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Nutritional characteristics of distillers dried grains with solubles and their effects on performance and economic viability for pigs

Características nutricionais de grãos secos destilados com solúveis e seus efeitos no desempenho e viabilidade econômica para suínos

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Abstract: The chemical and nutritional characteristics of the four distillers dried grains with solubles (DDGS) were determined for dry matter (DM), mineral matter (MM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF) and gross energy analyzed (GEa), from which the values of gross energy (GE), digestible energy (DE), metabolizable energy (ME) and net energy (NE) were estimated. There were differences in the contents of EE, NDF, GEa, GE, DE, ME and NE between the lots. A total of 40 barrows with an initial weight of 72.69 ± 5.66 kg were assigned to a randomized block design, fed diets containing 0, 100, 200 and 300 g kg^{-1} DDGS for 28 days and were subjected to performance assessment. The inclusion of DDGS in the diets did not affect daily feed intake (DFI), daily weight gain (DWG) or feed conversion (FC) but linearly reduced the final weight. Based on the results of the performance and prices of ingredients in the local market, we calculated the costs of feed, revenue and gross operating profit (GOP). Inclusions of DDGS in pig diets reduced costs and revenues but did not affect GOP. DDGS presented chemical and nutritional variation between the lots. Levels of inclusion up to 300 g kg^{-1} DDGS do not affect finishing pig performance and profitability.

Keywords: chemical composition; corn ethanol; DDGS; metabolizable energy; profit.

Resumo: As características químicas e nutricionais de quatro distillers dried grains with solubles (DDGS) foram determinados quanto a matéria seca (MS), matéria mineral (MM), proteína bruta (PB), extrato etéreo (EE), fibra em detergente neutro (FDN) e energia bruta analisada (EBa), dos quais os valores de energia bruta (EB), digestíveis (ED), metabolizável (EM) e liquida (EL) foram estimados. Houve diferenças no conteúdo de EE, FDN, EBa, EB, ED, EM e EL entre lotes. Um total de 40 machos castrados 72.69 ± 5.66 kg foram distribuídos em blocos ao caso, alimentados com dietas com 0, 100,

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200 e 300 g kg^{-1} DDGS por 28 dias. A inclusão de DDGS não afetou consumo de ração diário, ganho de peso diário e conversão alimentar mas reduziu de forma linear o peso final. Baseados nos resultados de desempenho e preços de ingredientes e mercado local foram calculados os custos de ração, receita e lucro operacional bruto (LOB). Inclusões de DDGS em dietas para suínos reduziu custos e receitas, mas não afetou LOB. DDGS apresentam variação química e nutricional entre lotes. Níveis de até 300 g kg^{-1} de DDGS não afeta desempenho e lucratividade com suínos em terminação.

Palavras-chave: composição química; DDGS; energia metabolizável; etanol de milho; lucro.

1. Introduction

Biofuel production is a reality in the top countries with the largest economies in the world and should continue to grow. World ethanol production reached 28 billion gallons in 2022, with 55% of the USA and 26% of Brazil generating 36 and 3.5 million metric tons of grain coproducts for animal feed, respectively (1, 2,3).

The production of ethanol based on grains generates a coproduct known as distillers dried grains with solubles (DDGS). It is estimated that the use of 100 kg grains results in 40.2 L ethanol, 32.3 kg DDGS and 32.3 kg CO2 (4), showing the importance of the industry and this coproduct as an alternative ingredient in animal diets with the emergence of first Brazilian industries.

Nutritional characteristics such as high contents of protein, oil, energy, and available phosphorus have promoted DDGS as an ingredient with great potential to replace traditional and expensive ingredients such as corn, soybean meal and dicalcium phosphate. However, chemical composition, digestibility and potential use in diets for pigs has shown great variability among studies (5,6), and there is a scarcity of information in Brazil. Thus, has been hypothesized that the DDGS produced in Brazil has a different characterization from that of other countries but also presents a difference between their production lots, with different energy values and effects on performance and economic viability.

Therefore, this study aimed to estimate the nutritional values of different corn DDGS produced in Brazil as well as the effects on growth performance and economic viability in finishing pig diets.

