CHAPTER 4

Chemical Composition and Energy Value of Distillers Corn Oil for Swine and Poultry

Introduction

DISTILLERS CORN OIL (DCO) IS USED AS A HIGH QUALITY ENERGY SOURCE primarily in poultry and swine diets because of its high metabolizable energy (ME) content and relatively low price compared with other feed fats and oils. The market price of DCO is closely related to the price of yellow grease in the U.S. fats and oils market, but DCO has substantially greater ME content than yellow grease, and a comparable ME content to that found in soybean oil. Some market segments of U.S. poultry and pork industries have chosen to produce chicken and pork by feeding only "vegetable-based" diets (which include vegetable oils) to meet specific consumer demands as part of their marketing strategies. Furthermore, the widespread outbreak of Porcine Epidemic Diarrhea virus in the U.S. in 2013 led many veterinarians and nutritionists to remove animal-(porcine) derived feed ingredients from swine diets (e.g. choice white grease, animal by-product protein meals), and use only plant-based ingredients (e.g. corn, soybean meal, distillers dried grains with solubles (DDGS) and distillers corn oil) to reduce the perceived risk of transmission of this virus and other pathogens that may be present in feed ingredients to commercial farms. However, use of distillers corn oil in swine diets has generally been limited to the nursery and early grower phases because feeding high concentrations of corn oil reduces pork fat firmness. A reduction in carcass fat firmness can reduce yields when processing pork bellies into bacon, and reduces pork quality acceptability in the Japanese export market. However, a GRAS-(Generally Recognized As Safe) approved commercial feed additive (Lipinate™, Nutriquest, Mason City, IA) can be used as an effective method of preventing a reduction in pork fat firmness when feeding high dietary inclusion rates of DDGS or DCO in the U.S.

As a result of the large quantities of DCO produced, its high ME content, and competitive price, an official definition for DCO use in animal feeds has been defined and approved by the Association of American Feed Control Officials (2017):

> "33.10 ____ Distillers Oil, Feed Grade, is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture and mechanical or solvent extraction of oil by methods employed in the ethanol production industry. It consists predominantly of glyceride esters of fatty acids and contains no additions of free fatty acids or other materials from fats. It must contain, and be guaranteed for, not less than 85 percent total fatty acids, not more than 2.5 percent unsaponifiable matter, and not more than one percent insoluble impurities. Maximum free fatty acids and moisture must be guaranteed. If an antioxidant(s) is used, the common or usual name must be indicated, followed by the words "used as a preservative." If the product bears a name descriptive of its kind of origin, i.e. "corn, sorghum, barley, rye," it must correspond thereto with the predominating grain declared as the first word in the name." Proposed 2015, Adopted 2016 rev. 1)

This definition, officially adopted in 2016, specifies the required guaranteed analysis and also applies to solvent-extracted corn oil, which is a different process than the centrifugation processes used by the majority of U.S. ethanol plants. Although limited quantities of deoiled corn DDGS are being produced, a pending AAFCO definition for this new co-product has been proposed as follows:

> "T27.9 ____Deoiled Corn Distillers Dried Grains with Solubles, Solvent Extracted, is the product resulting from the solvent extraction of oil from corn distillers dried grains with solubles (DDGS) to result in a crude fat content of less than three percent on an as-fed basis. It is intended as a source of protein. The label shall include a guarantee form minimum crude protein and maximum sulfur. The words "solvent extracted" are not required when listing as an ingredient in a manufactured feed." (Proposed 2015)

Chemical Composition of Distillers Corn Oil

One of the distinguishing features of distillers corn oil compared with refined corn oil is that DCO sources have greater free fatty acid content (**Table 1**), which can range from less than two percent to as much as 18 percent. Previous studies evaluating various feed lipids have shown that increasing free fatty acid content reduces ME content for pigs and poultry, which led to the development of DE (swine) and AME_n (poultry) prediction equations (Wiseman et al., 1998). Corn oil is distinguishable from other lipid sources because of its relatively high polyunsaturated acid (PUFA) content, especially oleic (9c-18:1; 28 to 30 percent of total lipid) and linoleic (18:2n-6; 53 to 55 percent of total lipid) acid content. Vegetable oils have greater PUFA content than animal fats, which results in vegetable oils having greater

