage compared to diet C; P<0.05). Although no significant differences were observed for dCP variable, contrast between Dnb and Dnw showed a relatively lower value for Dnb (–3.2 points of percentage), perhaps related to their higher proportion of CP bound to NDF (0.33 and 0.22 of the total CP for barley and wheat DDGS, respectively). In fact, Dnb diet had the lower digestibility coefficients for main of amino acids (significantly lower for alanine, histidine, isoleucine, leucine, lysine, serine, threonine and valine, respect to diet C).

In the case of corn DDGS, animals fed with Dnc had greater dDM, dEE, dGE (+2.7 points of percentage), daNDFom, dADFom and dCellulose than those obtained for C animals (P<0.05), and although no differences were observed for dCP, digestibility coefficients for alanine and serine were also significantly higher (P<0.05). However, in the case of Dbc, although digestibility of GE (+2.2 points of percentage) and alanine were also significantly increased (P<0.05), digestibility coefficients of histidine and valine were even reduced respect to C diet (P<0.05).

Finally, the inclusion of the national wheat DDGS (Dnw) increased both dDM and dGE values (+3.0 points of percentage compared to C diet; P<0.05), presented the highest values for dCP and digestibility of main amino acids, significant in the case of glutamic acid, proline and serine (P<0.05).

The nutritive value of the evaluated DDGS is shown in Table 5. DDGS from national barley had lower dDM, dEE and DP values than DDGS from national wheat (–11, –17 percent and –95 g

DP kg^{-1} DM, respectively; P<0.05), having both DDGS from corn intermediate values. DDGS from national barley had a significantly lower dEE (on av. –16 points of percentage; P<0.05) and DE values (on av. –3.56 MJ DE kg^{-1} DM; P<0.05)than the values obtained for corn and wheat DDGS.

Discussion

Chemical composition of the DDGS evaluated

In general, DDGS can be characterized as a raw material very rich in fibre (aNDFom and NDSF) and CP (on av. 352, 208 and 318 g kg^{-1} DM, respectively). These values, initially place DDGS as an interesting raw material for rabbit nutrition compared to other monogastric species for its high fibre content, especially soluble fibre with attributed properties for gut health in weaned rabbits (Gómez-Conde et al., 2007; Martínez-Vallespín et al., 2011), although its high protein content means caution must be exercised when including it in these diets (Carabaño et al., 2009).

The principal differences between the analyzed DDGS seem to be mainly related to the differences in the chemical composition of the original grain sources (De Blas et al., 2010), especially in terms of fibre and protein content, although no great differences compared to the values given by the literature were found. Therefore, ADF and CP values obtained for barley DDGS were similar to those previously reported (on av. 131 and 286 g kg^{-1} DM, respectively; De Blas and Mateos, 2010; Waller et al., 2010). However for wheat DGGS, the obtained values were clearly lower in ADF (on av. 104 vs. 150 g kg^{-1} DM) and CP (353 vs. 384 g kg^{-1} DM) than the averages reported in recent literature (Distillers Grains Technology Council, 2005; Nyachoti et al., 2005; Widyaratne and Zijlstra, 2007; Emiola et al., 2009; Nuez-Ortin et al., 2009; Avelar et al., 2010; Cozannet et al., 2010; De Blas et al., 2010), although similar to those presented by Emiola et al. (101 and 344 g kg^{-1} DM, respectively) in 2009. Ethanol industries have improved their efficiency over time (better efficacy in the starch extraction process, the level of inclusion and recovery of the yeast used in the fermentation…) which could contribute to the observed variability in DDGS composition, especially in protein content.

In fact, the EE value obtained for the corn DDGS was relatively higher than the average given by the literature (141 vs. 107 g kg^{-1} DM), although within the range (58 to165 g kg^{-1} DM; Villamide et al., 1989; Cromwell et al., 1993; NRC, 1998; Spiehs et al., 2002; Sauvant et al., 2004; Stein, 2006; US Grains Council, 2007; Belyea et al., 2004; Shurson et al., 2004;

Widyaratne and Zijlstra, 2007; Nuez-Ortin et al., 2009; De Blas et al., 2010). These differences in EE content could be related to differences in the laboratory analysis method (use or not of acid hydrolysis; AOAC, 2000), and/or to the level of inclusion of solubles during manufacture of the DDGS that some authors have related to EE content increase (Noll et al., 2007; Ganesan et al., 2008).

On the other hand, DDGS protein can be considered as poorer in three of the most limiting amino acids in rabbit diets (lysine, sulpphur-cointaining amino acids and arginine; Xiccato and Trocino, 2010) compared to other protein concentrates frequently used in rabbit nutrition, such as soya and sunflower meals (Villamide et al., 2010). Although the available information for DDGS from barley is scarce (De Blas et al., 2010), amino acid composition obtained for corn and wheat DDGS were similar to that widely reported for these products in the available literature (recently, Widyaratne and Zijlstra, 2007; Stein and Shurson, 2009; Avelar et al., 2010; Yang et al., 2010; Kim et al., 2010). The variability and the relative unbalance observed in DDGS amino acid composition could be mainly attributed to their protein of origin, but also to differences in fermentation effectiveness, drying temperature, as well as the amounts of solubles added to dried distillers grains (Martínez-Amezcua et al., 2007: US Grains Council, 2007; Han and Liu, 2010).

