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Rice oil as a soybean oil replacement in weanling pig diets

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ABSTRACT

The motivation for including oils in the diets of weanling pigs is to increase dietary energy density to meet the pigs' energy requirements. The purpose of this study was to determine the digestible and metabolizable energy values of semi-refined rice oil (RO) and refined soybean oil (SO) for weanling pigs (Experiment 1), as well as to evaluate how replacing SO with RO in weanling pig diets affects performance, intestinal histology, organ morphometry and the occurrence of diarrhea (Experiment 2). In Experiment 1, 21 barrows, averaging 19.63 ± 0.37 kg body weight (BW), were used in a randomized complete block design experiment, with seven replications per treatment and one pig per experimental unit (metabolism cage). The treatments consisted of a reference diet and two test diets. The test diets were obtained by using 90% of the reference diet and 10% of RO or SO. The experimental period consisted of a 7 days adaptation period, followed by a 5 days collection period of feces and urine. The values of the apparent digestible energy, apparent metabolizable energy and N-corrected apparent metabolizable energy of the oils were, respectively, 26.24, 25.78 and 26.01 MJ kg^{-1} for RO and 31.74, 31.35 and 31.51 MJ kg^{-1} for SO. In Experiment 2, 120 weaned pigs, castrated males and females, averaging 6.74 ± 0.42 kg BW, were used in a randomized complete block design experiment, with eight replications per treatment and three pigs per experimental unit (pen) to evaluate the effects of five replacement levels of SO with RO in isonutritive weanling pig diets. The treatments were as follows: 4:0—basal diet with 4% of SO; 3:1—basal diet with 3% of SO and 1% of RO; 2:2—basal diet with 2% of SO and 2% of RO; 1:3—basal diet with 1% of SO and 3% of RO; and 0:4—basal diet with 4% of RO. No effects of the replacement levels were observed in the weanling pigs' performance, organ morphometry or in their occurrence of diarrhea. However, a quadratic effect on the villus width and a cubic effect on the villus height:crypt depth ratio were observed in the duodenum. Therefore, if the determined values of energy are used in the feed formulation, refined soybean oil can be replaced with semi-refined rice oil in weanling pig diets without affecting their growth performance.

1. Introduction

The period immediately after weaning is considered critical to pigs because it is associated with low feed intake, reduced growth rate, alterations of the intestinal epithelium and the occurrence of diarrhea (Pluske et al., 1997). In addition, a decrease in the vitamin E status has been observed in weanling pigs (Lauridsen, 2010; Lauridsen et al., 2011; Wilburn et al., 2008). Thus, it is essential to increase the energy density of the diets of weanling pigs, as well as to supplement their diets with vitamin E.

Among the vegetable oils, soybean oil has been widely used in pig diets to increase energy density and to meet their high energy requirements. However, weanling pigs have a limited capacity to digest vegetable oils, which is mainly influenced by the fatty acid profile, the unsaturated:saturated fatty acids ratio and the free fatty acid content in the oil (Powles et al., 1994, 1995).

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Rice oil has a high content of compounds with antioxidant properties, such as oryzanols, tocopherols and tocotrienols (Danielski et al., 2005). It also has been shown that rice oil may reduce serum cholesterol (Wilson et al., 2007) and modulate the immune response (Sierra et al., 2005). Recent research has demonstrated that there is an increase in the weight gain and feed intake of weanling pigs fed diets containing rice oil as a substitute for soybean oil (Lima et al., 2009). However, there is a lack of data regarding the nutritional value of rice oil for these young pigs.

The purposes of this study are as follows: (1) to determine the digestible and metabolizable energy values of semi-refined rice oil (RO) and refined soybean oil (SO) for weanling pigs (Experiment 1); (2) to evaluate how replacing SO with RO in weanling pig diets affects performance, intestinal histology, organ morphometry and the occurrence of diarrhea (Experiment 2).

2. Material and methods

All procedures using animals were approved by the "Committee of Ethics for the Use of Animals in Research—CEUAP/ESALQ/USP" (Protocol 2010-1).