ME content (Kerr et al., 2015). As a result, DCO contains one of highest ME concentrations of all feed fats and oils, but it is also more susceptible to peroxidation (Kerr et al., 2015; Shurson et al., 2015; Hanson et al., 2015). Feeding peroxidized lipids to pigs and broilers has been shown to reduce growth rate, feed intake and gain efficiency (Hung et al., 2017), and highly peroxidized corn oil reduces efficiency of energy utilization and antioxidant status in nursery pigs (Hanson et al., 2016). However, the addition of commercially available antioxidants to distillers corn oil are effective in minimizing peroxidation of DCO when stored at high temperature and humidity conditions (Hanson et al., 2015). Although the extent of peroxidation (peroxide value, anisidine value and hexanal) in DCO is somewhat greater than in refined corn oil, it is much less than in the peroxidized corn oil fed in the nursery pig study by Hanson et al. (2016), where reductions in growth performance were observed.

Table 1. Chemical composition and peroxidation measures of refined corn oil and distillers corn oil (DCO) sources (adapted from Kerr et al., 2016)

Measurement	Refined corn oil	DCO (4.9 % FFA[1])	DCO (12.8 % FFA)	DCO (13.9 % FFA)
Moisture, %	0.02	1.40	2.19	1.19
Insolubles, %	0.78	0.40	1.08	0.97
Unsaponifiables, %	0.73	0.11	0.67	0.09
Crude fat %	99.68	99.62	98.96	99.63
Free fatty acids, %	0.04	4.9	12.8	13.9
Fatty acids, % of total fat				
Palmitic (16:0)	11.39	13.20	11.87	13.20
Palmitoleic (9c-16:1)	0.10	0.11	0.11	0.11
Margaric (17:0)	0.07	0.07	0.07	0.07
Stearic (18:0)	1.83	1.97	1.95	1.97
Oleic (9c-18:1)	29.90	28.26	28.92	28.26
Linoleic (18:2n-6)	54.57	53.11	54.91	53.11
Linolenic (18:3n-3)	0.97	1.32	1.23	1.32
Nonadecanoic (19:0)	ND[1]	0.65	0.65	0.65
Arachidic (20:0)	0.40	0.39	0.39	0.39
Gonodic (20:1n-9)	0.25	0.24	0.24	0.24
Behenoic (22:0)	0.13	0.13	0.12	0.13
Lignoceric (24:0)	0.17	0.19	0.18	0.19
Other fatty acids	0.21	0.41	ND	0.41
Peroxidation measure				
Peroxide value, MEq/kg	1.9	2.9	3.3	2.0
Anisidine value[3]	17.6	80.9	70.3	73.3
Hexanal, µg/g	2.3	4.4	3.9	4.9

