Effects of full fat rice bran and defatted rice bran on growth performance and carcass characteristics of growing-finishing pigs¹

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ABSTRACT: The objective was to test the hypothesis that increasing inclusion levels of full fat rice bran (FFRB) or defatted rice bran (DFRB) are not detrimental to growth or carcass characteristics, longissimus muscle (LM) quality, or fat quality when fed to growing-finishing pigs. A total of 224 barrows and gilts were randomly allotted to 7 treatments, with 4 pigs per pen and 8 pen replicates per treatment. Pigs had an average initial BW of 28.2 ± 4.1 kg and a 3-phase feeding program was used. A basal diet containing corn and soybean meal, 3 diets containing corn, soybean meal, and 10, 20, or 30% FFRB, and 3 diets containing corn, soybean meal, and 10, 20, or 30% DFRB were formulated within each phase. Daily feed allotments and pig BW at the start of the experiment and at the conclusion of each phase were recorded. On the last day of the experiment, 1 pig per pen was harvested and carcass characteristics, LM quality, and fat quality were determined. For the overall experimental period, no effects of dietary treatments were observed for average daily gain. However, average daily feed intake (ADFI) decreased (linear, $P < 0.05$) and gain to feed ratio (G:F) increased (linear, $P < 0.05$)

for pigs fed diets with increasing concentrations of FFRB. In contrast, ADFI increased linearly ($P < 0.05$) and G:F decreased (linear, $P < 0.05$) as DFRB was included in the diets. There were no effects of dietary treatments on LM quality. The length of the bellies decreased (linear and quadratic, $P < 0.05$) as the inclusion of FFRB or DFRB increased in the diets. The concentration of crude fat in the adipose tissue of pigs increased linearly ($P < 0.05$) as the concentration of FFRB or DFRB increased in the diets. The concentration of saturated fatty acids in the adipose tissue of pigs fed diets containing FFRB decreased (linear, $P < 0.05$), whereas the concentration of polyunsaturated fatty acids (PUFA) increased (linear, $P < 0.05$). In contrast, addition of DFRB did not affect the concentration of fatty acids in adipose tissues. In conclusion, 30% FFRB included in diets for growing-finishing pigs may improve G:F without affecting carcass characteristics or LM quality with the exception that PUFA in adipose tissues will increase. However, inclusion of DFRB in diets for growing-finishing pigs will reduce G:F without affecting the LM quality or composition of adipose tissues.

Key words: carcass characteristics, defatted rice bran, fat quality, full fat rice bran, growth, pigs

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J. Anim. Sci. 2018.96:2293–2309

doi: 10.1093/jas/sky145

INTRODUCTION

Rice bran is a coproduct of the rice milling process that is needed to produce white polished rice, which is the main food for more than 3 billion people in the world (Serna-Saldivar, 2010). Therefore, large quantities of rice bran are

¹Donation of full fat rice bran from RiceBran Technologies (Scottsdale, AZ) is appreciated.

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Received January 31, 2018.

Accepted April 14, 2018.

available for animal feeding. The concentration of crude fat ranges from 14.1% to 24.4% in full fat rice bran (FFRB) and from 3.1% to 5.4% in defatted rice bran (DFRB; Sauvante et al., 2004; Kaufmann et al., 2005; de Blas et al., 2010; NRC, 2012). Oleic acid represents approximately 40% of fatty acids in FFRB and linoleic acid and palmitic acid contribute approximately 35.9% and 18.0%, respectively (Sauvante et al., 2004). The concentration of fatty acids in diets affects the composition and fat quality of pigs (Wood et al., 2008) because the concentration of oleic and linoleic acids in pork cuts is related to a reduced melting point (Chae and Lee, 2002; Wood et al., 2008).

Inclusion of 20% FFRB or DFRB in diets for weanling pigs may improve average daily gain (ADG) and gain to feed ratio (G:F; Casas and Stein, 2016a), but effects of including FFRB or DFRB in diets for growing-finishing pigs on growth performance traits and longissimus muscle (LM) quality were inconclusive. Inclusion of 20% FFRB that was not stabilized increased ADG and G:F and had no effect on carcass yield or backfat thickness (Chae and Lee, 2002). In contrast, inclusion of 30% of FFRB decreased ADG, average daily feed intake (ADFI), and G:F (de Campos et al., 2006). Likewise, inclusion of 10% or 20% DFRB had no effect on growth performance, but inclusion of 30% increased ADFI and reduced G:F (Warren and Farrell, 1990). However, because pigs do not need feed ingredients but instead need nutrients and energy, we hypothesized that FFRB or DFRB is not detrimental to growth performance and has no negative effects on carcass characteristics, LM quality, or fat quality when fed to growing-finishing pigs provided that diets are carefully formulated using values for digestible amino acids and phosphorus.

MATERIALS AND METHODS

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois.

Animals and Housing

Two blocks of 84 and 140 pigs, respectively, for a total of 224 pigs, were allotted to 7 dietary treatments using a completely randomized block design. Pigs were the offspring of Line 359 boars mated to Camborough sows (Pig Improvement Company, Hendersonville, TN). There were 3 pens per treatment in block 1 and 5 pens per treatment in block

2 for a total of 8 pen replicates per treatment. Four pigs were housed in each pen with 2 barrows and 2 gilts in replicates 1 to 7, and 1 gilt and 3 barrows in replicate 8. Pigs had an average initial BW of 28.24 ± 4.1 kg, and pigs were housed in mechanically ventilated rooms in pens of 2.59×1.83 m to provide $1.18 \text{ m}^2/\text{pig}$. Pens had a single space dry-box feeder and a nipple drinker. The room temperature was maintained at a minimum of 18.5°C .

Diets and Feeding

Defatted rice bran was purchased from Riceland Foods (Stuttgart, AR), FFRB was donated by RiceBran Technologies (Scottsdale, AZ), and corn and soybean meal were sourced from the University of Illinois Feed Mill (Champaign, IL; Table 1).

A 3-phase feeding program was used and a basal diet containing corn and soybean meal, 3 diets containing 10%, 20%, or 30% FFRB, and 3 diets containing 10%, 20%, or 30% DFRB were formulated within each phase. Grower diets were fed from days 0 to 35 (Tables 2 and 3), early finisher diets were fed from days 36 to 70 (Tables 4 and 5), and late finisher diets were fed from days 70 to 97 (Tables 6 and 7). All diets were formulated to meet or exceed requirements for all nutrients by growing pigs (NRC, 2012). All diets contained 1,500 units per kg of phytase (Quantum Blue 5G [5,000 units per gram]; AB Vista, Marlborough, UK). Feed was provided on an ad libitum basis and water was available at all times. The amount of feed added to the feeders daily was recorded and the feed left in the feeders was recorded on the last day of each phase. Individual pig weights were recorded at the start of the experiment and at the conclusion of each phase.

Slaughter Procedures and Evisceration

On the last day of the experiment, pig weights were recorded, and 1 pig per pen was transported to the University of Illinois Meat Science Laboratory (Urbana, IL). From replicates 1, 3, 5, and 7, the gilt with a BW closest to the average for the pen was selected, whereas from replicates 2, 4, 6, and 8, the barrow with a BW closest to the pen average was selected.