2. Material and methods

The study was performed at the Instituto de Ciências Agrárias e Ambientais da Universidade Federal de Mato Grosso (UFMT) (Sinop, Mato Grosso, Brazil, latitude -11° 86’ 26” and longitude -55° 48’ 49”). All practices involving the use of the animals were in accordance with the ethical principles in animal experimentation approved by the Ethics Committee in the Use of Animals of the UFMT (23108.017482/2022-58).

For the chemical and nutritional characterization of the different coproducts, samples of four corn DDGS were collected from different distilleries in Brazil and were sent to the laboratory. From the initial volume, a subsample of each DDGS source was collected and ground in a knife mill with 1.0 mm sieves.

Each sample was analyzed in quadruplicate and quantified for dry matter (DM, method 934.01) [7], crude protein (CP, method 2001.11) [7], ether extract (EE, method 945.38) [7], mineral matter (MM, method 923.03) [7] and neutral detergent insoluble fiber (NDF; method INCT-CA F-001/1) [8]. NDF analysis was performed with filter bags and fiber extractors (Ankom®), corrected for MM and CP, in which the residue of the neutral detergent digestion was incinerated in a muffle furnace at 600°C for three hours, and the correction for protein was performed using neutral detergent insoluble crude protein (PIDN) [8]. The gross energy analyzed (GEa) was determined by means of complete combustion in a calorimetric bomb (PARR 6400), and particle size (PS) was determined according to Zanotto & Bellaver [9].

The gross (GE), digestible (DE), metabolizable (ME) and net energy (NE) were calculated: GE = 4,583+(50.6*EE)-(0.1*PS [10]; DE = -2,161+(1.39*GE)-(20.7*NDF)-(49.3*EE) [5]; ME = -261+(1.05*DE)-(7.89*CP)+(2.47*NDF)-(4.99*EE) [5]; and NE = (115.01* EE) + 1,501.01 [11].

The performance assessment was carried out using 40 barrows of 72.69 ± 5.66 kg for diets based on corn and soybean meal [12], with 0, 100, 200 or 300 g kg^{-1} DDGS of larger-scale commercial (Table 1). Animals were assigned to a randomized block design with four treatments, five replicates (blocks), and two animals per experimental unit. The initial weights of the pigs were used as criteria for the blocks. The performance of the animals was assessed in relation to the daily feed intake (DFI), daily weight gain (DWG) and feed conversion (FC) in period 1 (0-14 days), period 2 (15-28 days) and the total period (0-28 days).

Based on the performance results, an economic feasibility analysis of the use of DDGS was carried out using the cost with feed (Cost), gross revenue (Revenue) and gross operating profit (GOP) with the following equations: Cost (U$/animal) = DFI (kg/day) x price of feed (U$/kg) x 28 days; Revenue (U$/animal) = final weight (kg) x price of pig (U$/kg); and GOP (U$/animal) = Revenue - Cost.

The cost of each ingredient (*R$* kg^{-1}) used in the formulations of the diets was DDGS 0.45, soybean meal 0.822, corn 0.508, dicalcium phosphate 2.28, calcitic limestone 0.13, common salt 0.13, L-lysine HCL 4.75), DL-methionine 22.97, and mineral-vitamin premix 3.40. The price of pigs was *R$* 2.81/kg. The prices of corn, soybean meal and pigs were obtained from the price quotation for the northern region of the state of Mato Grosso performed by the Mato Grosso Institute of Agricultural Economics, and the results were converted to dollars.

Data on the chemical and energy compositions were tested by analysis of variances and compared by Duncan's test by the GLM procedure, while performance and economic data were obtained by partitioning the sum of squares of treatments into orthogonal contrasts to evaluate the linear and quadratic effects by the MIXED procedure using SAS (SAS Institute, Inc., Cary, NC, USA) at the 0.05 probability level.

