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Nutritional value of Brazilian distillers dried grains with solubles for pigs as determined by different methods

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ABSTRACT - The objective of this study was to determine the digestibility coefficient (DC) of nutrients and the digestible energy (DE), and metabolizable energy (ME) values of distillers dried grains with solubles (DDGS) produced in Brazil by different methods. Eight barrows with 23.3±4.1 kg were housed in metabolic cages in a randomized block design and fed diets containing 0, 200, 400, and 600 g kg^{-1} of corn DDGS. We determined the digestibility of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), mineral matter (MM), neutral detergent fiber (NDF), and gross energy (GE) by the total collection (TC) and chromium oxide marker (Cr) methods. Distillers dried grains with solubles provided the respective DM, OM, CP, EE, MM, NDF, and GE values of 910, 863, 286, 66.9, 46.8, 500 g kg^{-1}, and 4,780 kcal kg^{-1}. The DE and ME values of DDGS were 3,739 and 3,401 kcal kg^{-1} and 3,691 and 3,213 kcal kg^{-1} as determined by TC and Cr methods, respectively. The growing inclusion of DDGS did not affect the DE or ME values. The digestibility coefficients of DM, OM, CP, EE, MM, and NDF were 767, 765, 827, 691, 883, and 821 g kg^{-1}, respectively, by the total collection method. The Cr underestimated the values of all variables compared with TC method. Levels up to 600 g kg^{-1} of the test ingredient do not influence the DE and ME of DDGS, but compromises the digestibility coefficients of DM, OM, and NDF.

Key Words: corn ethanol, digestibility, DDGS, marker, metabolizability, total feces collection

Introduction

Distillers dried grains with solubles (DDGS) are byproducts from ethanol production whose chemical properties allow for a broad use in swine diets. Studies conducted with DDGS produced in the USA (Anderson et al., 2012), China (Li et al., 2015), and Europe (Cerisuelo et al., 2012) have demonstrated the large variety in their composition and nutritional value. In Brazil, ethanol is commonly obtained from sugarcane and only recently has it been produced from corn, especially in regions where the supply of this cereal is abundant.

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Reduced starch contents and elevated concentrations of protein, ether extract, and fiber make DDGS a potential ingredient to replace the corn and soybean meal in pig diets; however, its nutritional composition – especially in terms of energy – must be determined for its proper use. Several factors can affect the composition of DDGS, e.g., the quality of grains, analytical methods, proportion of solubles, and processing method. Nevertheless, the composition of the DDGS from corn produced in Brazil has not yet been determined.

In feedstuff digestibility assays, the most frequently employed methods are total feces and urine collection and indigestibility markers such as chromium oxide. According to Sakomura and Rostagno (2007), the main limitation of the total collection method is control during the collection of feces and urine samples without contaminations such as shedding of skin, hair, and feed, which may interfere with the determination of the energy content of a feedstuff. On the other hand, the use of markers does not require quantification of intake and feces and a partial collection of the sample can be performed to reduce possible contamination. However, the use of this method requires uniform mixture into the diet and standardization

for chemical analyses, which may lead to a significant variability of results.

It has thus been hypothesized that the energy and nutritional values of DDGS produced are distinct and may be influenced by the evaluation method. Therefore, the present study was conducted to determine the digestible energy, metabolizable energy, and nutritional values of DDGS produced in Brazil, using different methods.

Material and Methods

The experiment was conducted in Sinop, Mato Grosso, Brazil (11º 51' 41" S, 55º 28' 57" W), complying with the ethical principles of animal experimentation adopted by the National Council for the Control of Animal Experimentation, and after being approved by the Committee of Ethics in Animal Use (case no. 23108.700673/14-4).

Eight genetically homogenous barrows originating from industrial crosses, with 23.3±4.1 kg, were distributed individually into metabolic cages. We adopted a randomized block design with four treatments and six replicates that were distributed along three 12-day periods, consisting of seven days for adaptation to the diet and five days for collection. The animal weight and the periods were used to characterize the blocks.