After arrival to the Meat Science Laboratory, pigs were held without feed, but with free access to water, for approximately 16 h. Pig weights were recorded before slaughter to determine the ending live weight (ELW). Pigs were slaughtered using head-to-heart electrical immobilization followed by exsanguination. Weights of the heart, liver, and both kidneys were recorded. The weight of the full

Table 1. Analyzed composition of corn, soybean meal, full fat rice bran (FFRB), and defatted rice bran (DFRB), as is basis

Item	Corn	Soybean meal	FFRB	DFRB
GE, kcal/kg	3,872	4,340	4,832	3,796
DM, %	84.29	90.22	93.36	86.98
CP, %	6.33	54.87	14.36	16.47
AEE ¹ , %	3.21	0.56	18.88	2.69
Ash, %	0.68	6.35	9.23	12.27
ADF, %	2.34	4.46	11.16	9.99
NDF, %	7.44	7.39	13.85	19.22
Fatty acids ^{2,3}				
Crude fat, %	1.46	0.30	17.52	1.81 %
C14:0	0.06	0.11	0.31	0.50
C16:0	14.61	17.78	16.41	17.87
C16:1	0.15	0.14	0.18	0.24
C17:0	0.10	0.19	0.05	0.08
C18:0	1.91	4.04	1.95	1.82
C18:1	25.94	11.57	40.40	35.83
C18:2	50.95	50.45	33.46	32.35
C18:3	1.28	7.06	1.17	1.19
C20:0	0.42	0.30	0.80	0.64
C20:1	0.27	0.17	0.60	0.45
C22:0	0.19	0.40	0.45	0.78
C22:1	0.04	ND ⁴	0.06	ND
C24:0	0.27	0.30	0.92	2.25
C24:1	0.09	ND	0.03	ND
Total SFA ⁵	17.28	22.93	20.00	21.75
Total MUFA ⁶	26.40	11.88	41.24	36.52
Total PUFA ⁷	52.22	57.51	34.62	33.53
IV ⁸	114.26	116.06	96.43	90.52

¹AEE = acid hydrolyzed ether extract.

²C14:1, C15:0, C20:4, C22:5, and C22:6 were analyzed, but not detected in any ingredients.

³Fatty acids are expressed as percent of crude fat.

⁴ND = not detected.

⁵Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

⁶Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1 + C22:1.

⁷Total PUFA = C18:2 + C18:3 + C20:2 + C20:3 + C20:4 + C20:3 + C22:4 + C22:5 + C22:6.

⁸Iodine value = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785) + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of total fat (AOCS, 1998).

gastrointestinal tract (GI) was recorded immediately after evisceration. Each section of the GI tract (esophagus, stomach, small intestine, and large intestine) was rinsed with water to remove the digesta or fecal material. Mesenteric fat was also separated, and the weight of each section was recorded as described by Boler et al. (2014).

Carcass Characteristics, Fresh Loin Quality, and Fat Quality

Each carcass was weighed to determine hot carcass weight (HCW) and then stored at 4 °C for 24 h. Carcasses were split down the midline and fresh LM quality was determined on the left side of the carcass. Fat depth was measured between the 10th and

the 11th ribs, at three-fourths the distance of the LM from the dorsal side of the vertebral column. Visual color, instrumental color, ultimate pH, drip loss, cooking loss, and Warner–Bratzler shear force (WBSF) evaluation were determined by trained University of Illinois personnel. Visual color, instrumental color, and ultimate pH were measured by a single individual according to the standards established by the National Pork Producers Council (NPPC, 1991), at the surface exposed by ribbing the carcass at the 10th rib while the carcass was still suspended. Visual color was measured on the surface of the LM using a scale from 1 to 6, visual marbling was measured subjectively using a scale from 1 to 10, and firmness was scored using a subjective scale from 1 to 5. Instrumental color on the

Table 2. Ingredient and analyzed composition of grower diets containing full fat rice bran (FFRB) or defat-
ted rice bran (DFRB), as fed basis

		FFRB			DFRB		
Item	Basal	10%	20%	30%	10%	20%	30%
Ingredient, %							
Ground corn	70.18	62.32	55.22	46.24	62.36	55.77	45.91
Soybean meal	24.00	22.00	19.00	18.00	22.00	18.5	18.5
Rice coproducts	—	10.0	20.00	30.00	10.0	20.00	30.00
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
L-Lys HCl	0.27	0.29	0.34	0.33	0.28	0.34	0.27
DL-Met	0.03	0.03	0.04	0.03	0.03	0.03	0.02
L-Thr	0.06	0.07	0.09	0.09	0.06	0.08	0.05
Ground limestone	1.16	1.59	1.61	1.61	1.57	1.58	1.55
Dicalcium phosphate	0.60	—	—	—	—	—	—
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Phytase premix ¹	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin-mineral premix ²	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Analyzed composition							
DM, %	88.81	89.26	89.08	90.22	55.48	87.95	87.6
GE, kcal/kg	4,076	4,174	4,179	4,261	3,975	3,983	3,964
ME, kcal/kg ³	3,378	3,345	3,305	3,267	3,255	3,124	2,997
NE, kcal/kg ³	2,553	2,530	2,505	2,473	2,458	2,364	2,256
CP, %	18.10	17.89	16.8	17.77	17.51	17.16	17.92
AEE, % ⁴	4.41	6.07	7.54	9.23	4.69	5.23	5.43
ADF, %	2.18	3.22	3.92	4.21	3.12	3.98	4.69
NDF, %	7.45	7.95	8.58	9.32	8.22	9.67	10.09
Ash, %	5.75	4.96	5.7	6.45	5.32	6.5	6.91
Ca, %	0.70	0.71	0.80	0.61	0.97	1.06	1.03
P, %	0.47	0.54	0.68	0.82	0.55	0.71	0.89
Indispensable AA, %							
Arg	1.09	1.08	1.10	1.10	1.13	1.13	1.15
His	0.46	0.44	0.44	0.44	0.46	0.45	0.45
Ile	0.77	0.73	0.73	0.70	0.77	0.73	0.71
Leu	1.52	1.42	1.43	1.36	1.50	1.42	1.39
Lys	1.30	1.12	1.19	1.20	1.24	1.20	1.19
Met	0.29	0.27	0.33	0.28	0.27	0.28	0.29
Phe	0.89	0.84	0.82	0.79	0.86	0.82	0.80
Thr	0.78	0.76	0.68	0.69	0.70	0.69	0.65
Trp	0.21	0.22	0.22	0.21	0.20	0.20	0.21
Val	0.85	0.83	0.85	0.83	0.87	0.86	0.86
Dispensable AA, %							
Ala	0.87	0.85	0.87	0.86	0.86	0.85	0.87
Asp	1.69	1.62	1.63	1.61	1.70	1.61	1.62
Cys	0.25	0.25	0.26	0.26	0.25	0.26	0.26
Glu	3.14	2.94	2.95	2.82	3.11	2.90	2.83
Gly	0.72	0.71	0.73	0.73	0.72	0.71	0.73
Pro	1.05	0.99	1.00	0.95	1.04	0.92	0.94
Ser	0.75	0.73	0.74	0.73	0.78	0.73	0.73
Tyr	0.56	0.54	0.52	0.51	0.55	0.53	0.52

¹The phytase premix was prepared by mixing 30 g of microbial phytase [Quantum Blue 5G (5,000 units per gram); AB Vista, Marlborough, UK] with 970 g of ground corn. The premix, therefore, contains 150,000 units of phytase per kilogram, and at 1% inclusion, 1,500 units of phytase are included per kilogram of complete feed.

²The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D₃ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B₁₂, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

³ME and NE values were calculated (NRC, 2012) rather than analyzed.

⁴AEE = acid hydrolyzed ether extract.