Table 1 Centesimal and calculated composition of the diets

	DDGS (g kg⁻¹)[1]			
Ingredient (g kg^{-1})	0	100	200	300
Corn	778.7	715.8	623.6	534.0
Soybean meal-45%	199.0	154.	140.0	127.0
DDGS		100.0	200.0	300.0
Dicalcium phosphate	11.9	11.0	10.5	9.9
Common salt	3.6	3.6	3.6	3.6
Calcitic limestone	3.0	10.0	17.0	20.0
L-Lysine	1.6	2.9	3.3	3.5
Mineral-vitamin mix[2]	2.0	2.0	2.0	2.0
DL-Methionine	0.3			
Calculated composition per kg of mixture				
Metabolizable energy swine (kcal)	3,240	3,245	3,250	3,270
Crude protein (g)	153.0	157.7	172.8	188.6
Calcium (g)	4.7	7.2	9.7	10.7
Available phosphorus (g)	2.6	2.6	2.7	2.8
Sodium (g)	1.6	1.6	1.6	1.6
Digestible lysine (g)	7.6	7.6	7.6	7.6
Digestible methionine (g)	2.4	2.4	2.8	3.1
Digestible met + cys (g)	4.8	4.8	5.1	5.5
Digestible threonine (g)	5.1	5.6	6.5	7.4
Digestible tryptophan (g)	1.5	1.4	1.4	1.4
Fat (g)	31.8	35.2	38.1	41.0
Crude fiber (g)	24.0	29.6	36.2	43.0
NDF (g)	120.4	156.8	193.7	231.3

[1] Composition per kg: 315.3 g CP; 48.8 g MM; 928.5 g DM; 86.8 g 1 EE 468.4 g kg-1 NDF; 2.8 g kg-1 digestible lysine; 5.6 g kg-1 digestible methionine; 8.4 g kg-1 methionine + digestible cystine; 13.4 g kg-1 digestible threonine; and 1.3 g kg-1 digestible tryptophan and 3,061 kcal ME. [2]Composition of supplement per kg of diet: vitamin A - 5.5 UI; vitamin B1- 0.0008 mg kg^{-1}; vitamin B2 - 0.0005 mg kg^{-1}; vitamin B6 - 0.0016 mg kg^{-1}; vitamin B12 - 0.0018 mcg kg^{-1}; vitamin D3 - 1.2 UI; vitamin E - 0.03 UI; vitamin K3 - 0.0025 mg kg^{-1}; nicotinic acid - 0.02 mg kg^{-1}; pantothenic acid - 0.012 mg kg^{-1}; folic acid - 0.00025 mg kg^{-1}; cobalt - 0.0005 mg kg^{-1}); copper - 0.01; iron - 0.06 mg kg^{-1}; zinc - 0.08 mg kg^{-1}; manganese - 0.03; selenium - 0.00028 mg kg^{-1}; iodine - 0.008 mg kg^{-1}; choline - 0.1 mg kg^{-1}; biotin - 0.01mcg kg^{-1}; ethoxyquin - 0.01 mg kg^{-1}; BHT - 0.02 mg kg^{-1}; bacitracin zinc - 0.03 mg.

3. Results and discussion

There were no differences between DDGS regarding DM, MM and CP (P> 0.05) (Table 2). DDGS 3 and 4 presented the highest values of EE, higher than DDGS 2, which in turn was higher than DDGS 1 (Table 2). For NDF, DDGS 2 had the lowest value, DDGS 1 had the highest value, and DDGS 3 and 4 did not differ from each other (Table 2). The DDGS with the lowest

GEa was source 1, with a difference of 204 kcal kg^{-1} compared to DDGS 4, which presented the highest concentration value. DDGS 3 was equal to source 4, which, in turn, was equal to DDGS 2 (P <0.05). The DDGS presented a mean CP (320.0 g kg^{-1}) close to those reported in other studies that found values ranging from 258.2 g kg^{-1} to 341.2 g kg^{-1} [5, 11, 13]. Large variation in chemical composition was recorded by Zeng et al. [6] with coefficients of variation of 25, 8, 36, and 13% for MM, CP, EE, and FDN with means of 41, 271, 88, and 340 g kg^{-1}, respectively, when analyzing corn DDGS.