[1]FFA = free fatty acids

[2]ND = not detected

[3]There are no units for anisidine value

Table 2 shows a comparison of the chemical composition and peroxidation indicators of two DCO sources with other common feed lipids (i.e. choice white grease, palm oil and soybean oil). Choice white grease (rendered pork fat) consists primarily of oleic acid (9c-18:1), palmitic acid (16:0), and stearic acid (18:0), which result in this lipid source being classified as a saturated fat source compared with DCO. In general, saturated animal fats (i.e. choice white grease) have less ME content than more unsaturated vegetable oil sources (i.e. distillers corn oil). Furthermore, choice white grease contains a greater proportion of saturated fatty acids which makes it less susceptible to lipid peroxidation than DCO, but the temperature and heating time used during rendering can result in a similar amount of peroxidation compared with DCO (**Table 2**). The predominant fatty acids in palm oil are palmitic (16:0) and oleic (9c-18:1) acid, and the linoleic acid content (9.85 percent) is much less than found in DCO (56 percent). As a result, palm oil is much more resistant to peroxidation, as indicated by a high oil stability index (OSI) compared with DCO, choice white grease and soybean oil (**Table 2**). In contrast, the fatty acid profile of soybean oil is similar to that of DCO, and contains high concentrations of linoleic acid (53 percent) with moderate concentrations of oleic (23 percent) and palmitic (11 percent) acids. However, unlike DCO, soybean oil contains relatively high concentrations of linolenic acid (18:3n-3), which theoretically makes it more susceptible to peroxidation than DCO because linolenic acid contains more double bonds than linoleic acid in its chemical structure. Surprisingly, the soybean oil source shown in **Table 2** had a lower aldehyde (products of peroxidation) content, as measured by anisidine value and 2,4 decadienal, compared with DCO, choice white grease and palm oil. Two other distinguishing chemical components in DCO compared with choice white grease, palm oil and soybean oil is its relatively high total tocopherol (626 to 730 mg/kg) and xanthophylls (92 to 175 mg/kg) content (**Table 2**). Only soybean oil had greater total tocopherol content than DCO, but soybean oil is essentially devoid of xanthophylls. Tocopherols and carotenoids (xanthophylls) are strong antioxidant compounds that appear to be beneficial in preventing greater peroxidation during the thermal exposure that occurs during the co-product production process. Furthermore, the relatively high concentrations of these compounds in corn oil present in DDGS appear to be beneficial in minimizing oxidative stress when feeding highly peroxidized DDGS sources to nursery pigs (Song et al., 2013). The high xanthophylls content of DCO is a "value-added" feature and incentive for its use in broiler and layer diets as a partial replacement for synthetic pigments to achieve desired pigmentation in broiler skin and egg yolks.

Table 2. Chemical composition and peroxidation measures of distillers corn oil (DCO), choice white grease (CWG), palm oil (PO) and soybean oil (SO; adapted from Lindblom et al., 2017)

Measurement	DCO (4.5 % FFA)	DCO (10 % FFA[1])	CWG	PO	SO
Moisture %	0.68	0.54	0.24	0.02	0.02
Insolubles %	0.18	0.04	0.22	0.02	0.02
Unsaponifiables %	1.53	1.86	0.63	0.21	0.33
Crude fat %	98.7	98.2	98.3	98.6	98.5
Free fatty acids %	4.5	10.0	13.4	0.07	0.04
Fatty acids % of total fat					
Capric (10:0)	ND[2]	ND	0.07	ND	ND
Lauric (12:0)	ND	ND	ND	0.22	ND
Myristic (14:0)	ND	ND	1.28	0.99	ND
Pentadecanoic (15:0)	ND	ND	ND	0.04	ND
Palmitic (16:0)	12.86	12.88	23.25	43.41	10.74
Palmitoleic (9c-16:1)	0.10	0.10	2.44	0.15	0.08
Margaric (17:0)	ND	ND	0.33	0.10	0.09
Stearic (18:0)	1.76	1.73	12.54	4.38	4.20
Oleic (9c-18:1)	26.95	26.56	41.38	39.90	23.08
Linoleic (18:2n-6)	55.88	56.50	16.52	9.85	53.19

Table 2. Chemical composition and peroxidation measures of distillers corn oil (DCO), choice white grease (CWG), palm oil (PO) and soybean oil (SO; adapted from Lindblom et al., 2017)