Finally, DGGS had a relative high fat content, especially in corn DDGS (from 70 in barley and wheat DDGS to 141g kg^{-1} in corn DDGS). Fat from corn DDGS was characterized for a higher UFA/SFA ratio than barley and wheat DDGS (31 vs. 17 and 18 g g^{-1}, respectively; $P<0.05$), which in addition to its higher EE content may lead to higher oxidation and rancidity potential (Cromwell et al., 2011).

Nutritive value of DDGS

As was expected, barley DDGS was characterized by the lowest nutritive value traits of evaluated DDGS (11.9 MJ DE and 168 g DP kg^{-1} DM), although comparable to other commonly used cereal by-products such as corn gluten feed (on av. 11.6 MJ DE, 162 g DP and 406 g NDF kg^{-1} DM; De Blas et al, 2010). The main consequence of including DDGS was the increase in soluble fibre content and cellulose digestibility of the experimental diet. Soluble fibre has been frequently related with a general promotion of caecal fermentative activity (including cellulase), increasing cellulose digestibility (Falçao-Cunha et al., 2004). In addition, and in spite of the difficulties in the determination of fiber digestibility of cereals in rabbits, Villamide and De Blas (1989), with diets including up to 60 percent of cereal grain, a high dADF for barley grain has been described (0.30).

In spite of the higher protein and lower fibre content of the Brazilian corn (+1.7 g CP and −31 g aNDFom kg^{-1} DM), no significant differences for the nutritive value between both corn DDGS were observed (on av. 15.3 MJ DE and 208 g DP kg^{-1} DM). The high energy content of corn DDGS, even greater than that reported for corn grain (14.6 MJ DE kg^{-1} DM; Villamide et al., 2010), seems to be mainly related to its high fat content (141 g EE kg^{-1} DM), rich in MUFA (28% of total fatty acids), and highly digestible (on av. 0.93). In general, these values were slightly higher than those reported for rabbits (14.1 MJ DE and 198 g DP kg^{-1} DM; Villamide et al., 2010), but close to those usually given for extra quality corn DDGS (15.7 MJ DE and 220 g DP kg^{-1} DM). Literature values for DE were closer to those reported for the Brazilian corn DDGS. The inclusion of national corn DDGS led to higher digestibility of the fibre (compared to both C and Dbc diets), which could contribute to explain this higher value.

On the other hand, wheat DDGS might be considered as the DDGS with the highest nutritive value of those evaluated (15.7 MJ DE and 263 g DP kg^{-1} DM), placing them close to some oil meals (such as rapeseed meal, 14.4 MJ DE and 273 g DP kg^{-1} DM) and legume seeds (such as Australian lupin, 15.2 MJ DE and 274 g DP kg^{-1} DM). The protein value obtained agrees with the report for the Spanish wheat DDGS (262 g PD kg^{-1} DM; De Blas et al., 2010), however the energy value was higher than expected (13.2 MJ DE kg^{-1} DM). This discrepancy can be partially explained by the high EE content of the evaluated wheat DDGS (76 g kg^{-1} DM, and very digestible 0.915), which usually ranges from 32 to 67 g kg^{-1} DM (Widyaratne and Zijlstra, 2007 ; Nuez-Ortín et al., 2010), as well as by its higher dCP to that reported for wheat DDGS in rabbits (0.75 vs 0.71; De Blas et al., 2010).

Finally, some authors have described (Stein et al., 2006; Pahm et al., 2008) the possible negative effect of heat treatment performed during DDGS manufacture on amino acids digestibility (especially on lysine) as the main limitation for the use of DDGS in pigs. Faecal digestibility of the main amino acids in the diets including corn and wheat DDGS was similar to that observed in the control diet, even higher for some amino acids, with only the diet with barley DDGS showing a generalized decrease in amino acids availability. Pahm et al. (2008), comparing corn DDGS with great differences in heat damage, suggested that the Lys:CP ratio can be considered an indicator of heat damage, with undamaged corn DDGS being considered those with a ratio higher than 0.029 (as in the present 0.031). On the other hand, the end result of the bacterial activity in the rabbit cacecum leads to a substantial change in the amino acid composition of the protein that enters the caecum, in turn this may lead to an enrichment in lysine, methionine and threonine, comparing the total faecal excretion hard and soft (Garcia et al., 2005). No information is available about the digestibility coefficients of the main amino acids for DDGS in rabbits. The literature values of apparent faecal digestibility for lysine, methionine and threonine in rabbit diets given for protein concentrates, cereals and cereal products (Garcia et al, 2005; Llorente et al., 2006, 2007) did not show any large variations from those found in this study.

From the results of this paper it can be concluded that, DDGS could be considered as interesting raw materials due to their high content of digestible protein and energy, comparable to other sources of protein frequently used in rabbit nutrition. On the other hand, their high fibre content (on av. 570 g of total fibre kg^{-1} DM) makes this by-product especially interesting for rabbit nutrition compared to other monogastric species. The inclusion of corn and wheat DDGS in rabbit diets did not negatively affect the digestibility of the main amino acids, as has been observed in other species when DDGS were heat-damaged. However, their protein could be considered as relatively poor in the most limiting amino acids for rabbit diets, and a supplementation of synthetic amino acids could perhaps be required if DDGS are included at high level.