Table 2 **Chemical and nutritional characteristics of different DDGSs**

Parameter	DDGS				P value*	CV (%)
	1	2	3	4		
DM (g kg^{-1})	909.4	907.3	918.8	923.8	0.6009	2.12
MM (g kg^{-1})	25.0	33.9	35.0	24.2	0.4098	7.97
CP (g kg^{-1})	325.1	316.5	322.9	315.3	0.7018	4.31
EE (g kg^{-1})	64.6^{c}	67.6^{b}	86.3^{a}	84.8^{a}	<0.001	2.37
NDF (g kg^{-1})	500.4^{a}	454.0^{c}	475.0^{b}	468.4^{b}	<0.001	1.56
GEa (kcal kg^{-1}) **	4,665^{c}	4,825^{b}	4,835^{ab}	4,869^{a}	<0.001	0.56
PS (μm)	772^{a}	667^{a}	553^{c}	628^{ab}	<0.001	13.93
GE (kcal kg^{-1})	4,833^{d}	4,859^{c}	4,965^{a}	4,949^{b}	<0.001	0.19
DE (kcal kg^{-1})	3,202^{b}	3,319^{a}	3,330^{a}	3,331^{a}	<0.001	0.48
ME (kcal kg^{-1})	2,936^{b}	3,053^{a}	3,056^{a}	3,061^{a}	<0.001	0.59
NE (kcal kg^{-1})	2,245^{c}	2,279^{b}	2,494^{a}	2,476^{a}	<0.001	0.87

Dry matter (DM), mineral matter (MM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), analyzed gross energy (GEa), particle size (PS), estimated values of gross energy (GE), digestible energy (DE), metabolizable energy (ME) and net energy (NE).
**Significance level <0,05 (means followed by different letters on the line show differences by Duncan's test); **Energy obtained by calorimetry; CV: coefficient of variation.*

All EE values from the different coproducts observed in this study may characterize DDGS with medium lipid content according to the classification of the NRC [14], which considers low (<40.0 g kg^{-1}), medium (> 60.0 g kg^{-1} and <90.0 g kg^{-1}) and high (> 10.0 g kg^{-1}) EE content. In this sense, Wu et al. [15] recorded a variation in the lipid content of 58.7 to 142.3 g kg^{-1} between DDGS. This variation may be related to the raw material or partial extraction of corn oil from many ethanol-producing industries ([10]).

NDF contents differed between DDGS, and mean values (474.5 g kg^{-1}) were higher than those reported in other studies [5, 11, 13]; furthermore, they were higher than the NDF content of corn and soybean meal [12]. In contrast to the results of this study, Wu et al. [15] evaluated DDGS with low and medium concentrations of EE and observed that DDGS with higher EE contents contained more NDF than DDGS with low EE contents. Differences in the CP and NDF contents may be related to raw materials and manufacturing processes. Thus, considering that DDGS has large amounts of fiber and its digestibility is lower than that in corn grains [16], high levels of inclusion may compromise the energy digestibility.

The estimated values of GE, DE, ME and NE varied between DDGS (P <0.05) (Table 2). DDGS 3 presented a value of GE higher than DDGS 4, which was higher than DDGS 2, which in turn was higher than DDGS 1. The values of DE and ME of DDGS 1 were lower than those of other lots, which did not differ from each other. DDGS 3 and 4 presented NE values higher than DDGS 2, which, in turn, was higher than DDGS 1.

The lowest DE content of DDGS 1 in relation to DDGS 4 may be associated with the lower EE content and higher NDF content of the first source. The values of ME followed the same trends as DE, where DDGS 4 presented a difference of 12 kcal kg^{-1} in relation to DDGS 1. Thus, the results of DE and ME of DDGS are in agreement with those reviewed in other literature that present values ranging from 3,417 to 4,332 kcal kg^{-1} and 3,216 and 4,141 kcal kg^{-1}, respectively, while NRC [14] establishes values of 3,582 and 3,396 kcal kg^{-1}, respectively. The ME of DDGS of Brazilian origin evaluated by Corassa et al. [17] was 3,668 and 3,213 kcal kg^{-1} by the total collection method and the marker technique, respectively. On the other hand, Stuani et al. [18], in an analytical approach, compiled results from several studies and obtained a mean value of 3,695 kcal kg^{-1} for ME.