Table 3. Concentration of crude fat and fatty acids in grower diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis

Item, %	Basal	FFRB			DFRB		
		10%	20%	30%	10%	20%	30%
Crude fat	3.44	5.32	6.53	8.36	3.7	4.01	4.47
C14:0	0.56	0.49	0.49	0.47	0.56	0.56	0.58
C14:1	ND ¹	ND	0.02	ND	ND	0.03	0.03
C16:0	18.31	17.50	17.58	17.19	17.96	17.75	18.13
C16:1	0.87	0.68	0.62	0.55	0.82	0.77	0.76
C17:0	0.23	0.18	0.16	0.14	0.23	0.20	0.20
C18:0	6.88	5.55	5.03	4.46	6.27	5.89	5.97
C18:1	28.35	31.82	34.34	35.80	30.45	31.18	32.43
C18:2	36.73	36.13	33.82	33.74	35.75	35.66	33.43
C18:3	1.57	1.43	1.36	1.36	1.37	1.36	1.28
C20:0	0.30	0.46	0.54	0.58	0.38	0.41	0.43
C20:1	0.50	0.53	0.57	0.58	0.52	0.51	0.54
C20:4	0.14	0.09	0.07	0.08	0.10	0.10	0.09
C22:0	0.14	0.22	0.28	0.31	0.22	0.27	0.33
C22:1	0.07	0.04	0.11	0.09	ND	0.08	0.10
C24:0	0.17	0.35	0.50	0.57	0.38	0.56	0.74
C24:1	ND	0.03	ND	0.03	0.03	0.03	0.03
Total SFA ²	26.48	24.43	24.13	23.19	25.66	25.13	25.69
Total MUFA ³	29.78	33.07	35.66	37.02	31.79	32.56	33.87
Total PUFA ⁴	38.43	37.65	35.25	35.18	37.22	37.12	34.81
IV ⁵	93.36	94.77	92.77	93.83	92.86	93.31	90.37

Fatty acids are expressed as percent of crude fat. Diets are also analyzed for C14:1, C15:0, C20:5, C22:5, and C22:6, but these fatty acids are not detected in any diets.

¹ND = not detected.

²Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

³Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1 + C22:1.

⁴Total PUFA = C18:2 + C18:3 + C20:2 + C20:3 + C20:4 + C20:5 + C22:4 + C22:5 + C22:6.

⁵Iodine value = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of crude fat (AOCS, 1998).

LM (L*, a*, and b*, CIE, 1978) was measured with 1 shot in center of the LM surface, taking care to avoid streaks of intramuscular fat, using a CR-400 Chroma meter (Minolta Camera Co., Ltd, Osaka, Japan) with a D65 light source and a 10° observed with an aperture size of 8 mm, using the procedure established by the National Pork Producers Council (NPPC, 1999). The longissimus muscle area (LMA) was measured by tracing the surface of the LM on a double-matted acetate paper. The images were digitized using a digitizer pad (Intuos Pro Digitizer Tablet and stylus; Wacom Technology Corporation, Vancouver, WA). Area of the LM was then measured using the magic wand tool of Adobe Photoshop CS6 (Adobe Systems Inc., San Jose, CA; (Overholt et al., 2016a). Ultimate pH was determined 24 h postmortem using a hand-held MPI pH meter fitted with a glass electrode (MPI pH meter, Topeka, KS). A section of approximately 10 cm of LM was collected from each carcass posterior to the 10th rib, and 2 chops approximately 2.5 cm thick were vacuum packaged,

aged for 14-d postmortem, and frozen and stored at −40 °C until thawed for evaluation of cooking loss, WBSF, and proximate analyses. An additional chop of 1.27 cm was used to measure drip loss. To determine drip loss, chops were weighed and suspended from a fish hook in a plastic bag for 24 h at 4 °C, and then weighed again and the difference was recorded as described previously (Boler et al., 2011). Cooking loss and WBSF were measured according to the procedure described by Overholt et al. (2016a) using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems Ltd., Godalming, UK) with a blade speed of 3.3 mm/s and a 100-kg load cell. Chops were cooked on one side to 35 °C and then flipped and cooked on the other side until they had reached an internal temperature of 70 °C. Chops were then allowed to cool to approximately 25 °C as described previously (Overholt et al., 2016a). Before proximate analyses of LM chops, subcutaneous fat tissues, and all accessory muscles were removed and then the chop was homogenized in a

Table 4. Ingredient and analyzed composition of early finisher diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis

		FFRB			DFRB		
Item	Basal	10%	20%	30%	10%	20%	30%
Ingredients, %							
Ground corn	77.05	68.56	59.68	50.87	69.64	61.65	53.17
Soybean meal	17.50	16.00	15.00	13.8	15.00	13.00	11.50
Rice coproducts	—	10.0	20.00	30.00	10.0	20.00	30.00
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
L-Lys HCl	0.24	0.24	0.22	0.21	0.26	0.26	0.25
L-Thr	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Ground limestone	1.06	1.4	1.35	1.37	1.35	1.34	1.33
Dicalcium phosphate	0.40	0.05	—	—	—	—	—
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Phytase premix ¹	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin-mineral premix ²	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Analyzed composition							
DM, %	86.09	88.17	88.43	89.33	87.23	86.25	87.33
GE, kcal/kg	4,020	4,097	4,235	4,257	4,097	4,235	4,257
ME, kcal/kg ³	3,397	3,359	3,325	3,286	3,271	3,142	3,013
NE, kcal/kg ³	2,601	2,571	2,541	2,509	2,506	2,406	2,304
CP, %	14.11	14.6	15.54	14.83	14.74	14.58	15.13
AEE ⁴ , %	4.74	6.18	7.67	9.52	4.73	5.35	5.43
ADF, %	2.81	3.32	4.11	4.42	3.82	4.65	4.75
NDF, %	8.50	9.29	10.12	9.07	8.25	10.27	10.00
Ash, %	4.13	4.88	4.23	6.26	4.82	5.61	7.01
Ca, %	0.68	0.68	0.18	0.60	0.67	0.86	0.93
P, %	0.40	0.48	0.63	0.80	0.48	0.68	0.88
Indispensable AA, %							
Arg	0.87	0.88	0.91	0.96	0.91	0.94	0.93
His	0.39	0.38	0.38	0.38	0.39	0.39	0.38
Ile	0.61	0.57	0.58	0.61	0.62	0.60	0.57
Leu	1.35	1.23	1.24	1.23	1.31	1.29	1.24
Lys	0.95	1.02	0.88	1.09	0.93	0.99	0.87
Met	0.22	0.22	0.22	0.23	0.23	0.22	0.24
Phe	0.72	0.69	0.70	0.72	0.73	0.71	0.68
Thr	0.60	0.55	0.56	0.56	0.55	0.56	0.55
Trp	0.21	0.19	0.18	0.18	0.18	0.18	0.18
Val	0.70	0.68	0.71	0.73	0.72	0.73	0.73
Dispensable AA, %							
Ala	0.78	0.76	0.78	0.78	0.79	0.79	0.80
Asp	1.33	1.29	1.29	1.32	1.32	1.31	1.25
Cys	0.22	0.22	0.24	0.23	0.24	0.23	0.25
Glu	2.63	2.42	2.43	2.39	2.53	2.47	2.36
Gly	0.61	0.62	0.64	0.64	0.64	0.65	0.66
Pro	0.95	0.90	0.87	0.87	0.94	0.85	0.87
Ser	0.64	0.62	0.63	0.60	0.61	0.61	0.60
Tyr	0.47	0.45	0.45	0.47	0.47	0.47	0.45

¹The phytase premix was prepared by mixing 30 g of microbial phytase (Quantum Blue 5G [5,000 units per gram]; AB Vista, Marlborough, UK) with 970 g of ground corn. The premix, therefore, contains 150,000 units of phytase per kilogram, and at 1% inclusion, 1,500 units of phytase are included per kilogram of complete feed.