Treatments were composed of a control diet based on corn and soybean meal (Table 1) formulated to meet the recommendations of Rostagno et al. (2011) and containing corn DDGS in an isometric substitution of 200, 400, and 600 g kg^{-1} of the control diet (Table 2), according to the methodology described by Sakomura and Rostagno (2007). To evaluate the digestibility, we simultaneously employed the total feces and urine collection (TC) and chromium oxide (Cr_2O_3) indigestibility marker (Cr) methods.

The distillers dried grains with solubles used here were obtained from ethanol production using corn as raw material (USIMAT Alcohol Distillery Ltd; Campos de Julio, MT, Brazil). Analyses for the chemical composition of diets and DDGS were performed following Silva and Queiroz (2002) (Table 2).

In the adaptation period, the diet was supplied *ad libitum* and orts were recorded for a later calculation of intake based on the metabolic weight ($LW^{0.75}$). To prevent losses and facilitate intake, the diets were weighed and moistened at a 1:1 ratio and supplied twice daily (07:30 and 17:30 h).

Feces and urine were collected once daily, in the morning. The material was weighed and homogenized and then samples of 200 g kg^{-1} of the total were collected, packed in plastic bags, identified, and stored in a freezer (−10 ºC). Urine was filtered as it was excreted using a filter tissue placed in a funnel beneath the urine collection box and then collected in plastic buckets containing 10 mL HCl (1:1). The total urine volume of each sample was counted using a 5-mL graduated beaker from which aliquots of 20% were taken for sampling, packaged, and stored in a freezer.

At the end of the collection period, feces samples were thawed, weighed, homogenized, and pre-dried in a forced-air oven at 60 ºC for 72 h for analyses of dry matter (DM), crude protein (CP), ether extract (EE), mineral matter (MM), neutral detergent fiber (NDF), and gross energy (GE), according to Silva and Queiroz (2002). The organic matter (OM) content was determined as the difference between the DM and MM contents. Analyses for the chromium content in the feces were undertaken by atomic absorption spectrophotometry (Willians et al., 1962). The urine samples were thawed and homogenized for the determination of total nitrogen and gross energy.

Table 1 - Composition and calculated nutritional values of control diet (as-fed basis)

Ingredient (g kg^{-1})	Control diet
Corn	604.8
Soybean meal	302.6
Rice bran	30.0
Soy oil	18.9
Calcitic limestone	5.2
Dicalcium phosphate	17.5
Vitamin-mineral mix[1]	10.0
Common salt	4.6
L-lysine	1.5
Chromium oxide	5.0
Total	1000
Calculated nutrient content (g kg^{-1})	
Metabolizable energy swine (kcal kg^{-1})	3,230
Crude protein	189.9
Calcium	7.2
Available phosphorus	3.6
Sodium	2.0
Digestible lysine	10.1

[1] Composition of the supplement per kg of diet: vitamin A, 13750 IU; vitamin B1, 2 mg; vitamin B2, 1.25 mg; vitamin B6, 4 mg; vitamin B12, 4.5 mcg; vitamin D3, 3000 IU; vitamin E, 75 IU; vitamin K3, 6.25 mg; nicotinic acid, 50 mg; pantothenic acid, 30 mg; folic acid, 0.625 mg; cobalt, 1.25 mg; copper, 25 mg; iron, 150 mg; zinc, 200 mg; manganese, 75 mg; selenium, 0.7 mg; iodine, 2 mg; coline, 250 mg; biotin, 25 mcg.

Table 2 - Chemical composition of diets and distillers dried grains with solubles (DDGS)

Item (g kg^{-1})	DDGS (g kg^{-1})				DDGS
	0	200	400	600	
Dry matter	892.6	898.1	900.4	901.8	910.0
Organic matter	955.6	956.9	958.3	959.7	863.2
Crude protein	202.3	218.3	247.8	264.0	286.0
Ether extrat	42.7	47.5	52.7	57.3	66.9
Mineral matter	44.4	43.1	41.7	40.3	46.8
Neutral detergente fiber	119.9	195.9	271.9	348.0	500.4
Gross energy (kcal kg^{-1})	3984	4153	4331	4557	4780

The digestibility coefficients (DC), digestible nutrients, and digestible energy (DE), metabolizable energy (ME), and their corrections for the nitrogen content (DEn and MEn) were determined according to Sakomura and Rostagno (2007).