In the estimated results for NE, there was a difference of 249 kcal kg^{-1} between DDGS 3 with higher NE content and DDGS 1 with lower NE content. The difference in EE between DDGS 3 and 1 was approximately 22.0 g kg^{-1}, which resulted in this difference in NE values. These results are in accordance with Graham et al. [11], which justified the difference of 115 kcal kg^{-1} for each 10.0 g kg^{-1} EE between samples of DDGS. However, according to Kerr et al. [10], not always the low EE content reduces the ME but rather the other factors associated with DDGS, such as the dietary fiber content present in the products.

The estimated NE values of the DDGS of this study were close to those established by NRC [14], which indicate values of 2,343 kcal kg^{-1}. Low, medium-low, medium-high, and high NE concentration predictions for finishing pigs fed with 400 g kg^{-1} inclusion indicated that animals receiving DDGS diets with lower NE contents are susceptible to higher DFI, lower DWG and consequently lower feed efficiency [13].

DDGS inclusion up to 300 g kg^{-1} did not affect the DFI, GW and FC in any of the evaluated periods (P> 0.05) (Table 3); however, the weight at 28 days reduced linearly according to increasing inclusion of DDGS in the diets (P <0.05) (Table 3).

The results resemble those of the meta-analysis evaluating 106 growth dates [19] whose majority (>65%) showed no changes in ADG, ADFI, and G:F, and 27% of the results showed a reduction in performance when DDGS was used. Unlike the results of this study, Schwarz et al. [20] recorded a reduction in DFI and HR when pigs were fed up to 15% DDGS but without affecting weight and GW.

Higher fiber in diets with higher DDGS inclusions can limit performance based on lower digestibility of these fractions [16] and decrease the absorption of nitrogen and amino acids by the body, resulting in higher excretion of N [21] in addition to excess nitrogen in diets.

The inclusion of DDGS in the diets linearly reduced feed costs and revenue (P <0.05) but did not affect gross operating profit (P> 0.05) (Figure 1), being directly influenced by the price of feed containing 0, 100, 200 and 300 g kg^{-1} DDGS (U$/kg 0.1991; 0.1905; 0.1863; 0.1824). The improvement in economic viability by the use of DDGS was also recorded by Schwarz et al. [20], with a reduction in the cost of feeding by 5 and 8% in growth and finishing diets, implying a reduction of 7 and 8% in the cost of each 1 kg of body weight, respectively.

The purpose of using this coproduct is precisely to prove itself as an alternative ingredient as a substitute for basic inputs such as corn, which has constant oscillations in price, and soybean meal and dicalcium phosphate, which have high prices. The relationship involving lower costs with lower revenues culminated in the lack of effect of the DDGS in the diets on the gross operating profit. This result suggests that there is no damage to the producer using levels of up to 300 g kg^{-1} DDGS in diets for finishing pigs. The value of DDGS used in this study showed that it is possible to produce feed with lower cost from its inclusion.

Table 3 **Daily weight gain (DWG), daily feed intake (DFI), feed conversion (FC) and weights of finishing pigs fed with different lots of DDGS**

	DDGS (g kg^{-1})				Significance *		CV (%)
	0	100	200	300	Linear	Quadr.	
Period 1 (0–14 days)							
DFI (g/day)	3,413	3,430	3,394	3,373	0.8536	0.8891	8.85
DWG (g/day)	1,028	1,027	924	844	0.0731	0.5000	13.19
FC (kg:kg)	3.32	3.35	3.69	4.03	0.0947	0.5105	13.86
Period 2 (15–28 days)							
DFI (g/day)	3,477	3,491	3,459	3,378	0.8299	0.7838	10.97
DWG (g/day)	952	920	886	859	0.3738	0.9639	15.50
FC (kg:kg)	3.66	3.80	3.91	3.95	0.5051	0.8575	16.97
Total Period (0-28 days)							
DFI (g/day)	3,445	3,436	3,427	3,376	0.8392	0.8693	8.05
DWG (g/day)	990	973	905	852	0.0572	0.6596	9.64
FC (kg:kg)	3.50	3.57	3.79	3.97	0.1412	0.7711	10.81
Weight (kg)							
Initial	71.45	71.49	71.41	71.59	0.9958	0.9323	2.39
Day 14	85.84	85.87	84.34	83.40	0.2422	0.7081	3.32
Day 28	99.17	98.74	96.75	95.43	0.0493	0.6882	2.48