²The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D₃ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B₁₂, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

³ME and NE values were calculated values (NRC, 2012).

⁴AEE = acid hydrolyzed ether extract.

Table 5. Concentration of crude fat and fatty acids in early finisher diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis

Item, %	Basal	FFRB			DFRB		
		10%	20%	30%	10%	20%	30%
Crude fat	3.15	4.86	6.69	8.18	3.8	3.99	3.82
C14:0	0.47	0.46	0.45	0.46	0.50	0.50	0.55
C14:1	ND ¹	ND	0.02	0.02	ND	ND	ND
C:15:0	0.04	0.05	0.04	0.05	0.05	0.05	0.05
C16:0	17.18	17.13	17.36	17.40	17.48	17.38	17.51
C:16:1	0.74	0.64	0.56	0.54	0.74	0.72	0.74
C17:0	0.21	0.17	0.16	0.13	0.20	0.20	0.19
C:18:0	6.09	5.20	4.64	4.41	5.98	5.66	5.74
C18:1	26.02	29.69	32.19	35.29	27.99	29.09	30.75
C18:2	42.14	39.50	36.89	33.81	39.62	38.18	36.26
C18:3	1.32	1.31	1.20	1.28	1.25	1.22	1.17
C20:0	0.38	0.44	0.53	0.58	0.40	0.42	0.43
C20:1	0.41	0.46	0.53	0.58	0.44	0.49	0.47
C20:4	0.09	0.08	0.07	0.06	0.10	0.09	0.09
C22:0	0.16	0.22	0.28	0.31	0.21	0.32	0.35
C22:1	0.06	0.07	ND	0.09	0.08	0.05	0.05
C24:0	0.18	0.36	0.49	0.56	0.39	0.61	0.78
C24:1	0.04	0.02	0.03	0.04	0.04	0.05	ND
Total SFA ²	24.54	23.66	23.46	23.33	24.81	24.53	24.81
Total MUFA ³	27.23	30.86	33.30	36.51	29.25	30.35	32.01
Total PUFA ⁴	43.54	40.90	38.15	35.15	40.98	39.49	37.52
IV ⁵	99.87	98.40	95.66	93.28	97.07	95.43	93.42

Fatty acids are expressed as percent of crude fat. Diets are also analyzed for C14:1, C15:0, C20:5, C22:5, and C22:6, but these fatty acids are not detected in any diets.

¹ND = not detected.

²Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

³Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1 + C22:1.

⁴Total PUFA = C18:2 + C18:3 + C20:2 + C20:3 + C20:4 + C20:5 + C22:4 + C22:5 + C22:6.

⁵Iodine value = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of crude fat (AOCS, 1998).

food processor. The remaining homogenized samples were lyophilized (Gamma 1–16 LSCplus; IMA Life North America Inc., Tonawanda, NY).

Fresh belly weights were recorded and the flop distance, width, length, and thickness of each belly were measured according to procedures described by Overholt et al. (2016b). Instrumental color of fat (L*, a*, and b*, CIE, 1978) was measured as described for LM, after peeling off the skin adjacent to the 10th rib. Efforts were made to evaluate the outer most layer of the fat tissue. Fat tissue samples were collected from each belly from the dorsal edge of the anterior end, and samples were analyzed for crude fat and fatty acids according to Overholt et al. (2016a). All 3 fat layers were included in the fat samples used to determine fatty acid profiles.

Chemical Analysis

All diets and corn, soybean meal, FFRB, and DFRB were analyzed for dry matter (Method

930.15; AOAC Int., 2007) and gross energy was analyzed using an isoperibol bomb calorimeter (Model 6300, Parr Instruments, Moline, IL) that used benzoic acid as the standard for calibration. Concentrations of crude protein (CP) were determined by combustion (Method 990.03; AOAC Int., 2007) using an Elementar Rapid N-cube Protein/Nitrogen apparatus (Elementar Americas Inc., Mt Laurel, NJ), and acid hydrolyzed ether extract (AEE) was analyzed using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY) followed by rapid determination of oil/fat utilizing high temperature solvent extraction (Procedure Am 5-04; AOCS, 2017) using an AnkomXT15 Extractor (Ankom Technology, Macedon, NY). Ash (Method 942.05; AOAC Int., 2007) was also analyzed in all diets and ingredients, and acid detergent fiber (ADF) and neutral detergent fiber (NDF) in these samples were determined using Ankom Technology methods 12 and 13, respectively (Ankom2000 Fiber

Table 6. Ingredient and analyzed composition of late finisher diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis

		FFRB			DFRB		
Item	Basal	10%	20%	30%	10%	20%	30%
Ingredients, %							
Ground corn	78.45	69.52	61.02	52.02	70.04	62.04	54.04
Soybean meal	16.50	15.50	14.00	13.00	15.00	13.00	11.00
Rice coproducts	—	10.0	20.00	30.00	10.0	20.00	30.00
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
L-Lys HCl	0.11	0.10	0.10	0.08	0.10	0.11	0.12
Ground limestone	1.04	1.18	1.18	1.20	1.16	1.15	1.14
Dicalcium phosphate	0.20	—	—	—	—	—	—
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Phytase premix ¹	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin-mineral premix ²	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Analyzed composition							
DM, %	88.57	88.98	89.36	90.01	87.59	88.63	88.33
GE, kcal/kg	3,975	4,101	4,169	4,292	3,998	4,003	3,961
ME, kcal/kg ³	3,412	3,375	3,337	3,298	3,285	3,156	3,026
NE, kcal/kg ³	2,618	2,586	2,556	2,523	2,517	2,417	2,317
CP, %	13.85	13.68	14.37	14.33	13.62	13.99	13.85
AEE ⁴ , %	4.50	5.83	7.82	9.90	4.95	4.94	4.38
NDF, %	9.61	9.47	9.96	12.48	8.50	9.40	10.92
ADF, %	2.46	3.22	3.96	4.64	3.47	4.11	4.86
Ash, %	4.42	4.53	5.44	5.89	4.23	4.56	5.87
Ca, %	0.69	0.69	0.63	0.73	0.61	0.70	0.77
P, %	0.36	0.49	0.66	0.80	0.50	0.69	0.86
Indispensable AA, %							
Arg	0.86	0.89	0.89	0.94	0.91	0.89	0.88
His	0.37	0.37	0.37	0.38	0.38	0.37	0.36
Ile	0.59	0.59	0.56	0.57	0.58	0.57	0.53
Leu	1.21	1.19	1.14	1.17	1.19	1.12	1.09
Lys	0.84	0.83	0.85	0.85	0.83	0.83	0.77
Met	0.21	0.21	0.22	0.24	0.22	0.22	0.22
Phe	0.69	0.69	0.67	0.69	0.69	0.66	0.61
Thr	0.51	0.51	0.50	0.52	0.52	0.50	0.48
Trp	0.19	0.17	0.18	0.19	0.18	0.18	0.18
Val	0.68	0.69	0.69	0.71	0.70	0.67	0.68
Dispensable AA, %							
Ala	0.73	0.73	0.73	0.78	0.75	0.74	0.73
Asp	1.32	1.32	1.28	1.32	1.32	1.26	1.19
Cys	0.22	0.22	0.23	0.24	0.22	0.22	0.22
Glu	2.46	2.40	2.29	2.33	2.42	2.23	2.13
Gly	0.61	0.63	0.63	0.65	0.64	0.64	0.60
Pro	0.90	0.87	0.84	0.84	0.88	0.84	0.81
Ser	0.60	0.59	0.58	0.61	0.61	0.58	0.54
Tyr	0.44	0.45	0.44	0.43	0.44	0.43	0.39

¹The phytase premix was prepared by mixing 30 g of microbial phytase (Quantum Blue 5G [5,000 units per gram]; AB Vista, Marlborough, UK) with 970 g of ground corn. The premix, therefore, contains 150,000 units of phytase per kilogram, and at 1% inclusion, 1,500 units of phytase are included per kilogram of complete feed.

