

Comparison of chemical composition, energy content, and digestibility of different sources of distillers corn oil and soybean oil for pigs

Vinicius Ricardo Cambito de Paula¹ , Natália Cristina Milani¹ ,
Cândida Pollyanna Francisco Azevedo¹ , Anderson Aparecido Sedano¹ ,
Leury Jesus de Souza¹ , Gerald Carlyle Shurson² , Urbano dos Santos
Ruiz^{1*} 

¹ Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz",
Departamento de Zootecnia, Piracicaba, SP, Brasil.

² University of Minnesota, Department of Animal Science, Saint Paul, MN, USA.

*Corresponding author:
usr Ruiz@usp.br

Received: June 10, 2021
Accepted: April 1, 2022

How to cite: Paula, V. R. C.; Milani, N. C.; Azevedo, C. P. F.; Sedano, A. A.; Souza, L. J.; Shurson, G. C. and Ruiz, U. S. 2022. Comparison of chemical composition, energy content, and digestibility of different sources of distillers corn oil and soybean oil for pigs. *Revista Brasileira de Zootecnia* 51:e20210115. <https://doi.org/10.37496/rbz5120210115>

Copyright: This is an open access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.



ABSTRACT - The objective of this study was to determine and compare the chemical composition; oxidation indicators; ether extract (EE) digestibility; and digestible, metabolizable, and net energy (DE, ME, and NE, respectively) content of distillers corn oil (DCO) from Brazil (CBR) and the United States (CUS), with refined (RSB) and degummed soybean oil (DSB) from Brazil offered to pigs. Fifty crossbred barrows (23.1±3.4 kg body weight) were fed a corn-soybean meal basal diet, or diets composed of 90% basal diet and 10% of one of the four oil sources (CBR, CUS, RSB, or DSB). Pigs were fed an amount of their respective experimental diets equivalent to 2.8 times the maintenance DE requirement for 9 d (sequentially 7 d for adaptation and 2 d for partial collection of feces). Distillers corn oil from Brazil contained lower linoleic acid (47.4%) than CUS (53.9%), RSB (54.2%), and DSB (51.5%), but greater contents of oleic (32.1%) and palmitic (14.6%) acids compared to CUS (27.0 and 12.9%), RSB (22.9 and 11.2%), and DSB (23.5 and 11.2%). The moisture and unsaponifiable contents of CBR (0.17 and 1.64%) and CUS (0.20 and 1.64%) were similar, but greater than the values found for RSB (0.05 and 1.20%) and DSB (0.12 and 1.02%). The anisidine value, free fatty acid content, and acidity of DCO samples were higher than soybean oils. The peroxide value and thiobarbituric reactive substances content increased in the oil samples over time. The apparent total tract digestibility (ATTD) of gross energy and the DE, ME and NE values of the oils did not differ among oil sources and ranged from 87.8 to 91.5%, and from 8280 to 8630, 8139 to 8459, and 7162 to 7444 kcal/kg, respectively. The ATTD of EE was greater in RSB and DSB than for CBR, but similar to CUS. The DCO produced in Brazil is an excellent energy source for pigs, with DE, ME, and NE values similar to those of DCO from the US and soybean oils.

Keywords: fatty acids, oxidation, polyunsaturated fatty acid, swine, unsaturated fatty acid

1. Introduction

The United States (US) and Brazil are responsible for more than 80% of global ethanol production (RFA, 2021). In Brazil, the main feedstock used for this purpose is sugarcane, while the US produces ethanol from corn (Chum et al., 2014). However, new programs have been launched by the Brazilian government to boost the production of renewable fuels, with a great increase in ethanol production from corn (EPE, 2019).

Ethanol production from corn generates co-products such as dried distillers grains (DDG), DDG with solubles (DDGS), and high protein DDG (HPDDG), which contain great content of lipids, crude protein, and energy, being widely used in non-ruminant feeding in North America (Stein and Shurson, 2009; Chatzifragkou and Charalampopoulos, 2018). Few studies about these corn co-products produced in Brazil over their nutritional value and the effects on pigs and poultry growth performance and carcass traits have been performed in the last few years (Corassa et al., 2017; Schone et al., 2017; Bittencourt et al., 2019; Corassa et al., 2019; Paula et al., 2021).

In the US, nearly all dry grind ethanol facilities separate a portion of the distillers corn oil (DCO) as an additional co-product to the wet or dried distillers grains with solubles produced (Shurson, 2018), and 51% of DCO in US is used in swine and poultry diets (RFA, 2017; Shurson, 2018). Although fats and oils are important energy sources in pig feeding, the chemical composition, extent of oxidation, and digestible (DE), metabolizable (ME), and net energy (NE) contents are highly variable among sources (Shurson et al., 2021). The DE, ME and NE contents for swine of soybean oil vary from 7977 to 9979, 7906 to 8868, and 4561 to 8132 kcal/kg, respectively (Shurson et al., 2021), and of DCO sources vary from 8001 kcal/kg for DE and 7921 kcal/kg for ME (Lindblom et al., 2017) to 8828 kcal/kg for DE and 8794 kcal/kg for ME (Kerr et al., 2016).