The experiment was conducted as a randomized block design in a split-plot arrangement, with analysis of variance performed according to the statistical model below:

$$Yijk = \mu + Di + Pj + Mk + Di \times Mk + \varepsilon ij + \varepsilon ijk,$$

in which Yijk = observation of the effect of DDGS level i, in period j, using the digestibility assessment method k; μ = overall mean; Di = effect of DDGS inclusion level (i = 0, 200, 400, or 600 g kg^{-1}); Pj = experimental period (j = 1, 2, or 3); Mk = effect of the digestibility assessment method (k = total collection or marker); Di×Mk = interaction effect between the DDGS level i and the digestibility assessment method k; εij = random error associated with the plot; and εijk = random error associated with the subplot.

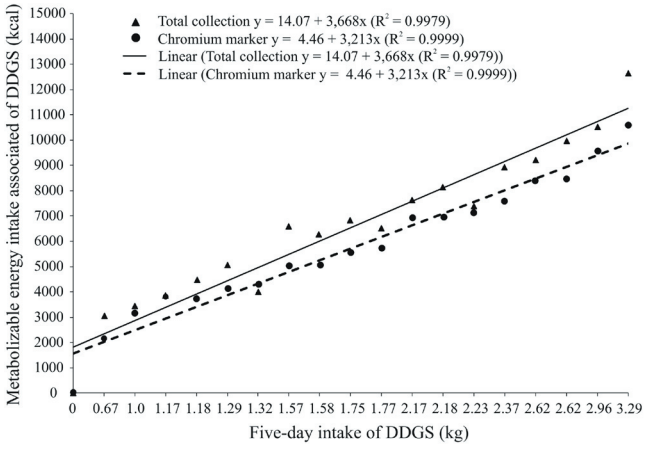
Effects related to the DDGS level were evaluated by decomposing the sum of squares of treatments into orthogonal contrasts to assess the linear and quadratic effects. The F test was used for the evaluation of collection methods.

The data were subjected to the mixed procedure of the SAS software (Statistical Analysis System, version 6.0), considering the 5% probability level. For the analysis of final weight and daily feed intake, we used the initial weight as a co-variable. Data pertaining to digestibility and metabolizability coefficients, digestible nutrients, digestible and metabolizable energy corrected for the nitrogen excretion of the diets, and of DDGS were subjected to an ANOVA considering the effects of the digestibility assessment method and the interaction between these and the DDGS inclusion level. The metabolizable energy value was estimated by regression analysis (Adeola and Ileleji, 2009) of ME intake (kcal) associated with DDGS vs. DDGS intake (g) by the TC and Cr methods.

Results

We did not detect interaction effects between the digestibility assessment methods and DDGS inclusion levels on the energy values of DDGS (Table 3). Digestible energy, DEn, ME, MEn, DE:ME, and DEn:MEn of DDGS were not influenced by the different inclusion levels of this ingredient (P>0.05); however, the total collection method generated higher values in comparison with the marker method, except for DEn. The slope of the linear relationship between ME intake and DDGS intake (Figure 1) shows that the TC and Cr methods generated different ME values (3,668 and 3,213 kcal kg^{-1}, respectively).

No interaction effect between the digestibility assessment methods and DDGS inclusion levels was observed on the digestibility coefficients of DDGS, except for NDF (Table 4). The digestibility coefficients of DM, OM, and NDF of DDGS decreased as the inclusion



DDGS - distillers dried grains with solubles; ME - metabolizable energy.

Figure 1 - Equations of ME of glycerin obtained from intake of ME (kcal kg^{-1}), associated to DDGS vs. DDGS intake (g) for five days determined by the total collection and chromium marker digestibility methods.