Fatty acids % of total fat	DCO (4.5 % FFA)	DCO (10 % FFA[1])	CWG	PO	SO
Linolenic (18:3n-3)	1.26	1.26	0.55	0.22	7.28
Nonadecanoic (19:0)	0.10	ND	ND	ND	0.31
Arachidic (20:0)	0.39	0.38	0.19	0.37	0.33
Gadoleic (20:1)	0.28	0.25	0.80	0.14	0.20
Eicosadienoic (20:2)	ND	ND	0.74	ND	ND
Homo-y linoleic (20:3)	ND	ND	0.11	ND	ND
Arachidonic (20:4)	ND	ND	0.30	ND	ND
Behenoic (22:0)	0.12	0.14	ND	0.07	0.35
Docosatrinoic (22:3)	ND	ND	0.14	ND	ND
Docosatetraenoic (22:4)	0.12	ND	ND	ND	ND
Docosapentaenoic (22:5)	0.18	0.19	ND	ND	ND
Other fatty acids	ND	ND	ND	0.15	0.16
Free glycerin %	0.85	0.53	0.58	0.74	0.31
Total tocopherols, mg/kg	730	626	253	67	1,083
Alpha	51	62	50	67	77
Beta	15	15	< 10	< 10	< 10
Delta	29	15	< 10	< 10	< 10
Gamma	635	534	203	< 10	817
Xanthophylls, mg/kg	92	175	< 1	< 1	< 1
Peroxidation measure					
Peroxide value, MEq/kg	1.4	0.4	0.4	1.2	1.6
Anisidine value[3]	30.76	21.47	23.26	11.22	5.87
2,4-decadienal, mg/kg	26.4	ND	17.6	ND	6.2
Hexanal, µg/g	ND	ND	14.7	ND	ND
OSI[4] at 110°C, h	5.15	10.75	4.15	30.05	6.35
Oxidized fatty acids %	1.6	0.9	2.2	1.2	1.4
Polar compounds %	9.38	9.55	20.53	7.40	3.46
TBA[3,5] value	0.04	0.03	0.03	0.01	0.06

[1]FFA = free fatty acids

[3]There are no units for anisidine value or TBA value.

[4]OSI = oil stability index

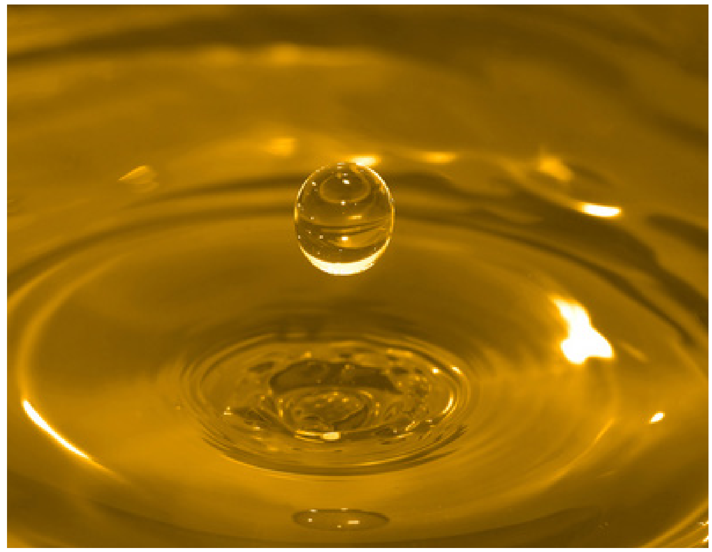
[5]TBA = thiobarbituric acid

Actual and Predicted Digestible and Metabolizable Energy Content of Distillers Corn Oil Sources for Swine

Two studies have been conducted to determine the digestible energy (DE) and ME content of DCO for swine. The first study was conducted by Kerr et al. (2016) to determine the DE and ME content of refined corn oil (0.04 percent FFA), three sources of commercially produced DCO with FFA content ranging from 4.9 to 13.9 percent, and an artificially produced high (93.8 percent) FFA corn oil source, and determine the effect of FFA content on ME content of DCO sources. As shown in **Table 3**, the ME content of DCO samples ranged from 8,036 to 8,828 kcal/kg, with the 4.9 percent FFA DCO sample containing similar ME content compared with refined corn oil. The ME values for refined corn oil (8,741 kcal/kg), 4.9 percent FFA DCO (8,691 kcal/kg) and 13.9 percent FFA DCO (8,397 kcal/kg) were similar to the value of 8,570 kcal/kg for corn oil reported in NRC (2012). Surprisingly, the 93.8 percent FFA corn oil source had the lowest GE content, but the highest DE and ME content of all corn oil sources. With the exception of the 12.8 percent FFA DCO source having the lowest ME content of all sources, there was no significant detrimental effect of FFA content on DE or ME content of DCO.