The digestibility of lipid sources and their energy values are affected by several factors including fatty acid (FA) chain length, degree of unsaturation, FA position in triglycerides, relative proportions of various FA in the lipid source, free FA (FFA) content, and age of pig (Shurson et al., 2021). Prediction equations based on FFA content and the ratio of unsaturated to saturated FA of fats and oils have been widely used to estimate the DE content of lipids for pigs (Wiseman et al., 1998), because digestibility is improved with the higher unsaturated to saturated FA ratio and low FFA content (Powles et al., 1995). Although DCO contains up to 15% FFA, the DE content among DCO sources with variable FFA was inconsistent (Kerr et al., 2016) and was generally overestimated using Wiseman et al. (1998) equations. Therefore, considering the great variability in DE content among DCO and soybean oil sources and the absence of published data on chemical composition and DE, ME, and NE content of DCO produced in Brazil, the objective of this study was to determine the chemical composition, DE content, and ether extract (EE) digestibility, and to predict ME and NE content of DCO produced in Brazil (CBR), DCO from US (CUS), refined soybean oil (RSB), and degummed soybean oil (DSB) when given to growing pigs.

2. Material and Methods

The experimental protocol used for this study was approved by the local institutional committee on animal use (protocol number 2017.5.1622.11.6). The experiment was carried out in Piracicaba, São Paulo, Brazil (22°43'30" S, 47°38'51" W, 524 m).

Fifty crossbred barrows (23.1±3.4 kg of body weight – BW) were housed individually in partially slatted floor pens equipped with nipple waterers and semi-automatic feeders. Pigs were assigned to dietary treatments based on BW using a randomized block design (10 blocks) and fed a corn-soybean meal basal diet, or diets composed of 90% of basal diet and 10% of one of the four lipid sources: CBR (FS Bioenergia Inc., Lucas do Rio Verde, MT, Brazil), CUS (Corn Plus Co-Op & LLP, Winnebago, MN, United States), RSB (Cocamar Coop., Maringá, PR, Brazil), or DSB (Brejeiro, Produtos Alimentícios Orlândia S.A., Orlândia, SP, Brazil) from Brazil, totalizing five treatments and 10 replicates per treatment. Experimental diets were formulated to meet NRC (2012) nutrient requirements for 11-25 kg pigs, and all diets contained 0.30% titanium dioxide as the indigestible marker (Table 1).

All pigs were fed an amount equivalent to 2.8 times the maintenance DE requirement (110 kcal DE/kg BW^{0.75}) based on their metabolic BW at the beginning of the trial. The daily feed allowance was offered in two equal portions, and water was provided *ad libitum* throughout the experimental period (7 d adaptation and 2 d of partial feces collection). Fresh fecal samples were collected from the floor of pens, soon after pigs defecated, disregarding the portions that came into contact with urine or wasted feed, during all days of collection. Feces were weighed, and around 300 g were placed in plastic bags, and stored at –20 °C. Prior to laboratory analysis, feces samples were thawed, homogenized by pig, subsampled, and dried at 55 °C for 72 h in a forced-draft oven (Model MA035, Marconi, Piracicaba, SP, Brazil). Fecal and

diet samples were ground through a 1-mm screen in a knife mill (Model MA680, Marconi, Piracicaba, SP, Brazil) and analyzed for titanium (Myers et al., 2004), dry matter (DM; method number 934.01; AOAC, 2006), ether extract (method number 2003.06; AOAC, 2006), and gross energy (GE) in adiabatic bomb calorimeter (Model C5003, Ika-Werke, Staufen, Germany). The oils were stored in polyethylene barrels and sampled in three (CBR = A - Feb. 26th, 2018; B - Mar. 26th, 2018; C - Apr. 25th, 2018) or two (CUS, RSB, and DSB = B - Mar. 26th, 2018; C - Apr. 25th, 2018) different dates, according to their arrival at the experimental unit, to evaluate their chemical composition and effect of time in oxidation parameters. The experiment was carried out using samples B. The oil samples were analyzed for FA content (method number 969.33 963.22; AOAC, 2006), FFA (method number Ca 5a-40; AOCS, 1989), acidity (method number Cd 3d-63; AOCS, 2011), peroxide value (method number 940.28; AOAC, 2006), thiobarbituric reactive substances (TBARS; method number Cd 19-90; AOCS, 2011), anisidine value (method number Cd 18-90; AOCS, 2011), moisture and volatile matter (method number Ca 2c-25;