Acknowledgments

The authors acknowledge Juan Carlos Moreno for his technical support and the Spanish Ministry of Education and Science (Project AGL2014-53405-C2-1-P) for the economic support to conduct this study.

References

Abengoa 2011. www.abengoabioenergy.com/corp/web/es/trading/productos/dgs/ Accesado en noviembre del 2011.

Amani, W. Y.; Soha, S. Abd El-Magid; A.H. Abd El-Gawad; Eman F. El-Daly and H.M. Ali. 2012. Effect of inclusion of distillers dried grains whit solubles (DDGS) on the productive performance of growing rabbits. Am-Eras. J. Agric. & Sci. 12(3): 321-326.

AOAC, 2000. Official methods of analysis of the AOAC International, 17th ed., AOAC International, Gaithersburg, MD (USA).

Avelar, E; Jha, R.; Beltranena, E.; Cervantes, M.; Morales, A and Zijlstra, R.T. 2010. The effect of feeding wheat distillers dried grain with solubles on growth performance and nutrient digestibility in weaned pigs. Anim. Feed Sci. Technol. 160:73–77.

Bandegan A., Guenter W., Hoehler D., Crow G.H., Nyachoti C.M., 2009. Standardized ileal amino acid digestibility in wheat distillers dried grains with solubles for broilers. Poultry Sci. 88, 2592-2599

Batal, A. B.; Dale, N. M. 2003. Mineral composition of distillers dried grains with solubles. J. Appl. Poult. Res. 12, 400–403.

Batey, I.L., 1982. Starch analysis using thermostable alpha-amylases. Starch/Stärke 34, 125–128.

Belyea, R. L.; Rausch, K. D.; Tumbleson, M. E. 2004. Composition of corn and distillers dried grains with solubles from dry grind ethanol processing. Bioresource Technology. 94: 293–298.

Cozannet, P.; Primot, Y.; Gady, C.; Métayer, J.P.; Callu, P.; Lessire, M.; Skiba, F. and Noblet, J. 2010. Composition and amino acids ileal digestibility of wheat distillers dried grains and solubles in pigs: Sources of variability. Livestock Science 134:176–179.

Cromwell, G. L.; Herkelman, K. L.; Stahly, T. S. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains with solubles for chicks and pigs. J. Anim. Sci. 71, 679–686

Cromwell, G. L; Azain M. J.; Adeola, O., Baidoo, S. K.; S. D. Carter, S. D.; Crenshaw, T. D.; Kim,S. W.; Mahan, D. C.; Miller, P. S.and Shannon, M. C. 2011. Corn distillers dried grains with solubles in diets for growing-finishing pigs: A cooperative study. J Anim. Sci, 89:2801-2811.

De Blas C., Mateos G.G. 2010. Feed formulation. In: De Blas, C., Wiseman, J. (Eds). The Nutrition of the Rabbit.2nd ed., CABI International. Wallingford (UK), pp. 222-232.

De Blas, C., Mateos, G.G., García-Rebollar, P. 2010. Tablas FEDNA de la composición y valor nutritivo de alimentos para la fabricación de piensos compuestos. Tercera edición. Madrid.

Díaz-Royón, F.; Rosentrater K. A. 2012. Composition of Fat in Distillers Grains. Livestock. Dairy Sc. IGrow February 2012. South Dakota State University.

Emiola; I.A.; Opapeju, F.O.; Slominski, B. A. and Nyachoti, C. . 2009. Growth performance and nutrient digestibility in pigs fed wheat distillers dried grains with solubles-based diets supplemented with a multicarbohydrase enzyme.

Erickson, G.E., Klopfenstein, T.J., Adams, D.C., Rasby, R.J., 2005. General overview of feeding corn milling co-products to beef cattle, in: University of Nebraska, Corn Processing Co-Products Manual: A Review of Current Research on Distillers Grains and Corn Gluten. Lincoln, Nebraska, USA, pp. 3-12.

Falcão e Cunha, L., Peres, H., Freire, J.P.B. and Castro-Solla, L. 2004. Effects of alfalfa, wheat bran or beet pulp, with or without sunflower oil, on caecal fermentation and on digestibility in the rabbit. *Animal Feed Science and Technology* 117, 131–149.

Fernández, C., Cobos, A. and Fraga, M.J. 1994. The effect of fat inclusion on diet digestibility in growing rabbits. *Journal of Animal Science* 72, 1508–1515.

Ganesan, V., K.A. Rosentrater, and K. Muthukumarappan. 2008. Effect of Moisture Content and Soluble Levels on the Physical and Chemical Properties of DDGS. Cereal Chem. 85(4):464-470

García, A.I., de Blas, J.C. and Carabano, R. 2005. Comparison of different methods for nitrogen and amino acid evaluation in rabbit diets. Animal Science 80, 169–178.

Gómez-Conde, M. S.;García, J.; Chamorro, S.;Eiras, P.; Rebollar, P.G.; Pérez de Rozas, A., Badiola, I.; De Blas, C. and Carabaño, R. 2007. Neutral detergent-soluble fiber improves gut barrier function in twenty-five-day-old weaned rabbits. J AnimSci, 85:3313-3321.