In a subsequent study, Lindblom et al. (2017) determined the DE and ME content of two different DCO sources (4.5 and 10 percent FFA), and compared these values with commercially available sources of choice white grease, palm oil and soybean oil (**Table 4**). The ME values obtained for both DCO samples were substantially less (7,921 and 7,955 kcal/kg) than the values obtained for two of the three DCO sources (8,397 to 8,691 kcal/kg) evaluated by Kerr et al. (2016). It is unclear why there was a difference in ME content of DCO sources between these two studies, but these results provide further support that FFA content of DCO does not appear to affect ME content for swine. It was also surprising the ME content for choice white grease (8,535 kcal/kg) was greater than the ME content of both DCO samples, and was also greater than the NRC (2012) value of 8,124 kcal/kg. It is well documented that unsaturated lipid sources have historically had greater lipid content than saturated fat sources (NRC, 2012). However, it is possible the widespread use of high dietary inclusion rates of DDGS in U.S. growing-finishing pig diets may have resulted in a shift toward more unsaturated fatty acid content in choice white grease obtained from carcasses of these pigs. Evidence for this is supported by the greater linoleic acid content (16 percent) of this source of choice white grease compared with linoleic acid content of (11.6 percent) reported by NRC (2012). Furthermore, there was a slight decrease in palmitic acid (23 percent) in this source of choice white grease compared with 26 percent palmitic acid reported in the NRC (2012). Furthermore, the ME content of the soybean oil source evaluated by Lindblom et al. (2017) was substantially greater (9,408 kcal/kg) than the value of 8,574 kcal/kg reported by NRC (2012). These results show the potential risks of over- or under-estimating ME content of feed fats and oils when using static values from reference databases.

Kerr et al. (2016) evaluated the accuracy of using of prediction equations developed by Wisemann et al. (1998) to predict DE content of DCO sources to determine if these widely used prediction equations are applicable to DCO sources, and provide more dynamic and accurate DE estimates based on variable FFA composition of DCO sources (**Table 3**). The Wiseman et al. (1998) equations use FFA content, unsaturated to saturated fatty acid ratio, and age of pig as the inputs to estimate DE content. Unfortunately, the results from using these equations showed that DE content was over-estimated in refined corn oil and the 12.8 percent and 13.9 percent FFA DCO sources, provided a similar estimate of DE content for the 4.9 percent FFA DCO source, and greatly underestimated (1,146 kcal/kg) the DE content of the experimentally produced high FFA DCO source. These results suggest that new prediction equations need to be developed specifically for DCO, because the use of the Wiseman et al. (1998) equations does not provide the accuracy and precision necessary to estimate DE content of DCO for swine.



Actual and Predicted Metabolizable Energy Content of Distillers Corn Oil Sources for Broilers

Only one study has been conducted to determine the AME_n content of distillers corn oil for poultry. Kerr et al. (2016) determined the AME_n content of refined corn oil (0.04 percent FFA), along with the same three sources of commercially

Table 3. Actual and predicted DE content and ME content of DCO for nursery pigs (adapted from Kerr et al., 2016)