**Significance level <0,05; CV: coefficient of variation.*

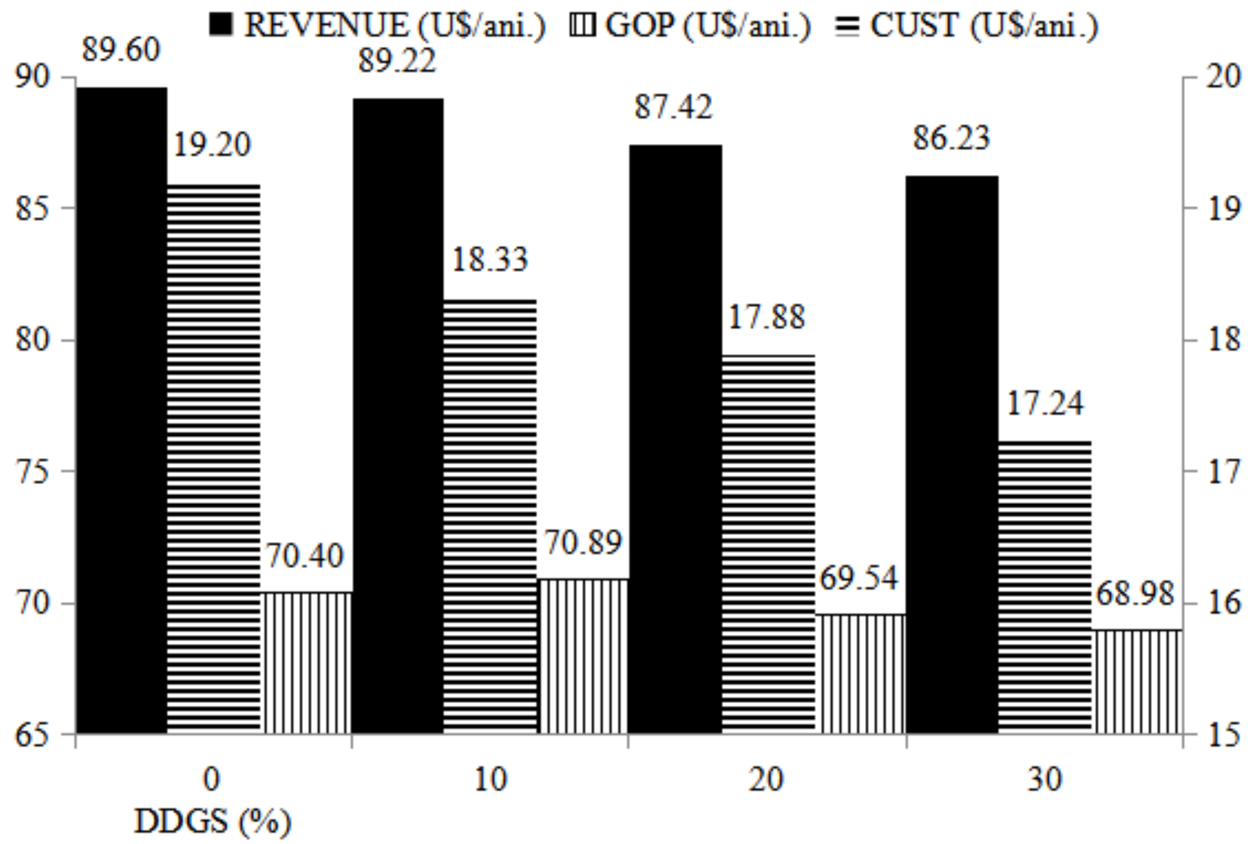

Figure 1 **Cost of feed (COST, U$/animal), revenue (REVENUE, U$/animal) and gross operating profit (GOP, U$/animal) of pigs fed different levels of DDGS. Linear effect for COST (P=0.0096) and REVENUE (P=0.0493).**

4. Conclusion

Distillers dried grains with solubles vary in chemical composition and energy content for pigs. Levels up to 300 g kg^{-1} DDGS in diets for finishing pigs have no effect on the performance but linearly decrease the final weight. Inclusions of DDGS in finishing pig diets reduce costs and revenues but do not change gross operating profit.