Han, J. C.; Liu, K. S. 2010. Changes in proximate composition and amino acid profile during dry grind ethanol processing from corn and estimation of yeast contribution toward DDGS proteins. J. Agric. Food Chem. 58, 3430–3437.

Kim, Y.; Mosier, S. N.; Hendrickson, R.; Ezeji, T.; Blaschek, H.; Dien, B.; Cotta, M.; Dale, B., Ladisch, M. R. 2008. Composition of corn dry-grind ethanol by-products: DDGS, wet cake, and thin stillage. Bioresource Technology. 99: 5165–5176.

Liu K S. 2011. Chemical composition of destillers grains, a review. J. Agric. Food Chem. 59: 1508-1526.

Liu, H.J., Chang, B.Y., Yan, H.W., Yu, F.H. y Liu, X.X. 1995. Determination of amino acids in food and feed by derivatization with 6-aminoquinolyl-Nhydroxysuccinimidyl carbamate and reverse-phase liquid chromatographic separation. *Journal of AOAC International.*78: 736-744.

Llorente, A., García, A.I., Nicodemus, N., Villamide, M.J. and Carabano, R. 2006. Digestibilidad ileal aparente y verdadera de aminoácidos de harinas de girasol, productos de soja y guisante en conejos. In: Proccedings of the XXXI Symposium de Cunicultura de ASESCU. Lorca, Spain, pp. 117–124.

Llorente, A., Villamide, M.J., García, A.I. and Carabano, R. 2007. Digestibilidad de la proteína de los aminoácidos de cereales y sus subproductos en conejos. Proceedings of XXXII Symposium de Cunicultura de ASESCU. Vila-Real, Portugal, pp. 87–90.

Martinez-Amezcua, C.; Parsons, C.M.; Singh, V.; Srinivasan, R. and Murthy G.S. 2007. Nutritional characteristics of corn Distillers Dried Grains with Solubles as affected by the Amounts of Grains Versus Solubles and Different Processing Techniques. Poult. Sci. 86:2624-2630.

Martínez-Vallespín B., Navarrete C., Martínez-Paredes E., Ródenas L., Cervera C., Blas E. 2011. Determinación de la Fibra Soluble en Detergente Neutro: Modificaciones del Método Original. AIDA. XIV Jornadas sobre Producción Animal, 1. Zaragoza: 291-293.

Noll, S., C. Parsons, B. Walters. 2006. What's New since September 2005 in Feeding Distillers Co-products to Poultry. Proceedings of the 67th Minnesota Nutrition Conference and University of Minnesota Research Update Session: Livestock Production in the New Millennium, pp. 149-154.

Noll, S.L., J. Brannon, C. Parsons. 2007. Nutritional Value of Corn Distiller Dried Grains with Solubles (DDGS): Influence of Solubles Addition. Poult. Sci. 86 (Suppl. 1): 68.

NRC. 1994. Nutrient Requirements of Poultry. (9th Ed.). National Academy Press, Washington, D.C.

Nuez Ortín, W. G.; Yu, P. 2009. Nutrient variation and availability of wheat DDGS, corn DDGS and blend DDGS from bioethanol plants. J. Sci. Food Agric. 89, 1754–1761.

Nyachoti, C.M., J.D. House, B.D. Slominski, and I.R. Seddon. 2005. Energy and Nutri-ent Digestibilities in Wheat Dried Distiller's Grains with Solubles Fed to Growing Pigs. J. Sci. Food Agr. 85: 2581–258

O´Fallon, J.V., Busboom, J.R., Nelson, M.L. & Gaskins, C.T. 2007. A direct method for fatty acid methyl ester synthesis: Application to wet meat tissues, oils, and feedstuffs. J. Anim. Sci. 85: 1511-1521.

Olentine, C., 1986. Ingredient profile: Distillers feeds. Proc. Distillers Feed Conf. 41, 13-24.

Pahm, A. A., C. Pedersen, and H. H. Stein. 2008. Application of the reactive lysine procedure to estimate lysine digestibility in distillers dried grains with solubles fed to growing pigs. J. Agric. Food Chem. 56:9441-9446.

Pedersen, C., Boersma, M. G. and Stein, H. H. 2007. Digestibility of energy and phosphorus in 10 samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168–1176.

Peiretti, P.G. and Meineri, G. 2008. Effects of golden flaxseed supplementation on the performance and feed digestibility of rabbits. *Journal of Animal and Veterinary Advances* 7, 56–60.

Pérez, J.M., Lebas, F., Gidenne, T., Maertens, L., Xiccato, G., Parigi-Bini, R., Dalle Zotte, A., Cossu, M.E., Carazzolo, A., Villamide, M.J., Carabaño, R., Fraga, M.J., Ramos, M.A., Cervera, C., Blas, E., Fernández- Carmona, J., Falcao e Cunha, L., Bengala Ferre, J., 1995. European reference method for in vivo determination of diet digestibility in rabbits. World Rabbit Sci. 3, 41-43.

Powles, J., J. Wiseman, D. J. A. Cole, and S. Jagger. 1995. Prediction of the apparent digestible energy value of fats given to pigs. J. Anim. Sci. 61:149–154.

Reese, D.E. and A.J. Lewis. 1989. Nutrient content of Nebraska corn. Nebraska Cooperative Extension Service EC 89-219, pp. 5-7.