Table 1 - Ingredient and chemical composition of experimental diets, as-fed basis

Ingredient (%)	Diet ¹				
	BD	CBR	CUS	RSB	DSB
Corn	65.29	58.76	58.76	58.76	58.76
Soybean meal	30.00	27.00	27.00	27.00	27.00
Distillers corn oil from Brazil	-	10.00	-	-	-
Distillers corn oil from United States	-	-	10.00	-	-
Refined soybean oil	-	-	-	10.00	-
Degummed soybean oil	-	-	-	-	10.00
Dicalcium phosphate	1.160	1.044	1.044	1.044	1.044
Limestone	1.220	1.098	1.098	1.098	1.098
Salt	0.680	0.612	0.612	0.612	0.612
Vitamin supplement ²	0.150	0.135	0.135	0.135	0.135
Trace mineral supplement ³	0.100	0.090	0.090	0.090	0.090
L-lysine HCl	0.565	0.509	0.509	0.509	0.509
DL-methionine	0.240	0.216	0.216	0.216	0.216
L-threonine	0.220	0.198	0.198	0.198	0.198
L-valine	0.050	0.045	0.045	0.045	0.045
Titanium dioxide	0.330	0.297	0.297	0.297	0.297
Total	100.0	100.0	100.0	100.0	100.0
Energy and nutrient composition					
Dry matter (%) ⁴	88.9	89.7	90.0	90.4	90.5
Gross energy (kcal/kg) ⁴	3930	4430	4440	4420	4360
Net energy (kcal/kg) ⁵	2409	2923	2923	2923	2923
Ether extract (%) ⁴	2.9	12.1	12.1	12.3	12.2
Crude protein (%) ⁵	20.04	18.03	18.03	18.03	18.03
SID lysine (%) ⁵	1.37	1.23	1.23	1.23	1.23
SID methionine + cystine (%) ⁵	0.75	0.68	0.68	0.68	0.68
SID threonine (%) ⁵	0.81	0.73	0.73	0.73	0.73
SID valine (%) ⁵	0.88	0.79	0.79	0.79	0.79
Ca (%) ⁵	0.77	0.70	0.70	0.70	0.70
STTD P (%) ⁵	0.37	0.33	0.33	0.33	0.33
Neutral detergent fiber (%) ⁵	8.3	7.5	7.5	7.5	7.5
Acid detergent fiber (%) ⁵	3.0	3.4	3.4	3.4	3.4

¹ BD - basal diet; CBR - diet with distillers corn oil from Brazil; CUS - diet with distillers corn oil from the United States; RSB - diet with refined soybean oil from Brazil; DSB - diet with degummed soybean oil from Brazil.

² Quantity per kg of feed: Se as sodium selenite and selenium yeast, 0.3 mg; vitamin A as retinyl acetate, 6500 IU; vitamin D3 as cholecalciferol, 1500 IU; vitamin E as DL-alpha tocopherol, 36 IU; vitamin K3 as menadione nicotinamide bisulfate, 2.75 mg; thiamin as thiamine mononitrate, 1.1 mg; riboflavin, 3.5 mg; pyridoxine as pyridoxine hydrochloride, 20 mg; vitamin B12, 0.02 mg; folic acid, 3.8 mg; pantothenic acid as D-calcium pantothenate, 13 mg; niacin, 28 mg; biotin, 0.1 mg.

³ Quantity per kg of feed: Fe as iron sulfate, 100 mg; Cu as copper sulfate, 13 mg; Mn as manganese monoxide, 50 mg; Zn as zinc sulfate, 97 mg; I as calcium iodate, 1 mg.

⁴ Analyzed values.

⁵ Calculated values.

AOCS, 2011), insoluble impurities (method number Ca 3a-46; AOCS, 2011), and unsaponifiable matter (method number Cd 8b-90; AOCS, 2011).

The apparent total tract digestibility (ATTD) of GE, EE, and DM of diets were calculated using the index method, and the ATTD of GE, EE, and DM of oil sources, and their respective DE values, were calculated by the difference approach (Adeola, 2001). The ME was estimated according to NRC (2012), and NE was estimated according to van Milgen et al. (2001). The ATTD of GE, EE, and DM of diets and oil sources, and DE, ME, and NE values of the oil sources were subjected to ANOVA using the MIXED procedure of SAS (Statistical Analysis System, version 9.2). Feed ingredient was the fixed effect, and blocks were random effect, as follows:

$$Y(ij) = \mu + t(i) + b(j) + \varepsilon(ij),$$

in which $Y(ij)$ = dependent response, μ = overall mean, $t(i)$ = fixed effect of dietary treatments ($i = 1, \dots, 4$, or 5), $b(j)$ = random effect of blocks ($j = 1, \dots, 10$), and $\varepsilon(ij)$ = residual error. All data were examined for residual normality, homogeneity of variance, and outliers. The least square means (LSMEANS) are reported in the tables. Treatment differences were considered statistically significant at $P < 0.05$ by Tukey's test.