²The vitamin-micromineral premix provided the following quantities of vitamins and micro-minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D₃ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B₁₂, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

³ME and NE values were calculated values (NRC, 2012).

⁴AEE = acid hydrolyzed ether extract.

Table 7. Concentration of crude fat and fatty acids in late finisher diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis

Items, %	Basal	FFRB			DFRB		
		10%	20%	30%	10%	20%	30%
Crude fat	2.93	4.29	6.03	7.88	3.0	2.61	2.7
C14:0	0.44	0.44	0.45	0.45	0.51	0.50	0.57
C:15:0	0.06	0.05	0.05	0.04	0.06	0.05	0.06
C16:0	18.01	17.66	17.75	16.80	17.76	17.47	18.51
C16:1	0.71	0.62	0.57	0.51	0.76	0.75	0.80
C17:0	0.20	0.16	0.15	0.13	0.21	0.19	0.21
C18:0	5.91	5.02	4.61	4.22	5.69	5.49	6.13
C18:1	28.61	31.60	33.81	35.44	29.33	29.93	31.06
C18:2	38.66	36.85	34.30	34.94	38.11	38.13	34.71
C18:3	1.40	1.33	1.23	1.13	1.34	1.34	1.27
C20:0	0.34	0.47	0.57	0.65	0.47	0.38	0.39
C20:1	0.41	0.51	0.55	0.57	0.48	0.46	0.50
C20:4	0.09	0.08	0.06	0.06	0.10	0.10	0.09
C22:0	0.16	0.23	0.29	0.34	0.25	0.19	0.24
C22:1	0.06	0.08	0.06	0.07	0.06	0.06	0.04
C24:0	0.20	0.39	0.50	0.59	0.33	0.41	0.57
C24:1	ND ¹	0.04	0.04	0.03	ND	0.04	ND
Total SFA ²	25.12	24.02	23.87	22.62	24.93	24.27	26.11
Total MUFA ³	29.79	32.80	34.98	36.59	30.63	31.20	32.39
Total PUFA ⁴	40.15	38.26	35.59	36.13	39.55	39.57	36.07
IV ⁵	96.28	95.52	92.71	94.94	95.88	96.40	91.30

Fatty acids are expressed as percent of crude fat. Diets are also analyzed for C14:1, C15:0, C20:5, C22:5, and C22:6, but these fatty acids are not detected in any diets.

¹ND = not detected.

²Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

³Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1 + C22:1.

⁴Total PUFA = C18:2 + C18:3 + C20:2 + C20:3 + C20:4 + C20:3 + C22:4 + C22:5 + C22:6.

⁵Iodine value = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785) + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of crude fat (AOCS, 1998).

Analyzer, Ankom Technology, Macedon, NY). Diets also were analyzed for Ca and P using inductively coupled plasma spectroscopy (Method 985.01 A, B, and C; AOAC Int., 2007) and for amino acids [Method 982.30 95 E (a, b, c)].

The concentration of moisture in LM chops was determined by drying duplicate samples of 10 g of the fresh homogenized LM chop in an oven at 110 °C for at least 24 h (Boler et al., 2014). The fat content of the LM was determined in the lyophilized sample by rapid determination of oil/fat utilizing high temperature solvent extraction (Procedure Am 5-04; AOCS, 2017) using an AnkomXT15 Extractor (Ankom Technology, Macedon, NY). Crude fat was also determined in diets, ingredients, and belly samples by ether extraction (Method 920.39 (A); AOAC Int., 2007). Methyl esters of fatty acids were extracted from diets, ingredients, and belly samples (Method Ce-266; AOCS, 2017), and the concentration of fatty acids in these samples was measured using capillary gas liquid chromatography (Method 996.06; AOAC Int., 2007).

Calculation and Statistical Analysis

The standardized fat free lean (SFFL) was calculated using the equation developed by Burson and Berg (2001): SFFL, % = [(8.588 + (0.465 × (0.465 × HCW, lb) – (21.896 × 10th rib backfat, inch) + (3.005 × 10th LMA, inch²)) ÷ HCW, lb) × 100. Iodine values (IV) were calculated from the fatty acid profiles using the AOCS (1998) equation: IV = [16:1 (0.95) + 18.1 (0.86) + 18.2 (1.732) + 18:3 (2.616) + 20:1 (0.785) + 22:1 (0.723)].

Data were summarized to calculate ADG, ADFI, and G:F. Percentage of organs were calculated by dividing the weight of the organ by ELW and multiplied by 100. Outliers were identified and removed using the PROC BOXPLOT option of SAS (SAS Institute Inc., Cary, NC). Normality of data among treatments was confirmed using the UNIVARIATE procedure. Data were analyzed using the MIXED procedure of SAS with a model that included diet as main effect and block

and replicate within block as random effects. Mean values were calculated using the LSMeans statement. Contrast statements were used to determine the linear and quadratic effects of inclusion level of FFRB or DFRB on all response variables using appropriate coefficients for equally spaced treatments. A contrast statement was also used to compare values between FFRB and DFRB. The pen was the experimental unit for all analyses and an α value of 0.05 was used to assess significance among means; tendencies were considered at $0.05 \leq P < 0.10$.

RESULTS

Growth Performance

The analyzed composition of all diets conducted with calculated values. The final BW of pigs was not affected by dietary treatments in any of the 3 phases (Table 8). In all phases, ADFI was greater ($P < 0.05$) and G:F was less ($P < 0.05$) in pigs fed diets containing DFRB than in pigs fed diets containing FFRB. During the grower phase, increased inclusion of FFRB or DFRB did not affect ADFI or ADG, but G:F tended (linear,

$P = 0.079$) to decrease as the inclusion of DFRB increased in the diet. In the early finisher phase, the ADFI of pigs fed diets containing FFRB tended to increase at the 10% inclusion level and then tended to decrease at greater inclusion levels (quadratic, $P = 0.083$). In contrast, the ADFI of pigs fed diets containing DFRB increased (linear, $P < 0.05$) as the inclusion of DFRB increased in the diet. The ADG was not affected by treatment in the early finisher phase, but G:F decreased (linear, $P < 0.05$) as the inclusion of DFRB increased in the diets.

The ADFI in the late finisher phase decreased (linear, $P < 0.05$) as the inclusion of FFRB increased, whereas ADFI of pigs fed diets containing DFRB decreased at 10% inclusion and then increased (quadratic, $P < 0.05$). The ADG of pigs fed diets containing DFRB tended to decrease linearly ($P = 0.064$) as the inclusion of DFRB increased in the diets. The G:F for pigs fed diets containing FFRB tended to increase linearly ($P = 0.061$), whereas G:F in pigs fed diets containing DFRB increased at 10% inclusion, and then decreased (quadratic, $P < 0.05$).