Renewable Fuel Association, 2012. RFA's 2012 ethanol industry outlook. Available at www.ethanolrfa.org

SAS. 2008. SAS/SAT User's Guide (Release 9.2). SAS Inst. Inc. Cary NC, USA.

Sauvant, D.; Perez, J. M.; Tran, G. 2004. Tablas de composición y de valor nutritivo de las materias primas destinadas a los animales de interés ganadero. Cerdos, aves, bovinos, ovinos, caprinos, conejos, caballos y peces. Ed. Mundi-Prensa. Madrid.

Shurson, J and Alghamdi, A. S. 2008. Quality and New Technologies to Create Corn Co-Products from Ethanol Production. In: Babcock, B.; Hayes, D. J, and Lawrence, J. D. (Eds).

Using Distillers Grains in the U.S. and International Livestock and Poultry Industries. Matric. Iowa State University. pp. 231-259.

Shurson, J., M. Spiehs, M. Whitney, and J. Knott. 2004. Nutritional and value added benefits of feeding maize DDGS and other dry-mill co-products to swine. Presented at the Eastern Nutrition Conf. Pre-conf. Symposium, Ottawa, Canada. May 11, 2004. http://www.ddgs.umn.edu/articles-swine/2004-Shurson-%20Eastern%20nutr%20conf.pdf. (Accesed October 2011)

Spiehs, M. J., M. H. Witney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639–2645.

Stein, H. H., C. Pedersen, C.; Gibson, M.L; and Boersma, M. G. 2006. Amino acid and energy digestibility in ten samples of distillers dried grain with solubles by growing pigs. J. Anim. Sci. 84:853–860.

Stein, H.H. and Shurson, G.C. 2009. The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292–1303.

Tazzoli, M. 2012. Feeding strategies to improved healt status and feed efficiency in growing rabbits. Thesis Ph.D. Universita Degli Studi Di Padova. Italy.

US Grains Council, 2007. Nutrient Content of DDGS. Variability and Measurement, in: US Grains Council (Eds.), DDGS Users Handbook, Washington DC, USA, pp. 1-18.

Van Soest, P. J.; Roberston, J. B.; Lewis, B. A. 1991.Methods for dietary fiber, neutral detergent fiber and non-starch polysaccharides in relation to animal nutrition.J. Dietary Sci., 74: 3583-3597.

Van Soest, P.J. 1982. Nutritional Ecology of the Ruminant, Second Edition. Cornell University Press, Ithaca, Villamide J. M., De Blas J.C. and Carabano R. 1989. Nutritive value of cereal by-products for rabbits: wheat bran, corn gluten feed and dried distillers grains and soluble. J. Appl. Rabbit Res. 12:152-155.

Villamide M.J., Martens L., Cervera C., Perez J.M., Xiccato G. 2001. A critical approach of the calculation procedures to be used in digestibility determination of feed ingredients for rabbits. World Rabbit Science 9, 19-25.

Waller J.C. 2004. Byproducts and unusual feedstuffs. Feedstuffs, 76: 18-22.

Widyaratne, G.P and Zijlstra, R.T. 2007. Nutritional value of wheat and corn distiller's dried grain with solubles: Disgetibility and digestible contents of energy, amino acids and phosphorus, nutient excretion and growth performance of grower-finisher pigs. Can. J. Anim. Sci. 87:103-114.

Xiccato, G. and Trocino, A. 2011. Energy and Protein Metabolism and Requirements. In: De Blas, C., Wiseman, J. (Eds). The Nutrition of the Rabbit.2nd ed., CABI International. Wallingford (UK), pp. 83-119.

Yang, Y; Kiarie, E.; Slominski, B. A.; Brule-Babel, A, and Nyachoti, C. M. 2010. Amino acid and fiber digestibility, intestinal bacterial profile, and enzyme activity in growing pigs fed dried distillers grains with solubles-based diets. J. Anim. Sci, 88:3304-3312.

Table 1. Ingredients (g/kg) of the basal diet (C) and the experimental diets (D) including the distillers dried grains with solubles (DDGS) evaluated.

	C	D
DDGS evaluated	-	*200*
Basal mixture	*982.4*	*782.4*
Barley grain	290	231
Alfalfa hay	270	215
Wheat bran	170	135
Sunflower meal 30%CP	85	68
Defatted grape seed	65	52
Soybean hulls	33	26
Oat hulls	33	26
Soybean oil	20	16
Beet molasses	10	8
L-Lysine HCL	3	2.6
DL-Methionine	0.6	0.5
L-Threonine	1.8	1.5
L-Tryptophan	1	0.8
Vitamin-mineral premix	*17.6*	*17.6*
Calcium carbonate	4.6	4.6
Sodium chloride	5	5
Vitamin-micromineral mixture	5	5
Antibiotics[3]	3	3

CP: Crude protein

Vitamin-micromineral mixture supplies per kg of feed: Vitamin A: 8.375 IU; Vitamin D3: 750 IU; Vitamin E: 20 mg; Vitamin K3: 1 mg; Vitamin B1: 1 mg; Vitamin B2: 2 mg; Vitamin B6: 1 mg; Nicotinic acid: 20 mg; Choline chloride: 250 mg; Magnesium: 290 mg; Manganese: 20 mg; Zinc: 60 mg; Iodine: 1.25 mg; Iron: 26 mg; Copper: 10 mg; Cobalt: 0.7 mg; Butyl hydroxylanysole and ethoxiquin mixture: 4 mg.