3. Results

Regarding the oil sampling B, the GE and EE contents among oil sources were similar, ranging from 9310 to 9400 kcal/kg, and 98.6 and 100%, respectively (Table 2). The CBR contained lower linoleic acid

Table 2 - Chemical composition of distillers corn oil from Brazil (CBR), distillers corn oil from United States (CUS), refined soybean oil (RSB), and degummed soybean oil (DSB), as-is basis

Item	Oil								
	CBR			CUS		RSB		DSB	
	A ¹	B	C	B	C	B	C	B	C
Gross energy (kcal/kg)	9290	9310	9380	9300	9310	9400	9400	9400	9310
Ether extract (%)	99.9	98.8	99.1	98.6	98.6	100	98.5	99.2	99.6
Fatty acids (% of total oil)									
Palmitic (16:0)	14.6	14.4	14.4	12.9	12.9	11.2	11.0	11.2	11.2
Palmitoleic (9c-16:1)	0.14	0.14	0.14	0.12	0.12	0.09	0.09	0.09	0.08
Margaric (17:0)	0.16	0.16	0.15	0.15	0.14	0.18	0.18	0.18	0.17
Stearic (18:0)	2.79	2.74	2.74	2.06	2.08	4.29	4.18	4.46	4.47
Oleic (9c-18:1)	32.1	31.9	31.9	27.0	27.0	22.9	23.6	23.5	23.6
Linoleic (18:2n-6)	47.4	46.9	46.9	53.9	53.8	54.2	52.5	51.5	51.8
Linolenic (18:3n-3)	1.11	1.08	1.08	1.31	1.31	5.51	5.20	6.63	6.67
Linolenic (18:3n-6)	-	-	-	-	-	0.03	0.04	-	0.02
Arachidic (20:0)	0.58	0.58	0.58	0.40	0.41	0.42	0.40	0.41	0.43
Gonodic (20:1n-9)	0.30	0.29	0.29	0.28	0.28	0.24	0.25	0.24	0.24
Bechenoic (22:0)	0.19	0.14	0.18	0.11	0.14	0.49	0.51	0.50	0.51
Lignoceric (24:0)	0.38	0.41	0.41	0.28	0.30	0.25	0.26	0.26	0.22
Other fatty acids	0.09	0.10	0.10	0.10	0.10	0.02	0.33	0.26	0.25
Total fatty acids	99.9	98.8	98.8	98.6	98.6	100	98.5	99.2	99.6
Moisture (%)	0.17	0.19	0.25	0.20	0.36	0.05	0.09	0.12	0.32
Insolubles (%)	-	-	0.07	0.17	0.09	0.25	0.04	-	-
Unsaponifiables (%)	1.64	1.52	1.36	1.46	1.61	1.20	0.57	1.02	0.59
Peroxide value (MEq/kg)	0.39	0.78	3.70	0.78	0.97	2.34	4.28	1.17	1.55
Anisidine value	6.42	7.04	6.24	4.81	5.10	1.34	2.39	2.13	1.28
Free fatty acids (%)	14.4	13.7	14.1	8.97	10.6	0.46	0.54	1.42	2.50
Acidity (mg KOH/g)	28.7	27.3	28.1	17.9	21.1	0.92	1.08	2.83	4.98
TBARS (mg/kg)	0.41	0.54	0.57	0.31	0.35	0.52	0.31	0.32	0.35

TBARS - thiobarbituric acid reactive substances.

¹ Oil sampling date: A - Feb. 26th, 2018; B - Mar. 26th, 2018; C - Apr. 25th, 2018.

(46.9%) than CUS (53.9%), RSB (54.2%), and DSB (51.5%), but greater contents of oleic (31.9%) and palmitic (14.4%) acids compared with CUS (27.0 and 12.9%), RSB (22.9 and 11.2%), and DSB (23.5 and 11.2%). The moisture and unsaponifiable contents of CBR (0.19 and 1.52%) and CUS (0.20 and 1.46%) were similar, but greater than the values found for RSB (0.05 and 1.20%) and DSB (0.12 and 1.02%). The peroxide values of CBR, CUS, RSB, and DSB were 0.78, 0.78, 2.34, and 1.17 MEq/kg, respectively and increased in the oil samples over time. The anisidine value (7.04), FFA (13.7%), and acidity (27.3 mg KOH/g) in CBR were higher than in CUS (4.81, 8.97%, and 17.9, mg KOH/g, respectively); however, the DCO contained greater values than RSB (1.34, 0.46%, and 0.92 mg KOH/g, respectively), and DSB (2.13, 1.42%, and 2.83 mg KOH/g, respectively).