Table 8. Growth performance of pigs fed basal diet or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)

Item	Diets							SEM	<i>P</i> -value				FFRB vs. DFRB
	Basal	FFRB			DFRB				FFRB		DFRB		
	—	10%	20%	30%	10%	20%	30%		Linear	Quad ¹	Linear	Quad ¹	
Growing, days 0 to 35													
Initial BW, kg	27.8	28.0	28.3	28.1	28.3	28.2	28.1	1.76	0.855	0.907	0.903	0.855	0.964
ADFI, kg	1.79	1.81	1.74	1.68	1.82	1.96	1.88	0.08	0.149	0.543	0.159	0.406	0.008
ADG, kg	0.856	0.833	0.836	0.820	0.832	0.882	0.851	0.03	0.345	0.864	0.753	0.900	0.211
G:F	0.477	0.462	0.484	0.489	0.462	0.451	0.454	0.01	0.209	0.314	0.079	0.353	0.008
Final BW, kg	57.9	57.3	57.7	56.9	57.5	58.1	58.0	1.93	0.773	0.974	0.913	0.938	0.721
Early finishing, days 36 to 70													
ADFI, kg/d	2.69	2.81	2.67	2.58	2.73	2.97	2.87	0.13	0.110	0.083	0.005	0.258	0.001
ADG, kg	1.00	1.04	1.02	1.00	0.98	1.02	0.99	0.02	0.863	0.192	0.820	0.809	0.283
G:F	0.374	0.371	0.383	0.387	0.358	0.347	0.346	0.02	0.142	0.629	0.006	0.292	<0.001
Final BW, kg	92.8	93.6	93.4	91.8	91.6	93.9	92.6	2.19	0.753	0.590	0.855	0.978	0.912
Late finishing, days 71 to 97													
ADFI, kg/d	3.52	3.45	3.23	3.22	3.25	3.44	3.71	0.31	0.007	0.723	0.067	0.004	0.028
ADG, kg	1.02	1.02	1.03	1.00	1.00	0.98	0.93	0.02	0.821	0.574	0.064	0.533	0.083
G:F	0.291	0.300	0.322	0.311	0.311	0.291	0.259	0.04	0.061	0.315	0.010	0.009	0.004
Final BW, kg	120.0	120.9	121.1	118.6	118.4	120.3	117.4	2.34	0.703	0.472	0.581	0.791	0.437
Overall, days 0 to 97													
ADFI, kg/d	2.60	2.61	2.49	2.42	2.54	2.73	2.73	0.13	0.009	0.430	0.019	0.684	0.001
ADG, kg	0.95	0.96	0.96	0.93	0.93	0.95	0.92	0.02	0.471	0.362	0.364	0.838	0.253
G:F	0.368	0.370	0.386	0.388	0.367	0.349	0.342	0.02	0.007	0.987	0.001	0.607	<0.001

Data are least squares means of 8 observations for all diets.

¹Quad = quadratic effect.

For the overall phase, ADG was not affected by dietary treatments, but ADFI decreased (linear, $P < 0.05$) and G:F increased linearly ($P < 0.05$) in pigs fed diets containing increasing levels of FFRB. In contrast, for pigs fed diets containing increasing levels of DFRB, ADFI increased linearly ($P < 0.05$), but G:F decreased (linear, $P < 0.05$).

Organ Weights

The weight or percentage of the esophagus, stomach, small intestine, mesenteric fat, or heart was not affected by dietary treatments (Table 9), but the weight and percentage of the full GI tract, gut fill, and of the large intestine were greater ($P < 0.05$) in pigs fed diets containing DFRB than

in pigs fed diets containing FFRB. Also, the weight of liver and the percentage of kidneys tended to increase if pigs were fed diets containing up to 20% DFRB, but then decreased at 30% inclusion (quadratic, $P = 0.078$ and 0.062 ; respectively), but the percentage of liver increased (linear and quadratic, $P < 0.05$) as the inclusion of DFRB increased in the diets.

Carcass Characteristics and Loin and Fat Composition

There were no effects of dietary treatments on ELW, HCW, LMA, 10th rib back fat, or SFFL (Table 10). Carcass yield tended (linear, $P = 0.071$) to decrease as DFRB increased in the diets. Values for

Table 9. Organs weights for pigs fed basal diet or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)

Item	Diets							P-value					
	Basal	FFRB			DFRB			SEM	FFRB		DFRB		FFRB vs. DFRB
	—	10%	20%	30%	10%	20%	30%		Linear	Quad ¹	Linear	Quad ¹	—
Full GI ² tract, kg	7.521	6.830	7.433	7.480	7.797	8.178	7.871	0.295	0.670	0.148	0.208	0.250	0.001
Full GI tract, % ³	6.577	5.960	6.575	6.621	6.746	7.189	6.808	0.268	0.448	0.136	0.250	0.214	0.005
Gut fill, kg ⁴	2.175	1.756	2.207	2.223	2.265	2.695	2.463	0.222	0.486	0.255	0.133	0.399	0.010
Gut fill, %	1.919	1.546	1.973	1.967	1.957	2.369	2.134	0.201	0.453	0.282	0.169	0.422	0.023
Esophagus, kg	0.077	0.072	0.075	0.069	0.078	0.080	0.069	0.006	0.405	0.953	0.374	0.287	0.433
Esophagus, %	0.067	0.063	0.066	0.061	0.068	0.071	0.060	0.005	0.450	0.952	0.315	0.229	0.531
Stomach, kg	0.606	0.575	0.576	0.535	0.609	0.624	0.547	0.035	0.167	0.889	0.286	0.245	0.265
Stomach, %	0.530	0.503	0.510	0.476	0.530	0.551	0.475	0.03	0.248	0.899	0.279	0.204	0.359
Small intestine, kg	1.647	1.492	1.648	1.588	1.640	1.620	1.534	0.09	0.955	0.564	0.333	0.637	0.747
Small intestine, %	1.444	1.298	1.465	1.416	1.425	1.433	1.332	0.078	0.801	0.517	0.335	0.587	0.950
Large intestine, kg	1.645	1.631	1.542	1.637	1.730	1.702	1.770	0.072	0.720	0.441	0.274	0.898	0.027
Large intestine, %	1.437	1.428	1.362	1.461	1.499	1.507	1.539	0.061	0.982	0.379	0.254	0.801	0.054
Mesenteric fat, kg	1.351	1.283	1.366	1.407	1.457	1.438	1.468	0.132	0.585	0.597	0.473	0.714	0.230
Mesenteric, fat, %	1.177	1.120	1.196	1.237	1.264	1.256	1.266	0.115	0.512	0.574	0.506	0.661	0.278
Heart, kg	0.331	0.354	0.331	0.340	0.331	0.339	0.344	0.011	0.949	0.509	0.312	0.754	0.644
Heart, %	0.289	0.310	0.294	0.302	0.288	0.300	0.299	0.009	0.581	0.446	0.322	0.988	0.345
Liver, kg	1.568	1.630	1.675	1.619	1.685	1.789	1.682	0.064	0.482	0.347	0.114	0.078	0.131
Liver, %	1.371	1.423	1.481	1.432	1.466	1.579	1.460	0.044	0.205	0.237	0.049	0.015	0.107
Kidneys, kg	0.386	0.390	0.380	0.367	0.389	0.408	0.366	0.015	0.280	0.554	0.511	0.114	0.431
Kidneys, %	0.337	0.340	0.338	0.325	0.339	0.361	0.317	0.013	0.440	0.483	0.475	0.062	0.628

Data are least squares means of 8 observations for all diets.