2.1. Experiment 1—The digestibility of refined soybean oil (SO) and semi-refined rice oil (RO) in weanling pigs

Twenty one barrows averaging 19.63 ± 0.37 kg BW were used in a randomized complete block design experiment, with seven replications per treatment and one animal per experimental unit (metabolism cage). The pigs were housed randomly and individually in stainless steel metabolism cages, which allowed for the separate collection of urine and feces, as described by Pekas (1968).

The experimental period consisted of 7 days adaptation period, followed by 5 days collection period of feces and urine, using protocols described by Sakomura and Rostagno (2007). The treatments included a reference diet (Table 1) that was formulated and based on the nutrient requirement table of weanling pigs (Rostagno et al., 2005) and two test diets (RO and SO). The test diets had a composition of 90% reference diet (as-fed basis) and 10% RO or SO. During the collection period, the daily feed intake was maintained constant, and the amount of feed provided for each pig was based on a lower feed intake per kg of metabolic BW ($BW^{0.75}$) observed during the adaptation period in each block. The diets were provided twice daily, and water was provided *ad libitum* during the entire experimental period. To determine the beginning and end of a collection period, ferric oxide (Fe_2O_3) at a dietary level of 2% was used as a fecal marker.

The feed intake and production of feces and urine were registered, and diet, feces and urine samples were collected. Feces samples were collected twice daily and stored at −18 °C. Urine samples were collected in buckets containing 20 mL of HCl (1:1 with distilled water), and 100 mL samples were stored under refrigeration at 3 °C. At the end of the experiment, following the procedures described by AOAC (2005), the samples were homogenized, lyophilized and analyzed for dry matter, ash, ether extract, nitrogen (N) and energy.

Table 1
Composition of the reference diet (as-fed basis).

Ingredient	Reference diet
Corn, %	71.56
Soybean meal (46%), %	19.77
Spray-dried plasma, %	1.17
Sugar, %	4.00
Dicalcium phosphate, %	1.63
Limestone, %	0.65
Salt, %	0.37
L-Lysine.HCl (78%), %	0.36
DL-Methionine (99%), %	0.06
L-Threonine (98,5%), %	0.09
Choline chloride (60%), %	0.10
Premix[a], %	0.20
Antibiotic: Clorohydroxyquinoline (60%), %	0.02
Antioxidant: Ethoxyquin, %	0.02
Calculated values:	
Metabolizable energy, MJ kg^{-1}	13.52
Crude protein, %	16.13
Calcium, %	0.72
Total phosphorus, %	0.58
Available phosphorus, %	0.40
Digestible lysine, %	0.99
Digestible methionine, %	0.30
Digestible met + cys, %	0.55
Digestible tryptophan, %	0.17
Digestible threonine, %	0.62
Analyzed values:	
Gross energy, MJ kg^{-1}	18.21
Crude protein, %	18.06
Ash, %	5.30
Dry matter, %	87.98
Ether extract, %	4.37

[a] Provided per kilogram of diet: manganese, 60 mg; zinc, 150 mg; iron, 100 mg; copper, 10 mg; iodine, 1.2 mg; vitamin A, 11,500 UI; vitamin D_3, 5850 UI; vitamin E, 45 UI; vitamin K_3, 3 mg; thiamine, 1.8 mg; riboflavin, 5.1 mg; pyridoxine, 3.5 mg; vitamin B_{12}, 24 μg; folic acid, 0.82 mg; pantothenic acid, 18 mg; niacin, 37.5 mg; biotin, 0.14 mg; selenium, 0.35 mg; ethoxyquin, 0.042 mg.

The digestibility coefficients of ether extract and organic matter and the values of digestible ether extract, digestible organic matter, apparent digestible energy (ADE), apparent metabolizable energy (AME) and N-corrected apparent metabolizable energy (AME_n) were determined according to equations proposed by Matterson et al. (1965). AME values are commonly corrected for N-retention because when 10% of the test oil is combined with 90% of the reference diet, all nutrient balances may be altered, and N may then be excreted as urea in the urine. Because the energy of urea is lost in the urine, the AME of the test oils (both SO and RO) would be underestimated (Sakomura and Rostagno, 2007).