Table 3 - Values and relations of energy of DDGS for pigs with different DDGS levels determined by the total collection (TC) and chromium marker (Cr) digestibility methods

	DDGS (g kg^{-1})			Digestibility method		Significance[1]			
	200	400	600	TC	Cr	L	Q	Digestibility method	SEM
DE (kcal kg^{-1})	3,556	3,567	3,587	3,739	3,401	0.7980	0.9685	0.0008	51.29
DEn (kcal kg^{-1})	3,436	3,440	3,406	3,471	3,384	0.7727	0.8642	0.2771	39.95
ME (kcal kg^{-1})	3,445	3,447	3,465	3,691	3,213	0.8618	0.9411	<0.0001	56.64
MEn (kcal kg^{-1})	3,404	3,372	3,371	3,562	3,203	0.7859	0.8877	0.0001	48.55
ME:DE	0.9688	0.9650	0.9657	0.9881	0.9449	0.3926	0.5122	<0.0001	0.027
MEn:DEn	0.9879	0.9842	0.9842	1.0259	0.9449	0.6196	0.7719	<0.0001	0.007

DDGS - distillers dried grains with solubles; DE - digestible energy; DEn - digestible energy corrected for nitrogen balance; ME - metabolizable energy; MEn - metabolizable energy corrected for nitrogen balance; L - linear effect; Q - quadratic effect; SEM - standard error of the mean.
[1] Significance level P<0.05.

of this test feedstuff in the diets was increased, whereas the digestibility coefficients of CP, EE, and MM were not influenced by the inclusions. In all DDGS fractions evaluated here, the DC were higher when determined by total collection as compared with the marker method.

There were no interaction effects between collection methods and DDGS levels on the digestible fractions of the feed (Table 5). The digestible contents of DM, OM, EE, and NDF decreased linearly as the inclusion of DDGS in the diets was elevated, whereas the digestible content of CP was increased. The digestible MM content was not changed by DDGS inclusion. All digestible fractions showed higher values when determined by the total collection method in relation to the marker method.

Discussion

The different inclusion levels of the test ingredient did not influence the determination of the energy values of DDGS. This finding agrees with Graham et al. (2014a), who calculated the caloric efficiencies, based on ADFI × dietary energy (Mcal kg^{-1}) divided by total body weight gain, and observed that DE and ME did not change with inclusions of 0, 250, 300, and 450 g kg^{-1} of DDGS.

The gross energy (4,780 kcal kg^{-1}) of the corn DDGS produced in Brazil evaluated in this study was lower than that of the seven samples evaluated by Anderson et al. (2012) (5,076 to 5,550 kcal kg^{-1}), but within the range of the ten samples evaluated by Pedersen et al. (2007) (4,571 to 4,851 kcal kg^{-1}) and 25 samples tested by Li et al. (2015) (4,763 to 5,371 kcal kg^{-1}). In the evaluation of DE, the 3,739 kcal kg^{-1} found with the total collection method was lower than the 3,947 to 4,593 kcal kg^{-1} found by Pedersen et al. (2007), but close to the lowest values found by Anderson et al. (2012) (3,705 to 4,332 kcal kg^{-1}); it was, however, within the range found by Li et al. (2015) (3,255 to 4,103 kcal kg^{-1}). The ME value of 3,691 kcal kg^{-1} of the present study is near the lowest values found by Pedersen et al. (2007) (3,674 to 4,336 kcal kg^{-1}) and Anderson et al. (2012) (3,650 to 4,141 kcal kg^{-1}), but within the range found by Li et al. (2015) (2,955 to 3,899 kcal kg^{-1}).