Measurement	Refined corn oil	DCO (4.9 % FFA[1])	DCO (12.8 % FFA)	DCO (13.9 % FFA)	DCO (93.8 %FFA)
GE, kcal/kg	9,423	9,395	9,263	9,374	9,156
DE, Kcal/kg	8,814[a]	8,828[a]	8,036[b]	8,465[ab]	8,921[a]
ME, kcal/kg	8,741[a]	8,691[a]	7,976[b]	8,397[ab]	8,794[a]
EE[2] digestibility %	93.2	94.0	91.7	95.0	92.7
UFA:SFA[3]	6.13	5.00	5.61	5.00	4.81
Predicted DE[4], kcal/kg	8,972	8,848	8,794	8,741	7,775
Difference between actual vs. predicted DE, kcal/kg	-158	-20	-758	-276	+ 1,146

[a,b]Means with different superscripts within rows are different (P less than 0.05).

[1]FFA = free fatty acids

[2]EE = ether extract

[3]UFA = unsaturated fatty acids, SFA = saturated fatty acids

[4]Equations based on young pigs (DE) obtained from Wiseman et al. (1998).

Table 4. Energy content and ether extract (EE) digestibility of distillers corn oil (DCO), choice white grease (CWG), palm oil (PO) and soybean oil (SO) in nursery pigs (adapted from Lindblom et al., 2017)

Measurement	DCO (4.5 % FFA)	DCO (10 % FFA[1])	CWG	PO	SO
GE, kcal/kg	9,392	9,395	9,365	9,419	9,419
DE, Kcal/kg	8,001[b]	8,052[b]	8,531[b]	8,293[b]	9,388[a]
ME, kcal/kg	7,921[b]	7,955[b]	8,535[b]	8,350[b]	9,408[a]
EE[2] digestibility %	84.6[b]	85.6[a]	85.5[a]	84.4[b]	85.1[ab]

[a,b]Means with different superscripts within rows are different (P less than 0.05).

[1]FFA = free fatty acids

[2]EE = ether extract

produced DCO used in the pig experiment that ranged in FFA content from 4.9 to 13.9 percent, and an artificially produced high (93.8 percent) FFA corn oil source. As shown in **Table 5**, the AME_n content was not different among the DCO sources and ranged from 7,694 to 8,036 kcal/kg, and were not different than the AME_n content of refined corn oil (8,072 kcal/kg). However, these values were substantially less than the AME_n values for refined corn oil in (9,639 to 10,811 kcal/kg) reported in NRC (1994). It is interesting that unlike the response in pigs, feeding the 93.8 percent FFA DCO source resulted in a substantial reduction in AME_n content (6,276 kcal/kg) compared with the AME_n content in other corn oil sources. It is unclear why broilers responded differently than pigs when fed this experimentally produced high FFA corn oil source, but these results support previous reports that increased FFA content of feed fats and oils generally reduces AME_n content in broilers.

Similar to the swine comparison, Kerr et al. (2016) evaluated the accuracy of using prediction equations developed by Wisemann et al. (1998) to estimate AME_n content of DCO sources for broilers to determine if these equations can provide accurate and more dynamic AME_n estimates based on variable FFA composition in DCO for broilers (**Table 5**). The Wiseman et al. (1998) equations use FFA content, unsaturated to saturated fatty acid ratio and age of the bird as the inputs to estimate AME_n content of fats and oils for broilers. Unfortunately, these equations over-estimated AME_n content of all corn oil sources by 379 to 659 kcal/kg. These results suggest that new AME_n prediction equations need to be developed specifically for DCO for broilers because the use of the Wiseman et al. (1998) equations resulted in over-estimating the AME_n content for broilers.