2.2. Experiment 2—The replacement of refined soybean oil (SO) with semi-refined rice oil (RO) in weanling pig diets

One hundred and twenty weaned pigs, castrated males and females, averaging 6.74 ± 0.42 kg BW, were used in a randomized complete block design experiment, with eight replications per treatment and three animals per experimental unit (pen). The pigs were housed in 1.2 m × 1.5 m pens with partially slatted floors in a naturally ventilated building. A feeder and a nipple drinker were provided in each pen, and the feed and water were given *ad libitum* to the pigs.

The treatments consisted of five replacement levels of SO with RO in the diets: 4:0—basal diet with 4% of SO; 3:1—basal diet with 3% of SO and 1% of RO; 2:2—basal diet with 2% of SO and 2% of RO; 1:3—basal diet with 1% of SO and 3% of RO; and 0:4—basal diet with 4% of RO.

Isonutritive diets (Tables 2, 3 and 4) were formulated based on the nutrient requirement of weanling pigs (Rostagno et al., 2005). The AME_n values of SO and RO of 31.51 and 26.01 MJ kg^{-1}, respectively, as determined in Experiment 1 (Table 5) were used for the feed formulation. A three-phase feeding program was adopted: pre-starter 1 (1 to 7 days of experiment), pre-starter 2 (7 to 21 days of experiment) and starter (21 to 35 days of experiment).

The average daily gain, daily feed intake and the feed:gain ratio were calculated using the individual weight data of the animals and by the quantification of the feed intake in each pen during the several periods. The occurrence of diarrhea was monitored every day for each animal (defining diarrhea to be liquid stool), and the percentage of days with diarrhea (PDD) and the percentage of animals with diarrhea (PAD) were calculated.

Table 2
Composition of the pre-starter 1 diets (as-fed basis).

Ingredient	Replacement levels SO:RO, % of diet				
	4:0	3:1	2:2	1:3	0:4
Corn, %	42.23	42.70	43.18	43.65	44.11
Soybean meal (46%), %	22.94	22.84	22.75	22.66	22.56
Spray-dried whey, %	9.62	9.61	9.61	9.61	9.61
Spray-dried whole milk, %	8.57	8.58	8.58	8.58	8.59
Spray-dried plasma, %	5.03	5.04	5.04	5.04	5.04
Sugar, %	2.50	2.50	2.50	2.50	2.50
Refined soybean oil (SO) , %	4.00	3.00	2.00	1.00	0.00
Semi-refined rice bran oil (RO) , %	0.00	1.00	2.00	3.00	4.00
Dicalcium phosphate, %	1.86	1.86	1.85	1.85	1.85
Limestone, %	0.59	0.59	0.59	0.60	0.60
Salt, %	0.02	0.02	0.02	0.02	0.02
Zinc oxide, %	0.30	0.30	0.30	0.30	0.30
Inert, %	1.52	1.14	0.76	0.37	0.00
L-Lysine.HCl (78%), %	0.30	0.30	0.30	0.30	0.30
DL-Methionine (99%), %	0.18	0.18	0.18	0.18	0.18
L-Threonine (98,5%), %	0.12	0.12	0.12	0.12	0.12
Choline chloride (60%), %	0.10	0.10	0.10	0.10	0.10
Trace mineral premix[a] , %	0.05	0.05	0.05	0.05	0.05
Vitamin premix[b], %	0.03	0.03	0.03	0.03	0.03
Antibiotic: Clorohydroxyquinoline (60%), %	0.02	0.02	0.02	0.02	0.02
Antioxidant: Ethoxyquin, %	0.02	0.02	0.02	0.02	0.02
Calculated values:					
Metabolizable energy, MJ kg^{-1}	14.65	14.65	14.65	14.65	14.65
Crude protein, %	21.05	21.05	21.05	21.05	21.05
Calcium, %	0.89	0.89	0.89	0.89	0.89
Total phosphorus, %	0.71	0.71	0.71	0.71	0.71
Available phosphorus, %	0.56	0.56	0.56	0.56	0.56
Digestible lysine, %	1.52	1.52	1.52	1.52	1.52
Digestible methionine, %	0.51	0.51	0.51	0.51	0.51
Digestible met + cys, %	0.85	0.85	0.85	0.85	0.85
Digestible tryptophan, %	0.26	0.26	0.26	0.26	0.26
Digestible threonine, %	0.96	0.96	0.96	0.96	0.96
Lactose, %	10.00	10.00	10.00	10.00	10.00