The energy value of the feedstuffs is closely related to their chemical composition. Positive correlations between ether extract and GE (r = 0.92), DE (r = 0.55), and ME (r = 0.54) and negative correlations between NDF and DE (r = −0.77) and ME (r = −0.76) of DDGS were observed by Li et al. (2015). In this way, differences in the energy content of the DDGS investigated here and the

Table 4 - Digestibility coefficients of the chemical composition of experimental diets for pigs with different DDGS levels determined by the total collection (TC) and chromium marker (Cr) digestibility methods

DC (g kg^{-1})	DDGS (g kg^{-1})			Digestibility method		Significance[1]			
	200	400	600	TC	Cr	L	Q	Digestibility method	SEM
DM	753.8	687.0	668.2	767.8	638.3	0.0043	0.3247	<0.0001	1.67
OM	740.7	689.8	679.4	765.1	641.6	0.0270	0.3827	<0.0001	1.53
CP	760.4	777.8	796.8	827.1	729.6	0.2522	0.9777	0.0006	1.47
EE	655.9	610.9	603.0	691.3	555.2	0.3831	0.7219	0.0091	2.59
MM	770.5	708.2	693.1	883.6	564.3	0.0664	0.5066	<0.0001	3.18
NDF	821.8	732.8	719.0	821.8	693.9	0.0140	0.279	0.0004	2.00

DDGS - distillers dried grains with solubles; DC - digestibility coefficient; DM - dry matter; OM - organic matter; CP - crude protein; EE - ether extract; MM - mineral matter; NDF - neutral detergent fiber; L - linear effect; Q - quadratic effect; SEM - standard error of the mean.
[1] Significance level P<0.05.
$\hat{Y}_{DC\text{-}DM} = 872.4242 - 2.4192x$ ($R^2 = 0.58$); $\hat{Y}_{DC\text{-}OM} = 870.5817 - 2.4328x$ ($R^2 = 0.57$); $\hat{Y}_{DC\text{-}NDF} = 836.8267 - 1.6682x$ ($R^2 = 0.28$).

Table 5 - Digestibility of the chemical composition of experimental diets for pigs with different DDGS levels determined by the total collection (TC) and chromium marker (Cr) digestibility methods

Digestible content (g kg^{-1})	DDGS (g kg^{-1})			Digestibility method		Significance[1]			
	200	400	600	TC	Cr	L	Q	Digestibility method	SEM
DM	695.5	637.6	619.9	702.3	599.6	0.0041	0.3475	<0.0001	1.39
OM	721.6	668.6	654.3	736.5	626.5	0.0180	0.4127	<0.0001	1.48
CP	226.4	241.9	249.8	250.1	228.6	0.0013	0.5057	0.0004	0.35
EE	45.1	40.7	39.1	46.2	37.1	0.0419	0.5732	0.0005	0.14
MM	30.2	26.4	25.6	34.2	20.6	0.4111	0.4509	<0.0001	0.15
NDF	411.1	366.6	359.9	411.2	347.7	0.0218	0.3343	0.0059	0.25

DM - dry matter; OM - organic matter; CP - crude protein; EE - ether extract; MM - mineral matter; NDF - neutral detergent fiber; L - linear effect; Q - quadratic effect; SEM - standard error of the mean; D - digestible.
[1] Significance level P<0.05.
$\hat{Y}_{D\text{-}DM} = 753.5342 - 1.4881x$ ($R^2 = 0.42$); $\hat{Y}_{D\text{-}OM} = 803.5125 - 1.6654x$ ($R^2 = 0.44$); $\hat{Y}_{D\text{-}CP} = 163.855 + 0.8259x$ ($R^2 = 0.79$); $\hat{Y}_{D\text{-}EE} = 28.4458 + 0.1008x$ ($R^2 = 0.30$); $\hat{Y}_{D\text{-}NDF} = 397.4425 - 0.0431x$ ($R^2 = 0.02$).