Declaration of conflicts of interest

The authors declare no conflicts of interest.

Author contributions

Conceptualization: A. Corassa. *Data curation*: T. I. S. Santos, D. R. Silva and I.W.W. Straub. *Formal Analysis*: A. Corassa, T. I. S. Santos, A. P. S. Ton, C. Kiefer, C.O. Brito and A.O. Teixeira. *Funding acquisition*: A. Corassa. *Investigation*: A. Corassa and T. I. S. Santos. *Methodology*: A. Corassa. *Project administration*: A. Corassa. *Supervision*: A. Corassa. *Writing-original draft*: T. I. S. Santos. *Writing-review&editing*: A. Corassa, A. P. S. Ton, M. Sbardella, C. Kiefer, C.O. Brito and A.O. Teixeira.

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References

1. RFA. Renewable Fuels Association. Ethanol Industry Outlook 2023. 40p. [Internet]. Washington: Renewable Fuels Association. 2023 Aug [cited 2023 Aug 19]. Available from: https://ethanolrfa.org/media-and-news/category/news-releases/article/2023/02/rfa-releases-2023-ethanol-industry-outlook-and-pocket-guide-ready-set-go

2. EPE. Empresa de Pesquisa Energética. Cenários de oferta de etanol e demanda de ciclo Otto 2023-2032. Nota técnica EPE/DPG/SDB/2022/06. [Internet]. Brasília: Empresa de Pesquisa Energética; 2022 Dez [cited 2023 Aug 19]. Available from: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-255/topico-653/NT-EPE-DPG-SDB-2022-06_Cenarios_de_oferta_de_etanol_2032.pdf

3. UNEM. União Nacional do Etanol de Milho. Setor do etanol de milho prospecta exportação de farelos de DDGS. [Internet]. Cuiabá: União Nacional do Etanol de Milho, 2022 Aug [cited 2023 Aug 18]. Available from: https://etanoldemilho.com.br/2022/12/01/setor-do-etanol-de-milho-prospecta-exportacao-de-farelos-de-milho/

4. Chatzifragkou A, Kosik, O, Prabhakumari PC, Lovegrove A, Frazier RA, Shewry PR, Charalampopoulos D. Biorefinery strategies for upgrading Distillers' Dried Grains with Solubles (DDGS). Proc Bioc, 2015: 50, 2194-2207, https://doi.org/10.1016/j.procbio.2015.09.005

5. Anderson PV, Kerr BJ, Weber TE, Ziemer CJ, Shurson GC. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn coproducts fed to finishing pigs. J. Anim. Sci. 2012; 90:1242-1254. https://doi:10.2527/jas.2010-3605

6. Zeng ZK, Shurson GC, Urriola PE. Prediction of the concentration of standardized ileal digestible amino acids and safety margins among sources of distillers dried grains with solubles for growing pigs: a meta-analysis approach. Anim. Feed Sci. Technol. 2017. 231, 150–159. https://doi.org/10.1016/j.anifeedsci.2017.07.010

7. AOAC. Official methods of analysis, association of official analytical chemists. 18th ed. Gaithersburgs (MD, USA): Association of Official Analytical Chemists. 2006.

8. Detmann E, Souza MA, Valadares Filho SC. Métodos para análise de alimentos - INCT - Ciência Animal. 1th ed. Visconde do Rio Branco: Suprema, 2012. 214p. Visconde do Rio Branco: Suprema, 214p.