[a] Provided per kilogram of diet: manganese, 60 mg; zinc, 150 mg; iron, 100 mg; copper, 10 mg; iodine, 1.2 mg.
[b] Provided per kilogram of diet: vitamin A, 11,500 UI; vitamin D_3, 5850 UI; vitamin E, 45 UI; vitamin K_3, 3 mg; thiamine, 1.8 mg; riboflavin, 5.1 mg; pyridoxine, 3.5 mg; vitamin B_{12}, 24 µg; folic acid, 0.82 mg; pantothenic acid, 18 mg; niacin, 37.5 mg; biotin, 0.14 mg; selenium, 0.35 mg; ethoxyquin, 0.042 mg.

Table 3
Composition of the pre-starter 2 diets (as-fed basis).

Ingredient	Replacement levels SO:RO, % of diet				
	4:0	3:1	2:2	1:3	0:4
Corn, %	49.57	50.05	50.53	51.01	51.45
Soybean meal (46%), %	25.39	25.30	25.20	25.11	25.02
Spray-dried whey, %	6.03	6.03	6.03	6.03	6.02
Spray-dried whole milk, %	4.65	4.65	4.65	4.65	4.67
Spray-dried plasma, %	2.79	2.79	2.80	2.80	2.79
Sugar, %	2.50	2.50	2.50	2.50	2.50
Refined soybean oil (SO) , %	4.00	3.00	2.00	1.00	0.00
Semi-refined rice bran oil (RO) , %	0.00	1.00	2.00	3.00	4.00
Dicalcium phosphate, %	1.53	1.53	1.52	1.52	1.52
Limestone, %	0.77	0.77	0.77	0.77	0.77
Salt, %	0.17	0.17	0.17	0.17	0.17
Zinc oxide, %	0.30	0.30	0.30	0.30	0.30
Inert, %	1.52	1.13	0.74	0.35	0.00
L-Lysine.HCl (78%), %	0.31	0.31	0.32	0.32	0.32
DL-Methionine (99%), %	0.14	0.14	0.14	0.14	0.14
L-Threonine (98,5%), %	0.11	0.11	0.11	0.11	0.11
Choline chloride (60%), %	0.10	0.10	0.10	0.10	0.10
Trace mineral premix[a], %	0.05	0.05	0.05	0.05	0.05
Vitamin premix[b], %	0.03	0.03	0.03	0.03	0.03
Antibiotic: Clorohydroxyquinoline (60%), %	0.02	0.02	0.02	0.02	0.02
Antioxidant: Ethoxyquin, %	0.02	0.02	0.02	0.02	0.02
Calculated values:					
Metabolizable energy, MJ kg^{-1}	14.30	14.30	14.30	14.30	14.30
Crude protein, %	19.81	19.81	19.81	19.81	19.81
Calcium, %	0.82	0.82	0.82	0.82	0.82
Total phosphorus, %	0.62	0.62	0.62	0.62	0.62
Available phosphorus, %	0.45	0.45	0.45	0.45	0.45
Digestible lysine, %	1.33	1.33	1.33	1.33	1.33
Digestible methionine, %	0.44	0.44	0.44	0.44	0.44
Digestible met + cys, %	0.74	0.74	0.74	0.74	0.74
Digestible tryptophan, %	0.23	0.23	0.23	0.23	0.23
Digestible threonine, %	0.84	0.84	0.84	0.84	0.84
Lactose, %	6.00	6.00	6.00	6.00	6.00

[a] Provided per kilogram of diet: manganese, 60 mg; zinc, 150 mg; iron, 100 mg; copper, 10 mg; iodine, 1.2 mg;
[b] Provided per kilogram of diet: vitamin A, 11,500 UI; vitamin D_3, 5850 UI; vitamin E, 45 UI; vitamin K_3, 3 mg; thiamine, 1.8 mg; riboflavin, 5.1 mg; pyridoxine, 3.5 mg; vitamin B_{12}, 24 µg; folic acid, 0.82 mg; pantothenic acid, 18 mg; niacin, 37.5 mg; biotin, 0.14 mg; selenium, 0.35 mg; ethoxyquin, 0.042 mg.