The ATTD of DM and GE of BD and of test diets containing CBR, CUS, RSB, and DSB did not differ ($P>0.05$) and were 86.7, 86.8, 86.7, 87.0, and 87.3%, respectively, and 86.5, 87.0, 87.1, 87.4 and 87.5%, respectively (Table 3). However, the ATTD of EE of BD was lower ($P<0.001$) than those of diets containing the different oil sources (60.1 vs. 84.5 to 87.6%, respectively). The ATTD of EE of the diet with CBR was lower ($P<0.001$) compared with the diet with DSB (84.5 vs. 87.6%, respectively).

The ATTD of GE and the DE, ME, and NE values of the oils (Table 4) did not differ ($P>0.05$) and ranged from 87.8 to 91.5% and from 8280 to 8630 kcal/kg, 8139 to 8459 kcal/kg, and 7162 to 7444 kcal/kg, respectively. The ATTD of EE was greater ($P = 0.004$) for RSB (94.6%) and DSB (95.1%) than for CBR (90.7%), but similar to CUS (93.5%).

Table 3 - Apparent total tract digestibility (ATTD) of dry matter, gross energy, and ether extract of experimental diets in pigs (23.1±3.4 kg of body weight)

Item (%)	Diet ¹					SEM	P-value
	BD	CBR	CUS	RSB	DSB		
Dry matter	86.7	86.8	86.7	87.0	87.3	1.8	0.533
Gross energy	86.5	87.0	87.1	87.4	87.5	1.8	0.298
Ether extract	60.1c	84.5b	86.3ab	87.2ab	87.6a	2.3	<0.001

SEM - standard error of the mean.

¹ BD - basal diet; CBR - distiller's corn oil from Brazil; CUS - distiller's corn oil from United States; RSB - refined soybean oil; DSB - degummed soybean oil.

Table 4 - Apparent total tract digestibility (ATTD) of gross energy and ether extract and digestible, metabolizable, and net energy values (DE, ME, and NE; dry matter basis) of oils in pigs (23.1±3.4 kg of body weight)¹

Item	Oil ²				SEM	P-value
	CBR	CUS	RSB	DSB		
ATTD						
Gross energy	90.2	87.8	90.9	91.5	4.9	0.384
Ether extract	90.7b	93.5ab	94.6a	95.1a	4.6	0.004
DE (kcal/kg)	8520	8280	8580	8630	464	0.384
ME (kcal/kg) ³	8351	8139	8405	8459	177	0.600
NE (kcal/kg) ³	7349	7162	7396	7444	155	0.600

SEM - standard error of the mean.

¹ Least square means based on 10 observations per dietary treatment.

² CBR - distillers corn oil from Brazil; CUS - distillers corn oil from United States; RSB - refined soybean oil; DSB - degummed soybean oil.

³ Estimated values according to the equations: ME = DE × 0.98 (NRC, 2012); NE = ME × 0.88 (van Milgen et al., 2001).

ab - Values within a row with different letters differ at $P<0.05$.

4. Discussion

This is the first study to determine the chemical composition and DE content, and to predict ME and NE contents of DCO produced in Brazil for swine, and to compare with the DE, ME, and NE contents of DCO from US, along with two refined and degummed soybean oils used in swine diets in Brazil.

Furthermore, there are no composition data or DE estimates for Brazilian DCO in the Brazilian tables of feedstuff composition for pigs and poultry (Rostagno et al., 2017).

The FA profile of CBR and CUS were slightly different for the three major FA: 46.9 vs. 53.9% linoleic acid, 31.9 vs. 27.0% oleic acid, and 14.4 vs. 12.9% palmitic acid, respectively. Kerr et al. (2016) evaluated three different DCO varying in FFA content produced in the US and reported that the average linoleic, oleic, and palmitic acids were 53.7, 28.5, and 12.8%, respectively, which were similar to the concentrations of these FA in CUS evaluated in this study. Similarly, Lindblom et al. (2017) reported that the average concentrations for linoleic, oleic, and palmitic acids from two DCO sources produced in the US were 56.2, 26.8, and 12.9%, respectively, and comparable to values for CUS obtained in the current study. The linoleic, oleic, and palmitic acid contents of RSB (54.2, 22.9, 11.2%, respectively) and DSB (51.5, 23.5, and 11.2%, respectively) were similar and were also similar to a soybean oil sample evaluated by Lindblom et al. (2019) (53.2, 23.1, and 10.7%, respectively). Furthermore, the concentrations of the FA were comparable to those in CUS. Both RSB and DSB had FA profiles similar to those reported in NRC (2012) and Rostagno et al. (2017).