9. Zanotto DL, Bellaver C. Método de determinação da granulometria para uso em rações de suínos e aves. Concórdia: EMBRAPA, CNPSA, Concórdia, SC, 1996. 5p. Available from: http://ainfo.cnptia.embrapa.br/digital/bitstream/item/58546/1/CUsersPiazzonDocuments215.pdf

10. Kerr BJ, Dozier WA, Shurson GC. Effects of reduced-oil corn distillers dried grains with solubles composition on digestible and metabolizable energy value and prediction in growing pigs. J. Anim. Sci. 2013. 91: 3231–3243. https://doi.org/10.2527/jas.2013-6252

11. Graham AB, Goodband RD, Tokach MD, Dritz SS, DeRouchey JM, Nitikanchana S, Updike JJ. The effects of low-, medium-, and high-oil distillers dried grains with solubles on growth performance, nutrient digestibility, and fat quality in finishing pigs. J. Anim. Sci. 2014. v.92, p.3610–3623. https://doi.org/10.2527/jas.2014-7678.

12. Rostagno HS, Albino LFT, Hannas MI, Donzele JL, Sakomura NK, Perazzo FG, Saraiva A, Abreu MLT, Rodrigues PB, Oliveira RF, Barreto SLT, Brito CO. Brazilian tables for poultry and swine: composition of feedstuffs and nutritional requirements. Ed. 4, Editora UFV, Viçosa, MG, Brasil. 2017. 488p.

13. Wu F, Johnston LJ, Urriola, PE, Hilbrands, AM, Shurson, GC. Evaluation of NE predictions and the impact of feeding maize distillers dried grains with solubles (DDGS) with variable NE content on growth performance and carcass characteristics of growing-finishing pigs. Anim. Feed Sci. Technol. 2016b. 215, 105–116, https://doi.org/10.1016/j.anifeedsci.2016.02.023

14. NRC - National Research Council. Nutrient Requirements of Swine. Publishing company: National Academy Press, Washington, D. C., 11th ed., 2012. 400p.

15. Wu F, Johnston LJ, Urriola PE, Hilbrands AM, Shurson GC. Evaluation of ME predictions and the impact of feeding maize distillers dried grains with solubles with variable oil content on growth performance, carcass composition, and pork fat quality of growing-finishing pigs. Anim. Feed Sci. Technol. v.213, p.128–141, 2016a. Available from: https://doi.org/10.1016/j.anifeedsci.2016.01.013

16. Stein HH, Lagos LV, Casas GA. Nutritional value of feed ingredients of plant origin fed to pigs. Anim. Feed Sci. Technol. 2016. 218:33–69. https://doi.org/10.1016/j.anifeedsci.2016.05.003

17. Corassa A, Lautert, IPA, Pina DS, Kiefer C, Ton APS, Komiyama CM, Amorim AB, Teixeira AO. Nutritional value of Brazilian distillers dried grains with solubles for pigs as determined by different methods. R. Bras. Zootec. 2017. 46, 740-746, https://doi.org/10.1590/S1806-92902017000900005.

18. Stuani JL, Corassa A, Silva IPA. Caracterização nutricional e uso de DDGS em dietas para suínos em crescimento e terminação - Abordagem analítica. Nativa, 2016. 4:116-120.

19. Jang J, Zeng Z, Urriola PE, Shurson GC. Effects of feeding corn distillers dried grains with solubles diets without or with supplemental enzymes on growth performance of pigs: a meta-analysis Transl. Anim. Sci. 2021.5:1-15. https://doi:10.1093/tas/txab029

20. Schwarz T, Przybulo M, Zapletal P, Turek A, Pabianczyk M, Bartlewski PM. Effects of Using Corn Dried Distillers' Grains with Solubles (cDDGS) as a Partial Replacement for Soybean Meal on the Outcomes of Pig Fattening, Pork Slaughter Value and Quality. Animals 2021, 11, 2956. https://doi.org/10.3390/ani11102956

21. Jaworski NW, Laerke HN, Bach Knudsen KE, Stein HH. Carbohydrate composition and in vitro digestibility of dry matter and nonstarch polysaccharides in corn, sorghum, and wheat and coproducts from these grains. J. Anim. Sci. 2015. 93: 1103–1113. https://doi.org/10.2527/jas.2014-8147