At the end of the experimental period (35 days), one animal per experimental unit was slaughtered to collect samples for intestinal histology analysis and for organ morphometry. Samples 2 cm in length were collected from the duodenum (15 cm from the pyloric valve of stomach) and the jejunum (150 cm from ileocecal junction). Four sections (cuts) of 6 µm per sample were prepared in paraffin and colored by the method of hematoxylin–eosin staining. The villus height, villus width and crypt depth were then measured in five villi per section using optical microscopy (AFIP, 1994). The digestive organs (stomach, pancreas, liver and small intestine) and the spleen were weighed, and the length of the small intestine was registered to calculate the weight of the organs in relation to the fasted body weight and weight:length ratio of the small intestine.

2.3. Statistical analysis of data for Experiments 1 and 2

The experiment was analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Institute

Table 4
Composition of the starter diets (as-fed basis).

Ingredient	Replacement levels SO:RO, % of diet				
	4:0	3:1	2:2	1:3	0:4
Corn, %	64.74	65.18	65.62	66.06	66.50
Soybean meal (46%), %	19.34	19.29	19.25	19.20	19.15
Spray-dried whey, %	3.52	3.52	3.52	3.52	3.52
Spray-dried plasma, %	1.60	1.60	1.60	1.60	1.60
Sugar, %	2.10	2.10	2.10	2.10	2.10
Refined soybean oil (SO) , %	0.00	1.00	2.00	3.00	4.00
Semi-refined rice bran oil (RO) , %	4.00	3.00	2.00	1.00	0.00
Dicalcium phosphate, %	1.53	1.53	1.53	1.53	1.52
Limestone, %	0.67	0.67	0.67	0.67	0.67
Salt, %	0.27	0.27	0.27	0.27	0.27
Inert, %	1.55	1.17	0.77	0.38	0.00
L-Lysine.HCl (78%), %	0.32	0.32	0.32	0.32	0.32
DL-Methionine (99%), %	0.07	0.06	0.06	0.06	0.06
L-Threonine (98,5%), %	0.07	0.07	0.07	0.07	0.07
Choline chloride (60%), %	0.10	0.10	0.10	0.10	0.10
Trace mineral premix[a], %	0.05	0.05	0.05	0.05	0.05
Vitamin premix[b], %	0.03	0.03	0.03	0.03	0.03
Antibiotic: Clorohydroxyquinoline (60%), %	0.02	0.02	0.02	0.02	0.02
Antioxidant: Ethoxyquin, %	0.02	0.02	0.02	0.02	0.02
Calculated values:					
Metabolizable energy, MJ kg^{-1}	13.98	13.98	13.98	13.98	13.98
Crude protein, %	16.04	16.06	16.07	16.09	16.10
Calcium, %	0.72	0.72	0.72	0.72	0.72
Total phosphorus, %	0.57	0.57	0.57	0.57	0.57
Available phosphorus, %	0.40	0.40	0.40	0.40	0.40
Digestible lysine, %	0.99	0.99	0.99	0.99	0.99
Digestible methionine, %	0.30	0.30	0.30	0.29	0.29
Digestible met + cys, %	0.55	0.55	0.55	0.55	0.55
Digestible tryptophan, %	0.17	0.17	0.17	0.17	0.17
Digestible threonine, %	0.62	0.62	0.62	0.62	0.62
Lactose, %	2.50	2.50	2.50	2.50	2.50

[a] Provided per kilogram of diet: manganese, 60 mg; zinc, 150 mg; iron, 100 mg; copper, 10 mg; iodine, 1.2 mg;

[b] Provided per kilogram of diet: vitamin A, 11,500 UI; vitamin D_3, 5850 UI; vitamin E, 45 UI; vitamin K_3, 3 mg; thiamine, 1.8 mg; riboflavin, 5.1 mg; pyridoxine, 3.5 mg; vitamin B_{12}, 24 µg; folic acid, 0.82 mg; pantothenic acid, 18 mg; niacin, 37.5 mg; biotin, 0.14 mg; selenium, 0.35 mg; ethoxyquin, 0.042 mg.

Table 5
Chemical composition and values of gross energy, apparent digestible energy (ADE), apparent metabolizable energy (AME) and N-corrected apparent metabolizable energy (AME_n) of refined soybean oil and semi-refined rice oil for weanling pigs (as-fed basis).