Antibiotics: Dinco-spectim (29 ppm dincomicina + 29 ppm spectinomicyn), 120 ppm neomicin, Apsamix Tiamulin (50 ppm tiamulin), normally used in rabbit farms whit high incidence of mucoid enteropathy (ME).

Table 2. Chemical, amino acid and fatty acids composition (g/kg DM) of the experimental diets [control diet (C) and diets including distillers dried grains with solubles (DDGS) from national barley (Dnb), national corn (Dnc), brazilian corn (Dbc) and national wheat (Dnw)].

	C	Dnb	Dnc	Dbc	Dnw
Dry matter, DM	908	915	914	912	911
Ash	74	73	70	67	67
Ether extract	44	48	63	64	49
Starch	192	162	164	166	164
Crude protein, CP	143	164	170	177	183
CP bound to aNDFom	22	32	28	26	38
Neutral detergent fibre, aNDFom	397	392	393	365	379
Acid detergent fibre, ADFom	208	196	186	174	184
Lignin (sa)	58	48	48	44	51
Insoluble hemicelluloses, aNDFom−ADFom	189	196	208	191	195
Celluloses, ADFom–Lignin (sa)	150	148	137	130	133
Neutral detergent soluble fibre	132	154	110	132	127
Gross energy, MJ/kg DM	19.0	19.1	19.7	19.6	19.5
Amino acid composition					
Alanine	6.9	7.5	10.2	10.7	8.6
Arginine	8.4	8.6	9.2	9.5	9.7
Aspartic acid	13.4	13.5	15.3	15.4	14.6
Cysteine	2.1	2.3	2.8	2.7	3.0
Glutamic acid	26.0	32.1	33.0	32.8	43.4
Glycine	8.3	8.5	9.4	9.2	9.4
Histidine	3.5	3.6	4.5	4.5	4.4
Isoleucine	5.3	5.8	6.5	6.6	6.8
Leucine	9.3	10.5	14.0	14.8	12.4
Lysine	9.1	8.7	9.2	9.4	9.7
Methionine	2.7	3.2	3.5	3.4	3.3
Phenylalanine	6.3	7.0	7.8	7.7	7.4
Proline	10.2	12.5	12.5	13.6	15.0
Serine	6.8	7.5	9.1	8.8	9.1
Threonine	7.1	7.2	8.3	8.3	8.3
Tyrosine	2.8	3.2	4.1	4.2	3.5
Valine	7.1	7.9	8.8	8.9	8.9
Fatty acid composition					
C14:0	0.2	0.1	0.1	0.1	0.1
C16:0	7.2	8.1	9.1	9.7	8.2
C18:0	1.3	1.2	1.4	1.5	1.1
C18:1ω7	0.6	0.6	0.7	0.8	0.6
C18:1ω9	7.4	7.6	12.1	14.4	7.8
C18:2	22.9	25.7	32.7	35.0	27.4
C18:3	2.5	2.5	2.3	2.4	2.6
C20:0	0.1	0.1	0.2	0.3	0.1
C22:0	0.1	0.1	0.1	0.1	0.1

Amino acid content was that rendered after acid hydrolysis.
Only fatty acids with a sample quantification of at least 0.1 g/kg DM were presented.

Table 3. Chemical, amino acid and fatty acids composition of the distillers dried grains with solubles (DDGS) samples evaluated (g/kg DM) by grain source.

	DDGS				
Grain source	Barley	Corn	Wheat	SEM[a]	P-value
No. of samples	2	2	4		
Chemical composition (g/kg DM):					
Dry matter, DM	918	930	917	3.1	0.262
Ash	61[b]	45[a]	46[a]	1.4	0.012
Ether extract	72[a]	141[b]	67[a]	0.9	<0.001
Starch	9[a]	25[b]	14[ab]	1.4	0.018
Crude protein, CP	262[a]	305[b]	353[c]	2.7	<0.001
CP bound to aNDFom	86	100	76		0.267
Neutral detergent fibre, aNDFom	401[b]	374[b]	317[a]	9.4	0.024
Acid detergent fibre, ADFom	129[b]	116[ab]	104[a]	3.3	0.057
Lignin (sa)	9	10	19	1.9	0.123
Insoluble hemicelluloses, aNDFom−ADFom	273[b]	257[ab]	213[a]	8.7	0.057
Celluloses, ADFom−Lignin(sa)	119[b]	106[b]	85[a]	2.3	0.003
Neutral detergent soluble fibre	210	217	203	19.6	0.947
Amino acids (g/kg of crude protein):					
Alanine	45[a]	75[b]	39[a]	1.0	<0.001
Arginine	51[b]	43[a]	46[a]	0.7	0.022
Aspartic acid	66[b]	68[b]	54[a]	1.0	0.002
Cysteine	16	16	20	1.5	0.489
Glutamic acid	244[b]	183[a]	290[c]	2.9	<0.001
Glycine	47	43	45	0.8	0.255
Histidine	23[a]	27[b]	22[a]	0.5	0.007
Isoleucine	39[b]	36[ab]	35[a]	0.4	0.048
Leucine	74[a]	114[b]	66[a]	2.3	<0.001
Lysine	31	31	24	1.6	0.193
Metionine	15	18	15	1.5	0.718
Phenylalanine	55[b]	47[a]	44[a]	1.4	0.035
Proline	107[c]	78[a]	92[b]	1.2	<0.001
Serine	50	52	50	0.4	0.173
Threonine	39[b]	40[b]	33[a]	0.4	<0.001
Tyrosine	25[a]	32[b]	24[a]	0.7	0.014
Valine	54[c]	49[b]	45[a]	0.5	0.002
Main fatty acids (g/kg total fatty acids):					
C16:0	236[c]	160[a]	211[b]	3.5	0.001
C18:0	22[b]	22[b]	16[a]	1.0	0.038
C18:1 ω9	131[a]	260[b]	132[a]	6.3	<0.001
C18:1 ω7	8[a]	12[c]	11[b]	0.1	<0.001
C18:2	548[ab]	522[a]	581[b]	8.4	0.065
C18:3 ω3	36[b]	10[a]	32[b]	1.1	<0.001
SFA	267[c]	188[a]	232[b]	4.4	0.003
MUFA	148[a]	278[b]	152[a]	6.4	<0.001
PUFA	586[ab]	534[a]	615[b]	9.3	0.033