¹Quad = quadratic effect.

²GI = gastrointestinal tract.

³Percent of ending live weight.

⁴Gut fill = full intestinal tract wt – (empty small intestine + empty large intestine + empty stomach + esophagus + mesenteric fat).

Table 10. Carcass characteristics of pigs fed basal diet or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)

Item	Diets							P-value					
	Basal	FFRB			DFRB			SEM	FFRB		DFRB		FFRB vs. DFRB
		10%	20%	30%	10%	20%	30%		Linear	Quad ¹	Linear	Quad ¹	
ELW ² , kg	114.48	114.45	112.94	112.83	115.07	113.34	115.27	2.619	0.425	0.981	0.935	0.711	0.434
HCW, kg	90.78	90.72	89.27	88.56	90.41	87.83	90.61	2.267	0.269	0.842	0.669	0.333	0.944
Carcass yield, %	79.31	79.29	78.76	78.81	78.87	78.12	78.63	0.433	0.195	0.919	0.071	0.185	0.161
LM area, cm ¹	54.48	55.19	56.39	53.74	54.39	52.12	55.43	2.552	0.901	0.360	0.943	0.354	0.451
10th-rib fat depth, cm	1.60	1.50	1.47	1.73	1.45	1.45	1.61	0.219	0.638	0.337	0.964	0.397	0.657
Standardized fat free lean ³ , %	56.61	57.21	58.38	56.16	57.33	57.21	56.83	1.261	0.967	0.154	0.903	0.572	0.874
Back fat L*	75.07	74.99	75.07	74.44	75.25	74.86	75.82	1.119	0.357	0.538	0.346	0.372	0.186
Back fat a* ⁵	4.96	4.95	4.59	4.62	4.74	5.07	4.57	0.411	0.354	0.952	0.569	0.672	0.789
Back fat b* ⁴	4.19	3.60	3.87	3.49	4.08	3.65	3.43	0.449	0.095	0.674	0.015	0.821	0.744
Back fat Lightness, L* ⁴	75.07	74.99	75.07	74.44	75.25	74.86	75.82	1.119	0.357	0.538	0.346	0.372	0.186

Data are least squares means of 8 observations for all diets.

¹Quad = quadratic effect.

²ELW = ending live weight.

³Standardized fat free lean = $\{[8.588 + (0.465 \times \text{HCW, lb}) - (21.896 \times 10^{\text{th-rib fat depth, in}}) + (3.005 \times 10^{\text{th-rib LMA, in}^2})] / \text{HCW} \times 100$ (Burson and Berg, 2001).

⁴L* = measure of lightness (greater value indicates a lighter color), a* = measure of redness (greater value indicates a redder color), and b* = measure of yellowness (greater value indicates a more yellow color).

L* and a* in back fat were not affected by inclusion of FFRB or DFRB in the diets, but b* decreased as the inclusion of DFRB increased in the diets (linear, $P < 0.05$) and tended (linear, $P = 0.095$) to decrease as FFRB was included in the diets.

Marbling score decreased (linear, $P < 0.05$) as the inclusion of FFRB or DFRB increased in the diets, but loins from pigs fed diets containing DFRB had greater ($P < 0.05$) marbling scores than pigs fed diets containing FFRB (Table 11). The L* values in loins from pigs fed diets containing DFRB tended to increase at 20% of inclusion, but decreased at 30% inclusion (quadratic, $P = 0.085$), and the L* values were greater ($P < 0.05$) for pigs fed diets containing DFRB than for pigs fed diets containing FFRB. Likewise, the percentage of cooking loss was greater ($P < 0.05$) in LM from pig fed diets containing DFRB than for pigs fed diets containing FFRB. There were no effects of dietary treatments on percentage of water and ash, but the percentage of protein increased (linear, $P < 0.05$) as FFRB or DFRB increased in the diet. In contrast, the percentage of lipids in LM decreased (linear, $P < 0.05$) as FFRB or DFRB increased in the diets.

There were no effects of treatments on weight, width, or thickness of bellies or on instrumental color of fat in bellies (Table 12). However, the length of the bellies decreased (linear, $P < 0.05$) as the inclusion of FFRB increased in the diets, whereas the length of bellies decreased at 10% inclusion of DFRB, but increased at 20% (quadratic, $P < 0.05$). Likewise, the flop distance of bellies from pigs fed diets containing FFRB or DFRB increased until 20% inclusion and then decreased (quadratic, $P < 0.05$).

Fatty Acid Profile of Belly Adipose Tissues

The concentration of crude fat in bellies increased (linear, $P < 0.05$) as the inclusion of FFRB or DFRB increased in the diets (Table 13). The concentration of crude fat tended ($P = 0.07$) to be greater in adipose tissues from pigs fed diets containing DFRB than in pigs fed diets containing FFRB.

The concentration of C14:0, C16:0, C16:1, C17:0, C18:0, C18:1, total SFA, and total MUFA decreased (linear, $P < 0.05$) and the concentration of C18:2, C18:3, and polyunsaturated fatty acids (PUFA) increased (linear, $P < 0.05$) as the inclusion

Table 11. Loin quality of growing pigs fed basal diets or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)

Item	Diets								P-value				
	Basal	FFRB			DFRB			SEM	FFRB		DFRB		FFRB vs. DFRB
		10%	20%	30%	10%	20%	30%		Linear	Quad ¹	Linear	Quad ¹	
Color ²	2.44	2.44	2.31	2.13	2.19	1.94	2.13	0.174	0.178	0.592	0.133	0.214	0.149
Marbling ²	1.88	1.13	1.13	1.00	1.50	1.50	1.25	0.176	0.002	0.082	0.021	0.724	0.025
Firmness ³	2.50	2.13	1.63	2.13	2.25	2.00	2.00	0.298	0.217	0.139	0.184	0.669	0.601
L* ⁴	50.46	50.26	51.01	50.04	51.89	54.09	51.55	1.678	0.921	0.735	0.283	0.085	0.029
a* ⁴	9.56	10.20	9.95	10.06	9.55	9.04	9.63	0.652	0.567	0.582	0.896	0.546	0.101
b* ⁴	2.28	2.40	2.01	1.73	2.27	2.53	2.35	0.531	0.348	0.671	0.817	0.861	0.395
Ultimate pH	5.60	5.61	5.57	5.57	5.58	5.56	5.55	0.093	0.257	0.981	0.110	0.865	0.363
Drip loss, %	3.49	3.23	3.40	3.97	3.42	3.84	4.69	0.65	0.584	0.523	0.173	0.481	0.397
Cook loss, %	26.04	24.85	25.12	24.53	26.74	27.61	28.14	0.988	0.365	0.765	0.131	0.932	0.002
WBSF ⁵ , kg	3.24	3.05	2.96	2.94	3.05	3.02	3.22	0.219	0.324	0.708	0.926	0.390	0.540
Moisture, %	73.61	73.48	73.99	73.80	73.18	73.62	73.75	0.232	0.307	0.910	0.411	0.229	0.212
Protein, %	23.38	24.32	24.49	25.01	24.48	24.41	25.32	0.884	0.023	0.664	0.010	0.848	0.743
Lipid, %	2.36	2.07	1.61	1.74	2.33	1.99	1.64	0.203	0.014	0.295	0.008	0.421	0.280
Ash, %	2.59	2.39	2.21	2.34	2.34	2.41	2.35	0.151	0.130	0.210	0.283	0.458	0.638

Data are least squares means of 8 observations for all diets.