Item	Refined soybean oil	Semi-refined rice oil	SE[a]	*P*-value
Fatty acid profile[b]				
Lauric (C12:0), %	0.80	0.85	–	–
Miristic (C14:0), %	–	0.29	–	–
Palmitic (C16:0), %	10.61	19.43	–	–
Stearic (C18:0), %	3.71	1.90	–	–
Oleic (C18:1), %	28.25	41.28	–	–
Linoleic (C18:2 ω6), %	49.93	32.37	–	–
α-Linolenic (C18:3 ω3), %	4.79	0.86	–	–
Arachidic (C20:0), %	0.42	0.80	–	–
Gadoleic (C20:1), %	0.59	0.55	–	–
Eicosadienoic (C20:2), %	0.48	0.21	–	–
Erucic (C22:1), %	–	0.31	–	–
Lignoceric (C24:0), %	–	0.53	–	–
Total saturated, %	15.54	23.80	–	–
Total unsaturated, %	84.04	75.58	–	–
Unsaturated:saturated ratio	5.41	3.18	–	–
Free fatty acids[c], %	0.02	0.92	–	–
γ-Oryzanol[d], %	0.04	1.58	–	–
Total vitamin E[e], mg kg^{-1}	388.00	212.00	–	–
α-Tocopherols, mg kg^{-1}	2.84	1.14	–	–
Dry matter[f], %	99.98	99.35	–	–
Ether extract (EE)[f], %	98.16	96.18	–	–
Coef. dig. of EE, %	89.25	88.01	5.38	0.864
Digestible EE, %	87.61	84.64	5.25	0.686
Nitrogen[f], %	0.08	0.10	–	–
Ash[f], %	1.52	1.39	–	–
Organic matter (OM)[f], %	98.46	97.96	–	–
Coef. dig. of OM, %	96.06	88.06	4.12	0.020
Digestible OM, %	94.58	86.27	4.05	0.017
Gross energy[f], MJ kg^{-1}	39.22	39.16	–	–
ADE, MJ kg^{-1}	31.74	26.24	3.13	0.201
AME, MJ kg^{-1}	31.35	25.78	3.18	0.206
AME_n, MJ kg^{-1}	31.51	26.01	3.01	0.189

[a] Standard error of mean.
[b] Methodology described by AOCS (1998).
[c] Methodology described by IUPAC (1979).
[d] Methodology described by Seetharamaiah and Prabhakar (1986).
[e] Methodology described by Parrish (1980).
[f] Methodology described by AOAC (2005).

Inc., Cary, North Carolina, USA). The model included the fixed effect of the treatments (the type of oil in Experiment 1 and the replacement levels in Experiment 2) and the random effect of block, as follows:

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

where *Y(ij)* is the dependent response, µ is the overall mean, *t(i)* is the fixed effect of treatments (Experiment 1: $i = 1,2$; Experiment 2: $i = 1,...5$), *b(j)* is the random effect of block (Experiment 1: $j = 1,...7$; Experiment 2: $j = 1,...8$) and ε*(ij)* is the residual error.

An analysis of the variance of the PDD was performed using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, North Carolina, USA) by considering a Poisson's data distribution and a heterogeneity in residual variance. The χ^2 test (chi-square) was used to analyze the PAD.

The results in the tables are presented as the least square means (LSMeans) and the standard error of the mean (SE). Probability values < 0.05 were considered significant. In Experiment 2, the relationship between the replacement levels and the duodenum epithelium histology was determined using a regression analysis.

3. Results and discussion

3.1. Experiment 1

The digestibility coefficients of organic matter and of the digestible organic matter of the RO were lower ($P < 0.05$) than those of the SO (Table 5). However, no difference ($P > 0.05$) between the RO and the SO was observed for the values of ADE, AME, AME_n, coefficient of digestibility of ether extract or digestible ether extract. However, the values of ADE, AME and AME_n of RO were, on average, 17.52% lower ($P < 0.21$) than those of SO. These differences were not significant ($P > 0.05$), possibly due to the high coefficients of variation (Lenth, 2007). Compared to growing-finishing pigs, high coefficients of variation have been observed in digestibility experiments with weanling pigs (Kim et al., 2007).