Table 5. Actual and predicted AMEn content of DCO for broilers (adapted from Kerr et al., 2016)

Measurement	Refined corn oil	DCO (4.9 % FFA[1])	DCO (12.8 % FFA)	DCO (13.9 % FFA)	DCO (93.8 % FFA)
GE, kcal/kg	9,423	9,395	9,263	9,374	9,156
AME_n[2], kcal/kg	8,072[a]	7,936[a]	8,036[a]	7,694[a]	6,276[b]
EE[3] digestibility %	91.6[a]	89.8[a]	89.0[a]	88.4a	83.0[b]
UFA:SFA[4]	6.13	5.00	5.61	5.00	4.81
Predicted AME_n[5], kcal/kg	8,680	8,484	8,415	8,329	6,935
Difference between actual vs. predicted AME_n, kcal/kg	- 608	- 548	- 379	- 635	- 659

[1]FFA = free fatty acids

[2]AME_n = nitrogen-corrected apparent ME

[3]EE = ether extract

[4]UFA = unsaturated fatty acids, SFA = saturated fatty acids

[5]Equations based on the average of young and old broilers (apparent ME) obtained from Wiseman et al. (1998) and adjusted to AME_n for broilers based on Lopez and Leeson (2007, 2008) and King et al. (2013).

References

AAFCO. 2017. Association of American Feed Control Officials – Official Publication. Champaign, IL.

Hanson, A.R., P.E. Urriola, L. Wang, L.J. Johnston, C. Chen, and G.C. Shurson. 2016. Dietary peroxidized maize oil affects the growth performance and antioxidant status of nursery pigs. Anim. Feed Sci. Technol. 216:251-261.

Hanson, A.R., P.E. Urriola, L.J. Johnston, and G.C. Shurson. 2015. Impact of synthetic antioxidants on lipid peroxidation of distiller's dried grains with solubles and distiller's corn oil under high temperature and humidity conditions. J. Anim. Sci. 93:4070-4078.

Hung, Y.T., A.R. Hanson, G.C. Shurson, and P.E. Urriola. 2017. Peroxidized lipids reduce growth performance of poultry and swine: A meta-analysis. Anim. Feed Sci. Technol. 231:47-58.

Kerr, B.J., W.A. Dozier III, and G.C. Shurson. 2016. Lipid digestibility and energy content of distillers' corn oil in swine and poultry. J. Anim. Sci. 94:2900-2908.

Kerr, B.J., and G.C. Shurson. 2016. Determination of ether extract digestibility and energy content of specialty lipids with different fatty acid and free fatty acid content, the effect of lecithin, for nursery pigs. The Professional Anim. Scientist 33:127-134.

Kerr, B.J., T.A. Kellner, and G.C. Shurson. 2015. Characteristics of lipids and their feeding value in swine diets. J. Anim. Sci. Biotechnol. 6:30.

King, E.J., F.H. de Witt, H.J. van der merwe, A. Hugo, and M.D. Fair. 2013. The effect of lipid saturation on nutrient digestibility of layer diets. S. Afr. J. Anim. Sci. 43:S131-S134.

Lindblom, S.C., W.A. Dozier III, G.C. Shurson, and B.J. Kerr. 2017. Digestibility of energy and lipids and oxidative stress in nursery pigs fed commercially available lipids. J. Anim. Sci. 95:239-247.

Lopez, G., and S. Leeson. 2007. Relevance of nitrogen correction for assessment of metabolizable energy with broilers to forty-nine days of age. Poult. Sci. 86:1696-1704.

Lopez, G., and S. Leeson. 2008. Assessment of the nitrogen correction factor in evaluating metabolizable energy of corn and soybean meal in diets for broilers. Poult. Sci. 87:298-306.

Shurson, G.C, B.J. Kerr, and A.R. Hanson. 2015. Evaluating the quality of feed fats and oils and their effects on pig growth performance. J. Anim. Sci. Biotechnol. 6:10.

Song, R., C. Chen, L. Wang, L.J. Johnston, B.J. Kerr, T.E. Weber, and G.C. Shurson. 2013. High sulfur content in corn dried distillers grains with solubles protects against oxidized lipids by increasing sulfur-containing antioxidants in nursery pigs. J. Anim. Sci. 91:2715-2728.

Wiseman, J., J. Powles, and F. Salvador. 1998. Comparison between pigs and poultry in the prediction of dietary energy value of fats. Anim. Feed Sci. Technol. 71:1-9.