other sources cited in the literature are directly related to the EE (66.9 g kg^{-1}) and NDF (500 g kg^{-1}) contents. These results are close to those reported by Li et al. (2015) (EE, 28.2 to 141.8 g kg^{-1}; NDF, 310 to 466 g kg^{-1}) and Anderson et al. (2012) (EE, 31.5 to 121 g kg^{-1}; NDF, 334 to 509.6 g kg^{-1}), but different from those found by Pedersen et al. (2007) (EE, 86 to 124 g kg^{-1}; NDF, 200 to 266 g kg^{-1}). The oil concentration of this DDGS produced in Brazil allows us to classify this ingredient as having a medium oil content, according to the NRC (2012) classification, which considers >100 g kg^{-1} as high-oil, 60 to 90 g kg^{-1} as medium-oil, and <40 g kg^{-1} as low-oil. By contrast, differences between sources in terms of ileal and total fiber digestion can contribute to differences in the digestibility of the energy in DDGS (Urriola et al., 2010). Variations in the chemical composition of different DDGS sources have also been previously reported (Anderson et al., 2012; Cerisuelo et al., 2012; Pedersen et al., 2007), suggesting it to be a critical point in their use as ingredients in animal feeding.

The variations in chemical composition between different sources may be related to characteristics of the grain and manufacturing processes (Urriola et al., 2009; Belyea et al., 2010), levels of inclusion of solubles and oil extraction (Li et al., 2015), and drying process, among others. The DDGS used in this study originated from a mill with capacity to generate ethanol also from sugarcane, which seems to be a unique feature.

The reduction of the DC (Table 4) and of the digestible fractions (Table 5) of DM, OM, and NDF with the increasing DDGS inclusion levels is likely related to the fiber fraction present in the test ingredient. According to Stein and Shurson (2009), this is explained by the fact that dietary fiber of DDGS reduces the digestibility of nutritional fractions and makes it less digestible in relation to other ingredients. Fermentation in bioethanol production removes most of the starch; thus, the fiber content in DDGS is high and less fermentable (Jha et al., 2015). As a result, fecal output increased with a reduction of DM digestibility (Widyaratne and Zijlstra, 2007). Reductions in DM digestibility as a function of an increase in DDGS in pig diets were also reported by Agyekum et al. (2016), Wang et al. (2016), Li et al. (2016), and Wahlstrom et al. (2013), who included up to 300, 200, 200, and 300 g kg^{-1} of the ingredient, respectively. However, the digestible DM values of the DDGS in the present study are lower than the respective 902, 923, and 913.7 g kg^{-1} reported by Cerisuelo et al. (2012), Jacela et al. (2010), and Urriola (2009), but close to the 619 to 719 g kg^{-1} observed by Gutierrez et al. (2014) for different DDGS.

After starch is removed in the ethanol production process, the organic matter present in DDGS will be closely linked to the protein, oil, and fiber fractions. Therefore, the higher NDF concentrations observed in DDGS in relation to corn end up negatively influencing the organic matter digestibility, which was observed in the current study. In this sense, higher inclusions of DDGS generated diets with higher NDF contents, which led to reduced digestibility of the very NDF content and of the DM, OM, and digestible EE contents. The higher fiber concentration of DDGS compared with corn and soybean meal may influence the reduction of digestibility, despite the fact that the corn processing during ethanol production (e.g., grinding, heating, and fermentation) may modify the structure of dietary fiber, making it more digestible than the corn fiber (Le Gall et al., 2009; Graham et al., 2014b).

According to Urriola et al. (2010), over 500 g kg^{-1} of the total fiber in DDGS pass through the gastrointestinal tract of pigs without being fermented and only 18% of the NDF is fermented in the large intestine (Gutierrez et al., 2014). Moreover, the type of fiber present in DDGS is mostly insoluble (Pedersen et al., 2014), which may lead to a lower use of the feedstuff due to alterations in the transit time and increased intestinal endogenous losses. In this regard, Agyekum et al. (2016) reported that the NDF digestibility was lower in diets containing DDGS compared with the control diet, which was confirmed in the present study.