The digestibility of lipids in swine is affected by the fatty acid composition of the lipid source, mainly due to the unsaturated:saturated fatty acids ratio and the content of free fatty acids (Powles et al., 1994, 1995). Compared to SO, RO has a lower unsaturated:saturated fatty acids ratio (3.18 vs. 5.41) and higher free fatty acid content (0.92 vs. 0.02%) (Table 5), which might be associated with the lower digestibility of RO for weanling pigs.

Based on feed ingredient composition tables (NRC, 1998; Rostagno et al., 2005), nutritionists have been considering the same energy values of different lipid sources for all animal age feed formulation. However, it is important to remember that most of the data of the published tables were determined with growing-finishing pigs. The values of ADE and AME_n determined in this study for SO (Table 5) were, respectively, 12.61% and 9.86% lower than the average published values of 36.32 and 34.96 MJ kg^{-1} (NRC, 1998; Rostagno et al., 2005). These differences may be due to the age (or BW) of the animals used to determine the energy values (Kim et al., 2005, 2007) because the ability to digest lipids increases with the age (or BW) of the swine (Cera et al., 1990; Liu et al., 2001). However, some other studies (Lauridsen et al., 2007) have shown opposite results.

When using prediction equations to estimate the ADE values for growing-finishing pigs, and considering the unsaturated:saturated fatty acids ratio and the free fatty acid content, values of 36.05 MJ kg^{-1} for RO and of 36.86 MJ kg^{1} for SO have been found (Powles et al., 1995). However, adjusting the same equations for weanling pigs, values of 30.71 MJ kg^{-1} for RO and of 32.52 MJ kg^{-1} for SO have been found (Powles et al., 1995), which are similar to the values found in the present study (Table 5) and lower than those values estimated for growing-finishing pigs. Therefore, the experimentally determined energy values of the oils should be used for each phase of pig feed formulation.

3.2. Experiment 2

3.2.1. Performance

No effects ($P>0.05$) of the dietary replacement levels of SO with RO were observed on the average daily gain, daily feed intake or feed:gain ratio of weanling pigs (Table 6). These results differ from those obtained by Lima et al. (2009), who observed an increase in feed intake (893 vs. 956 g day^{-1}) and average daily gain (442 vs. 487 g day^{-1}) with a 2% replacement of soybean oil with rice oil in the diets of weanling pigs (from 21 to 63 days of age). These differences may be due to the energy content of the oils. While Lima et al. (2009) considered the same values for both oils, the present study showed that the AME_n of RO is 17.5% lower than that of SO (Table 5). The feed intake of any animal species is determined by their energy requirements (Woods, 2004), and an increase in the feed intake of pigs is observed as their dietary energy density is lowered (Beaulieu et al., 2006).

The α-tocopherol and total vitamin E contents of the rice oil used in this experiment (Table 5) were lower than the published average contents of 375 and 1105 mg kg^{-1}, respectively (Lima et al., 2009; Rodrigues et al., 2004). Rice oil may present a high variation of vitamin E, which is mainly due to factors such as the methods and conditions of extraction and refining techniques (Rodrigues and Oliveira, 2010; Rodrigues et al., 2004). Pigs may be susceptible to reduced vitamin E depots just after weaning (Lauridsen, 2010; Lauridsen et al., 2011), and vitamin E in its natural form has been demonstrated to have higher activity than in its synthetic form (Lauridsen et al., 2002, 2011; Wilburn et al., 2008). In addition, when compared to sunflower oil, rice oil in rat diets has been shown to have anti-allergic properties. For example, it increases lymphocytes B and cytokines TH1 and reduces cytokines TH2 and IgE (Sierra et al., 2005).

Table 6
Effects of the dietary replacement levels of refined soybean oil (SO) with semi-refined rice oil (RO) on body weight (BW), average daily gain (ADG), average daily fed intake (ADFI), feed:gain ratio, and villus height, crypt depth, villus width and villus height:crypt depth ratio (VH:CD) of the duodenum and jejunum of weanling pigs.