The sum of moisture, insoluble, and unsaponifiables among the four types of oil was less than 2% and comparable to values commonly observed in commercial feed mills (Shurson et al., 2015). In fact, the CBR evaluated in the current study met all requirements established by the AAFCO – Association of American Feed Control Officials (2017) – for the composition of DCO offered to animals, including an FA content greater than 85%, as well as unsaponifiable matter and insoluble impurities below 2.5 and 1%, respectively.

Measures of lipid peroxidation (peroxide value, anisidine value, FFA, and TBARS) increased over time of sampling regardless of oil source. According to Dibner et al. (2011) and Song and Shurson (2013), the extent of the peroxidation in lipid-rich ingredients may vary depending on storage and processing conditions. Additional factors that may influence the lipid peroxidation are temperature, presence oxygen or transition metals, undissociated salts, moisture, and the degree of FA unsaturation (Shurson et al., 2015). The CBR and CUS sources had greater FFA content and anisidine value compared with soybean oil sources, but these numerical differences in peroxidation indicators were apparently not great enough to affect DE content of these oils. This is not surprising because of the poor correlations of individual peroxidation indicators with DE content of fats and oils (Shurson et al., 2015; Shurson et al., 2021). The peroxide values of CBR and CUS during early sampling periods and anisidine values observed for these DCO sources in the current study were less than those determined by Kerr et al. (2016), and anisidine values were lower in DCO samples evaluated by Lindblom et al. (2017), suggesting minimal peroxidation had occurred at the time of feeding.

Increased FFA content in lipid sources can be a result of peroxidation. Although FFA content has been considered to be a major factor affecting DE and ME content of fats and oils for pigs (Powles et al., 1995), various studies have shown that FFA content is not as predictive of DE content as once thought (Kerr et al., 2016; Kellner and Patience, 2017; Lindblom et al., 2017). Although the ATTD of EE of CBR were lower compared with that in the soybean oils evaluated in this study, the higher FFA content in CBR did not affect ATTD of GE and DE contents. According to Shurson et al. (2015), there may be a threshold level above which feeding peroxidized lipids causes metabolic oxidative stress in pigs at the point to affect ATTD values. Our results are in agreement with those reported by Lindblom et al. (2017), in which a reduction in EE digestibility of DCO was observed when the FFA content increased from 4.5 to 10%, but no differences were observed in DE content between those sources.

The DE values and predicted ME values of CBR (8520 and 8351 kcal/kg, respectively) and CUS (8280 and 8139 kcal/kg, respectively) were within the range of 8036 to 8828 kcal/kg for DE and 7976 to 8794 kcal/kg for ME for DCO sources with variable FFA content evaluated by Kerr et al. (2016), with the DE value of CBR being comparable to the DE value for the 13.9% FFA of DCO (8465 kcal/kg) determined by Kerr et al. (2016). However, Lindblom et al. (2017) found lower DE and ME values of two DCO sources (8000 and 8052 kcal/kg, and 7921 and 7955 kcal/kg, respectively). Nevertheless, the ATTD of EE, DE values, and predicted ME values of both DCO sources evaluated in this study were

in accordance with values reported for corn oil (88.8%, 8580, and 8280 kcal/kg, respectively) by Rostagno et al. (2017).

The ATTD of GE and DE, ME, and NE contents of both soybean oils in the present study were similar and not different than the values obtained for the DCO sources. Although the DE, ME, and NE values for RSB (8580, 8405, and 7396 kcal/kg, respectively) and DSB (8630, 8459, and 7444 kcal/kg, respectively) were similar to the DE and ME values of 8532 and 8413 kcal/kg, respectively, reported by Zhao et al. (2017), the DE, ME, and NE values were lower than the 8749 kcal/kg DE, 8574 kcal/kg ME, and 7545 kcal/kg NE values reported by NRC (2012) and the 9388 kcal/kg DE and 9408 kcal/kg ME value reported by Lindblom et al. (2017). However, Rostagno et al. (2017) reported an ATTD of EE of 88.5% and DE, ME, and NE values of 8600, 8300, and 7364 kcal/kg, respectively, which are closer to the results found in this study. Therefore, the DE, ME, and NE values for soybean oil sources were within the range of previously reported values and similar to the energy contents of DCO produced in Brazil.

5. Conclusions

The distillers corn oil and soybean oil sources had similar digestible energy values that were comparable to results from previous studies. Distillers corn oil produced in Brazil is an excellent energy source for pigs with a digestible, metabolizable, and net energy values similar to those of distillers corn oil from US and those of degummed and refined soybean oils produced in Brazil.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: G.C. Shurson and U.S. Ruiz. Formal analysis: V.R.C. Paula. Funding acquisition: U.S. Ruiz. Investigation: V.R.C. Paula, N.C. Milani, C.P.F. Azevedo, A.A. Sedano and L.J. Souza. Project administration: V.R.C. Paula, N.C. Milani, C.P.F. Azevedo and U.S. Ruiz. Resources: U.S. Ruiz. Supervision: U.S. Ruiz. Validation: V.R.C. Paula. Visualization: V.R.C. Paula and U.S. Ruiz. Writing-original draft: V.R.C. Paula and U.S. Ruiz. Writing-review & editing: V.R.C. Paula, G.C. Shurson and U.S. Ruiz.