The DC of the crude protein in DDGS (827.1 g kg^{-1}) was close to those obtained by Graham et al. (2014a) (831 g kg^{-1}) and Pedersen et al. (2007) (830 g kg^{-1}). The inclusion levels of DDGS did not change the DC of crude protein, although an increase was observed in the digestible CP content of DDGS, which was promoted by the higher concentration of CP in the diets with greater participation of the ingredient. This finding agrees with Graham et al. (2014a) and Pedersen et al. (2007), who did not report differences in the digestibility of CP when comparing DDGS with corn. However, the results of the present study contrast with the findings of Wang et al. (2016), who observed a linear decrease in the DC of crude protein with an increase in DDGS from 0 to 200 g kg^{-1}, and Agyekum et al. (2016), who observed a reduction in the digestibility of nitrogen (N) with the inclusion of 300 g kg^{-1} DDGS. Our findings also disagree with Wahlstrom et al. (2013), who evaluated DDGS inclusion levels of 50 to 300 g kg^{-1} and found that levels above 200 g kg^{-1} reduced the DC of crude protein.

The DDGS inclusion to the control diet did not change the DC of ether extract, although it reduced the digestible EE content of DDGS. This observation agrees with Agyekum et al. (2016), who did not find differences in EE

digestibility between control diet and a diet containing 300 g kg^{-1} DDGS. In general, the digestibility of ether extract increases as the oil content in DDGS (Graham et al., 2014b) and the dietary oil content (Kil et al., 2010) increase. Graham et al. (2014 a,b) suggested an increase in the EE digestibility of DDGS in relation to corn due to a higher dietary EE content, which did not occur in the present study. Endogenous fat losses might have led to a lower digestible EE fraction of DDGS as a result of the addition of fiber to the diets and the worsened digestibility as a whole.

Lower DE and ME values of the DDGS obtained by the chromium oxide marker method can also be observed in the comparison between the results of Gutierrez et al. (2014), who used Cr_2O_3, with those of Anderson et al. (2012), who adopted the total collection method, both evaluating the same DDGS sources. The variations between 338 and 478 kcal kg^{-1} for DE and ME, respectively, between the methods used in the present study are close to the 261 to 678 kcal kg^{-1} for DE and 244 to 620 kcal kg^{-1} for ME observed by Gutierrez et al. (2014) and Anderson et al. (2012). Li et al. (2016) also recorded a lower energy digestibility in diets containing DDGS as determined by the marker method in comparison with total collection.

The use of the chromium oxide marker method led to lower DC and digestible fractions in relation to the total collection method for all variables. This is in line with results reported by Li et al. (2016), who observed greater digestibility of DM and nitrogen (trend) in diets evaluated by the total collection method in comparison with the titanium dioxide (TiO_2) marker method. Lower digestibility estimates observed by the Cr method in comparison with TC were also reported by Verussa et al. (2017) in an evaluation of glycerin for swine. The variability of results related to the Cr method compared with TC was explained by Sakomura and Rostagno (2007), who emphasized the possibility of chromium oxide not being fully retrieved in the feces, which interferes with the indigestibility factor used in the calculations of digestibility.

The DC of mineral matter in DDGS showed a high difference (319.3 g kg^{-1}) between both methods. This finding may be related to the higher experimental error margin in nutrients at a low concentration in the tested ingredients because the nutrient value is calculated by difference and the analytical methods may not be precise enough to determine small nutrient concentrations (Gutierrez et al., 2014). Gutierrez et al. (2014) also stated that the partial separation of dietary fiber components and Cr_2O_3 as they flow through the digestive tract may also negatively affect the reliability in the estimate of the dietary fiber digestibility.

In this scenario, Li (2013) suggested that digestibility estimates were lower using the index method compared with the total collection method when marker recovery was below 100%. According to Kavanagh et al. (2001), by using an assumed marker concentration in the diet, the marker is thought to be properly dispersed through the feed, but the marker can be lost during the mixing stage, particularly if a mill is being used. However, the concentration measured in the diet is more accurate, particularly when the same sampling procedure and laboratory analysis have been perfected over a long period to ensure accurate sampling.

Conclusions

Brazilian distillers dried grains with solubles contain 3,668 and 3,213 kcal kg^{-1} metabolizable energy as determined by the total collection method and the chromium oxide marker technique, respectively. Levels up to 600.0 g kg^{-1} of the test ingredient do not influence the digestible or metabolizable energy of distillers dried grains with solubles, but compromises the digestibility coefficients of dry matter, organic matter, and neutral detergent fiber.

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