Period	Replacement levels SO:RO, % of diet					SE[a]	P-value
	4:0	3:1	2:2	1:3	0:4		
Performance							
Initial BW, kg	6.74	6.72	6.73	6.76	6.73	–	–
Final BW, kg	25.98	26.26	26.06	26.37	26.10	1.18	0.982
ADG, g day^{-1}	550	558	552	560	553	24	0.982
ADFI, g day^{-1}	872	922	909	884	894	43	0.414
Feed:gain ratio	1.58	1.66	1.64	1.58	1.61	0.03	0.220
Intestinal epithelium histology							
Duodenum							
Villus height, μm	593	587	591	595	590	18.16	0.253
Crypt depth, μm	384	391	386	383	390	17.41	0.125
Villus width, μm	93	92	91	91	94	2.08	0.046[b]
VH:CD	1.59	1.54	1.57	1.60	1.55	0.12	0.025[c]
Jejunum							
Villus height, μm	686	684	681	684	684	17.28	0.253
Crypt depth, μm	385	384	384	385	385	18.53	0.990
Villus width, μm	80	81	82	81	81	1.81	0.392
VH:CD	1.83	1.83	1.83	1.83	1.83	0.13	0.997

[a] Standard error of the mean.
[b] Polynomial regression: $Y=0.05862x^2-3.5217x+96.185$ ($R^2=0.69$, P value = 0.009).
[c] Polynomial regression: $Y=-0.0126x^3+0.1123x^2-0.2919x+1.7774$ ($R^2=0.99$, P value = 0.001).

Thus, the variations of rice oil composition, mainly in vitamin E, might be an important factor to be considered in future weanling pig studies.

The results of this experiment are similar to those of experiments with broilers, where no differences were observed in the average daily gain, daily feed intake or feed:gain ratio, with the replacement of corn oil with rice oil (Fan et al., 1995) or soybean oil with rice oil (Moraes et al., 2009), or when rice oil was included from 0 to 5% in broiler diets (Anitha et al., 2007). The metabolizable coefficient of dietary fat with either rice oil or soybean oil for broilers did not differ (57.8 vs. 55.4%, respectively) (Moraes et al., 2009), which indicates that the values of metabolizable energy of both oils for the broilers were similar. However, the AME_n of RO is lower than that of SO for weanling pigs (Table 5). These results show that the determined energy values of oils must be used in the feed formulation for weanling pigs.

3.2.2. Intestinal epithelium histology

The dietary replacement levels of the SO with RO showed a quadratic effect ($P<0.01$) on villus width and a cubic effect ($P<0.01$) on villus height:crypt depth ratio in the duodenum (Table 6). Other variables of the intestinal epithelium histology were not affected ($P>0.05$) by the dietary replacement levels of SO with RO (Table 6). There are some indications that there is an ideal dietary proportion of fatty acids to meet enterocytes requirements exists (Lauridsen, 2010; Li et al., 1990). Thus, the mix of SO and RO may have resulted in a different proportion of fatty acids than those required by the enterocytes, modifying the villus width (Table 6). However, a biological explanation for a cubic effect of dietary replacement levels of oils on the villus height:crypt depth ratio in the duodenum of weanling pigs (Table 6) was not found.

3.2.3. Organ morphometry

The relative weight of the digestive organs and the spleen was not influenced ($P>0.05$) by a dietary replacement of SO with RO (data not shown), which may indicate that the RO did not alter the metabolism. Studies comparing organ morphometry of animals supplemented with rice oil were not found in the literature.

3.2.4. Occurrence of diarrhea

No effects ($P>0.05$) of the dietary replacement levels of SO with RO were observed in the occurrence of diarrhea (data not shown). These results were similar to those found by Lima et al. (2009) with weanling pigs and by Sierra et al. (2005) with rats.

Regardless of the replacement levels, for 1 to 7 days and 1 to 14 days of experiment, the average of PAD were 46.67 and 59.17%, respectively. No diarrhea was observed after the 14th day of the experiment, which indicates that the critical period for the pigs is the two first weeks after weaning.

4. Implications

If the experimentally determined values of semi-refined rice oil energy are used in the feed formulation, then semi-refined rice oil can be used as replacement for refined soybean oil in weanling pig diets without affecting the pigs' growth performance, organ morphometry or occurrence of diarrhea.

Conflict of interest

The authors declare that there is no conflict of interest.

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