Acknowledgments

The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) – Brazil, for the scholarship granted to the first author. This research was financially supported by FS Bioenergia (Lucas do Rio Verde, Mato Grosso, Brazil).

References

- AAFCO - Association of American Feed Control Officials. 2017. Official publication. 5th ed. Champaign, IL.
- Adeola, O. 2001. Digestion and balance techniques in pigs. p.903-916. In: Swine nutrition. 2nd ed. Lewis, A. J. and Southern, L. L., eds. CRC Press, New York, NY.
- AOAC - Association of Official Agricultural Chemists International. 2006. Official methods of analysis. 18th ed. AOAC International, Gaithersburg, MD.
- AOCS - American Oil Chemists' Society. 1989. Official methods and recommended practices of the AOCS. 4th ed. AOCS, Champaign, IL.
- AOCS - American Oil Chemists' Society. 2011. Official methods and recommended practices of the AOCS. 6th ed. AOCS, Champaign, IL.
- Bittencourt, T. M.; Lima, H. J. D.; Valentin, J. K.; Martins, A. C. S.; Moraleco, D. D. and Vaccaro, B. C. 2019. Distillers dried grains with solubles from corn in diet of japanese quails. *Acta Scientiarum. Animal Sciences* 41:e42759.

- Chatzifragkou, A. and Charalampopoulos, D. 2018. Distiller's dried grains with solubles (DDGS) and intermediate products as starting materials in biorefinery strategies. p.63-86. In: Galanakis, C. M., ed. Sustainable recovery and reutilization of cereal processing by-products. Elsevier, Amsterdam.
- Chum, H. L.; Warner, E.; Seabra, J. E. A. and Macedo, I. C. 2014. A comparison of commercial ethanol production systems from Brazilian sugarcane and US corn. *Biofuels, Bioproducts and Biorefining* 8:205-223. <https://doi.org/10.1002/bbb.1448>
- Corassa, A.; Lautert, I. P. A. S.; Pina, D. S.; Kiefer, C.; Ton, A. P. S.; Komiyama, C. M.; Amorim, A. B. and Teixeira, A. O. 2017. Nutritional value of Brazilian distillers dried grains with solubles for pigs as determined by different methods. *Revista Brasileira de Zootecnia* 46:740-746. <https://doi.org/10.1590/S1806-92902017000900005>
- Corassa, A.; Stuani, J. L.; Ton, A. P. S.; Kiefer, C.; Sbardella, M.; Brito, C. O.; Amorim, A. B. and Gonçalves, D. B. C. 2019. Nutritional value of distillers dried grains with solubles from corn and sorghum and xylanase in diets for pigs. *Revista Brasileira de Zootecnia* 48:e20190012. <https://doi.org/10.1590/rbz4820190012>
- Dibner, J.; Vazquez-Anon, M. and Knight, C. D. 2011. Understanding oxidative balance and its impact on animal performance. p.1-7. In: *Proceedings 2011 Cornell Nutrition Conference for Feed Manufacturers*, East Syracuse, NY.
- EPE - Empresa de Pesquisa Energética. 2019. Ethanol supply scenarios and Otto cycle demand 2020-2030. Executive summary. Available at: <https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-255/topico-503/EPE-DPG-SGB-Bios-2019-Executive_Summary_Ethanol_Supply_Scenarios.pdf>. Accessed on: Jun. 8, 2020.
- Kellner, T. A. and Patience, J. F. 2017. The digestible energy, metabolizable energy, and net energy content of dietary fat sources in thirteen- and fifty-kilogram pigs. *Journal of Animal Science* 95:3984-3995. <https://doi.org/10.2527/jas.2017.1824>
- Kerr, B. J.; Dozier III, W. A. and Shurson, G. C. 2016. Lipid digestibility and energy content of distillers' corn oil in swine and poultry. *Journal of Animal Science* 94:2900-2908. <https://doi.org/10.2527/jas.2016-0440>
- Lindblom, S. C.; Dozier III, W. A.; Shurson, G. C. and Kerr, B. J. 2017. Digestibility of energy and lipids and oxidative stress in nursery pigs fed commercially available lipids. *Journal of Animal Science* 95:239-247. <https://doi.org/10.2527/jas.2016.0915>
- Lindblom, S. C.; Gabler, N. K.; Bobeck, E. A. and Kerr, B. J. 2019. Oil source and peroxidation status interactively affect growth performance and oxidative status in broilers from 4 to 25 d of age. *Poultry Science* 98:1749-1761. <https://doi.org/10.3382/ps/pey547>