SEM: standard error of the means. Amino acid content was that rendered after acid hydrolysis. Only fatty acids with a sample quantification of at least 0.1 g/kg DM were presented. SFA, saturated fatty acids [C14:0+C16:0+C17:0+C18:0+C20:0+C22:0]; MUFA, monounsaturated fatty acids [C16:1+C18:1w9+C18:1w7+C20:1+C22:1w9]; PUFA, poliunsaturated fatty acids [C18:2+C18:3w6+C18:3w3+C20:2+C22:2]. [a,b,c] Means not sharing the same superscript were significantly different at P<0.05.

Table 4. Daily feed intake, growth rate and apparent digestibility coefficients of main nutrients for the experimental diets [control diet (C) and diets including distillers dried grains with solubles (DDGs) from national barley (Dnb), national corn (Dnc), brazilian corn (Dbc) and national wheat (Dnw)].

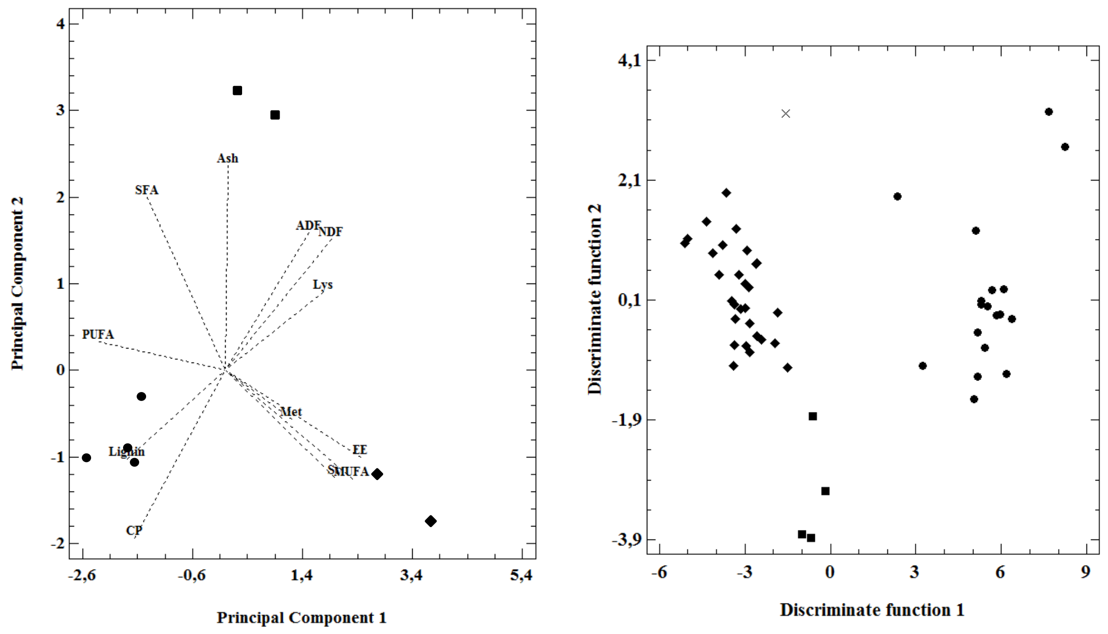
	Diets						
	C	Dnb	Dnc	Dbc	Dnw	SEM	P-value
No. of animals	12	12	12	12	12		
Feed intake (g/d)	141	144	133	135	139	4	0.8753
Growth rate (g/d)	53.0	54.0	50.4	52.6	55.3	1.6	0.9053
Apparent digestibility coefficients[2]*:*							
dDM	0.582^{a}	0.583^{ab}	0.597^{bc}	0.592^{abc}	0.600^{c}	0.002	0.0468
dCP	0.718	0.703	0.719	0.711	0.735	0.005	0.2262
dEE	0.879^{ab}	0.875^{a}	0.895^{c}	0.893^{bc}	0.882^{abc}	0.006	0.0482
dGE	0.579^{a}	0.582^{ab}	0.606^{c}	0.598^{bc}	0.609^{c}	0.003	0.0015
daNDFom	0.244^{ab}	0.263^{b}	0.295^{c}	0.234^{a}	0.264^{b}	0.005	0.0001
dADFom	0.094^{a}	0.134^{b}	0.136^{b}	0.083^{a}	0.090^{a}	0.006	0.0020
dHemicelluloses	0.409^{bc}	0.393^{ab}	0.437^{c}	0.371^{a}	0.428^{c}	0.006	0.0008
dCellulose	0.140^{a}	0.181^{b}	0.183^{b}	0.131^{a}	0.135^{a}	0.006	0.0017
dAlanine	0.712^{b}	0.686^{a}	0.771^{c}	0.765^{c}	0.729^{b}	0.010	0.0001
dArginine	0.778	0.743	0.773	0.769	0.767	0.013	0.3104
dAspartic acid	0.661	0.586	0.658	0.634	0.629	0.015	0.0029
dCysteine	0.512	0.589	0.633	0.564	0.662	0.034	0.1271
dGlutamic acid	0.809^{ab}	0.802^{ab}	0.816^{b}	0.795^{a}	0.863^{c}	0.007	0.0001
dGlycine	0.667	0.646	0.682	0.668	0.672	0.013	0.3551
dHistidine	0.843^{b}	0.814^{a}	0.832^{ab}	0.812^{a}	0.845^{b}	0.007	0.0007
dIsoleucine	0.748^{bc}	0.711^{a}	0.750^{bc}	0.735^{ab}	0.764^{c}	0.011	0.0092
dLeucine	0.745^{b}	0.714^{a}	0.763^{b}	0.753^{b}	0.770^{b}	0.009	0.0006
dLysine	0.837^{c}	0.778^{a}	0.819^{bc}	0.808^{b}	0.817^{bc}	0.007	0.0001
dMethionine	0.702	0.746	0.771	0.739	0.771	0.030	0.4337
dPhenylalanine	0.780	0.751	0.778	0.763	0.776	0.007	0.1262
dProline	0.771^{a}	0.764^{a}	0.767^{a}	0.765^{a}	0.812^{b}	0.007	0.0005
dSerine	0.718^{b}	0.704^{a}	0.760^{c}	0.737^{b}	0.756^{c}	0.008	0.0001
dThreonine	0.832^{b}	0.796^{a}	0.833^{b}	0.820^{b}	0.816^{b}	0.006	0.0005
dTyrosine	0.741^{ab}	0.725^{a}	0.773^{b}	0.749^{ab}	0.745^{ab}	0.009	0.0566
dValine	0.723^{b}	0.680^{a}	0.719^{b}	0.698^{a}	0.727^{b}	0.010	0.0072
dSulphur	0.619	0.680	0.710	0.661	0.719	0.035	0.2555