- Myers, W. D.; Ludden, P. A.; Nayigihugu, V. and Hess, B. W. 2004. A procedure for the preparation and quantitative analysis of samples for titanium dioxide. *Journal of Animal Science* 82:179-183. <https://doi.org/10.2527/2004.821179x>
- NRC - National Research Council. 2012. Nutrient requirements of swine. 11th ed. National Academies Press, Washington, DC.
- Paula, V. R. C.; Milani, N. C.; Azevedo, C. P. F.; Sedano, A. A.; Souza, L. J.; Mike, B. P.; Shurson, G. C. and Ruiz, U. S. 2021. Comparison of digestible and metabolizable energy and digestible phosphorus and amino acid content of corn ethanol coproducts from Brazil and the United States produced using fiber separation technology for swine. *Journal of Animal Science* 99:skab126. <https://doi.org/10.1093/jas/skab126>
- Powles, J.; Wiseman, J.; Cole, D. J. A. and Jagger, S. 1995. Prediction of the apparent digestible energy value of fats given to pigs. *Animal Science* 61:149-154. <https://doi.org/10.1017/S1357729800013631>
- RFA - Renewable Fuels Association. 2017. Annual industry outlook. Available at: <<https://www.ethanolrfa.org/pages/annual-industry-outlook>>. Accessed on: Mar. 8, 2021.
- RFA - Renewable Fuels Association. 2021. Annual industry outlook. Available at: <https://ethanolrfa.org/file/274/RFA_Outlook_2021_fin_low.pdf>. Accessed on: Jul. 23, 2020.
- Rostagno, H. S.; Albino, L. F. T.; Hannas, M. I.; Donzele, J. L.; Sakomura, N. K.; Perazzo, F. G.; Saraiva, A.; Teixeira, M. L.; Rodrigues, P. B.; Oliveira, R. F.; Barreto, S. L. T. and Brito, C. O. 2017. Tabelas brasileiras para aves e suínos. Composição de alimentos e exigências nutricionais. 4th ed. UFV, Viçosa, MG.
- Schone, R. A.; Nunes, A. V.; Frank, R.; Eying, C. and Castilha, L. D. 2017. Resíduo seco de destilaria com solúveis (DDGS) na alimentação de frangos de corte (22-42 dias). *Revista Ciência Agronômica* 48:548-557.
- Shurson, G. C. 2018. DDGS User handbook. Precision DDGS nutrition. 4th ed. U.S. Grains Council, Washington, DC. Available at: <https://www.grains.org/wp-content/uploads/2019/07/USGC-Precision-DDGS-Handbook-2019_07_02-WEB.pdf>. Accessed on: Feb. 24, 2019.
- Shurson, G. C.; Hung, Y. -T.; Jang, J. C. and Urriola, P. E. 2021. Measures matter – Determining the true nutri-physiological value of feed ingredients for swine. *Animals* 11:1259. <https://doi.org/10.3390/ani11051259>
- Shurson, G. C.; Kerr, B. J. and Hanson, A. R. 2015. Evaluating the quality of feed fats and oils and their effects on pig growth performance. *Journal of Animal Science and Biotechnology* 6:10. <https://doi.org/10.1186/s40104-015-0005-4>
- Song, R. and Shurson, G. C. 2013. Evaluation of lipid peroxidation level in corn dried distillers grains with solubles. *Journal of Animal Science* 91:4383-4388. <https://doi.org/10.2527/jas.2013-6319>

Stein, H. H. and Shurson, G. C. 2009. Board-Invited Review: The use and application of distillers dried grains with solubles in swine diets. *Journal of Animal Science* 87:1292-1303. <https://doi.org/10.2527/jas.2008-1290>

van Milgen, J.; Noblet, J. and Dubois, S. 2001. Energetic efficiency of starch, protein and lipid utilization in growing pigs. *Journal of Nutrition* 131:1309-1318. <https://doi.org/10.1093/jn/131.4.1309>

Wiseman, J.; Powles, J. and Salvador, F. 1998. Comparison between pigs and poultry in the prediction of the dietary energy value of fats. *Animal Feed Science and Technology* 71:1-9. [https://doi.org/10.1016/S0377-8401\(97\)00142-9](https://doi.org/10.1016/S0377-8401(97)00142-9)

Zhao, J.; Li, Z.; Lyu, M.; Liu, L.; Piao, X. and Li, D. 2017. Evaluation of available energy and total tract digestibility of acid-hydrolyzed ether extract of cottonseed oil for growing pigs by the difference and regression methods. *Asian-Australasian Journal of Animal Sciences* 30:712-719. <https://doi.org/10.5713/ajas.16.0546>