SEM: standard error of the means.
d, apparent digestibility coefficient; DM, dry matter; CP, crude protein; GE, gross energy; aNDFom, neutral detergent fibre; ADFom, Acid detergent fibre; Hemicelluloses, aNDFom−ADFom; Celluloses, ADFom−Lignin (sa).

Table 5. Apparent digestibility coefficients (d) of dry matter (DM), crude protein (CP), ether extract (EE) and gross energy (GE), and nutritive value [digestible protein (DP) and digestible energy (DE) values] for the evaluated distillers dried grains with solubles (DDGS) in growing rabbits.

	DDGS					
	National barley	National Corn	Brazilian corn	National wheat	SEM	P-value
dDM	0.647[b]	0.722[ab]	0.684[ab]	0.754[a]	0.014	0.0547
dCP	0.635	0.656	0.704	0.748	0.016	0.0827
dEE	0.767[a]	0.921[b]	0.945[b]	0.915[b]	0.014	0.0001
dGE	0.582[c]	0.718[ab]	0.653[cb]	0.750[a]	0.014	0.0006
DP, g/kg DM	168[a]	195[ab]	221[b]	263[c]	5	0.0001
DE, MJ/kg DM	11.87[a]	15.89[b]	14.72[b]	15.69[b]	0.30	0.0001

SEM: standard error of the means.
[a,b,c] Means not sharing the same superscript were significantly different at $P<0.05$.



(a) (b)

Figure 1. (a) Distribution of the evaluated distillers dried grains with solubles (DDGS) by grain source [■ barley, ◆ corn, ● wheat and × sorghum] in the first two principal components obtained from their main chemical composition [Ash; S, starch; EE, ether extract; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; Lignin; Lys, Lysine; Met, methionine; SFA: saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids]. (b) Distribution of DDGS described in the literature by grain source in the first two discriminate functions from their main available chemical composition [dry matter; ash, CP, EE, NDF, ADF and RES (as 100–Ash–CP–EE–aNDFom–Starch)].

Literature DDGS sample sources: Villamide et al., 1989; Cromwell et al., 1993; NRC, 1998; Spiehs et al., 2002; Sauvant et al., 2004; Shurson et al., 2004; Distillers Grains Technology Council, 2005; Nyachoti et al., 2005; Stein et al., 2006; Widyaratne and Zijlstra, 2006; US Grains Council, 2007; Widyaratne and Zijlstra, 2007; Babcock et al., 2008; Emiola et al., 2009; Nuez-Ortin et al., 2009; Avelar et al., 2010; Cozannet et al., 2010; De Blas et al., 2010; Waller, 2004; present study.