¹Quad = quadratic effect.

²National Pork Producers Council (1999). NPPC color (1 = pale pink to 6 = dark purplish red). NPPC marbling (1 = 1% intramuscular lipid to 10 = ≥10% intramuscular lipid).

³National Pork Producers Council (1991). NPPC firmness (1 = very soft to 5 = very firm).

⁴L* = measure of lightness (greater value indicates a lighter color), a* = measure of redness (greater value indicates a redder color), and b* = measure of yellowness (greater value indicates a more yellow color).

⁵WBSF = Warner–Bratzler shear force.

Table 12. Characteristics of bellies from pigs fed basal diet or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)

Item	Diets								P-value				
	Basal	FFRB			DFRB			SEM	FFRB		DFRB		FFRB vs. DFRB
		10%	20%	30%	10%	20%	30%		Linear	Quad ¹	Linear	Quad ¹	
Belly wt, kg	6.24	5.93	6.32	5.94	6.02	6.58	6.19	0.204	0.589	0.860	0.645	0.680	0.239
Belly length, cm	68.89	66.51	66.06	66.16	64.16	66.13	66.03	1.149	0.025	0.145	0.084	0.008	0.245
Belly width, cm	27.69	26.83	28.16	26.67	27.27	28.07	26.96	0.451	0.400	0.485	0.492	0.443	0.568
Belly thickness, cm, ²	2.83	2.77	3.11	2.99	3.14	3.25	3.12	0.184	0.326	0.882	0.236	0.246	0.162
Flop distance, cm	7.53	8.58	11.91	7.75	10.11	12.58	7.88	1.45	0.450	0.032	0.507	0.003	0.423

Data are least squares means of 8 observations for all diets.

¹Quad = quadratic effect.

²Thickness is the average of measurements measured at 8 locations from the anterior to posterior, with 4 measurements on each of the dorsal and ventral edges.

of FFRB increased in the diets, but this was not the case if the inclusion of DFRB increased. The concentration of C14:0, C14:1, C16:0, C16:1, C18:0, C18:1, and total SFA was greater ($P < 0.05$) in bellies from pigs fed diets containing DFRB compared with pigs fed diets containing FFRB, but the concentration of C:18:2, C:18:3, and total PUFA

was greater ($P < 0.05$) in bellies from pigs fed diets containing FFRB than in pigs fed diets containing DFRB. The IV of belly fat increased (linear, $P < 0.05$) as the inclusion of FFRB increased in the diet and the IV was greater in belly fat from pigs fed diets containing FFRB compared with pigs fed diets containing DFRB.

Table 13. Fatty acid profile of belly adipose tissue (% of total fat) of pig fed basal diets or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)

Item	Diets								<i>P</i> -value				FFRB vs. DFRB
	Basal	FFRB			DFRB			SEM	FFRB		DFRB		
		10%	20%	30%	10%	20%	30%		Linear	Quad ¹	Linear	Quad	
Crude fat	74.07	71.56	78.08	81.47	78.55	82.05	81.35	3.43	0.007	0.198	0.025	0.292	0.070
C14:0	1.21	1.21	1.09	1.06	1.24	1.18	1.25	0.043	0.002	0.646	0.750	0.606	0.002
C15:0	0.07	0.05	0.07	0.06	0.08	0.06	0.06	0.006	0.886	0.616	0.269	0.351	0.266
C16:0	22.89	21.92	19.89	19.85	22.20	21.62	21.80	0.404	<0.001	0.229	0.036	0.274	<0.001
C16:1	2.18	1.78	1.63	1.36	2.20	1.87	2.07	0.210	<0.001	0.373	0.054	0.240	<0.001
C17:0	0.48	0.36	0.38	0.30	0.44	0.44	0.39	0.027	<0.001	0.426	0.018	0.675	<0.001
C18:0	11.30	11.35	9.30	8.97	10.39	11.03	10.74	0.719	<0.001	0.641	0.582	0.457	0.015
C18:1	44.13	42.26	42.65	41.98	43.85	44.50	44.11	1.548	0.016	0.273	0.812	0.920	0.000
C18:2	13.05	16.33	19.90	21.39	14.52	14.36	14.32	1.063	<0.001	0.229	0.275	0.309	<0.001
C18:3	0.47	0.56	0.68	0.72	0.51	0.49	0.49	0.036	<0.001	0.494	0.823	0.526	<0.001
C20:0	0.18	0.23	0.21	0.21	0.19	0.21	0.20	0.011	0.086	0.044	0.070	0.432	0.070
C20:1	0.84	0.80	0.82	0.83	0.85	0.86	0.86	0.030	0.878	0.355	0.606	0.993	0.108
C20:4	0.30	0.33	0.37	0.33	0.33	0.33	0.34	0.021	0.104	0.073	0.191	0.476	0.534
C22:5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.003	0.446	0.802	0.458	0.909	0.710
Total SFA ²	36.17	35.16	30.99	30.50	34.63	34.57	34.86	1.091	<0.001	0.734	0.241	0.228	<0.001
Total MUFA ³	47.19	44.88	45.13	44.31	46.94	47.31	47.08	1.780	0.003	0.215	0.986	0.982	<0.001
Total PUFA ⁴	13.89	17.29	21.03	22.51	15.45	15.25	15.22	1.102	<0.001	0.229	0.286	0.317	<0.001
IV ⁵	64.58	68.47	75.16	77.14	67.02	66.96	66.72	1.140	<0.001	0.406	0.219	0.244	<0.001

Data are least squares means of 8 observations for all diets. C14:1, C20:5, C22:0, C22:1, C22:1, C22:6, C24:0, and C24:1 are analyzed, but concentrations are below 0.03% in all samples.

¹Quad = quadratic effect.

²Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

³Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1n9 + C22:1.

⁴Total PUFA = C18:2 + C18:3 + C18:3 + C20:2 + C20:3 + C20:4 + C20:3 + C22:4 + C22:5 + C22:6.

⁵IV = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of crude fat (AOCS, 1998).

DISCUSSION

Chemical Composition of Ingredients

The analyzed proximate composition of corn and soybean meal concurs with reported values, except for the concentration of CP in soybean meal, which was greater than reported by NRC (2012). Likewise, concentrations of CP, ash, NDF, and ADF in FFRB and DFRB were within the range of reported values (Sauvant et al., 2004; NRC, 2012; Casas and Stein, 2017), and concentrations of most fatty acids in all ingredients were within the range of reported values (NRC, 2012; Lee et al., 2013).

Rice bran contains pericarp, seed coat, germ, and aleurone layers of rice, which are the fractions of the grain that contain most of the lipids (Juliano, 1983; Zhou et al., 2002). Lipids in the bran may be extracted from FFRB using expeller or chemical processes to produce rice oil and DFRB (Serna-Saldivar, 2010). The concentration

of acid hydrolyzed ether extract in FFRB used in this experiment was 18.8%, which is slightly greater than previously reported (Sauvant et al., 2004; NRC, 2012; Casas and Stein, 2017), whereas the concentration of acid hydrolyzed ether extract in DFRB was 2.6%, which is less than reported values (Sauvant et al., 2004; Rostagno et al., 2011). Variation in the content of fat in FFRB is a result of differences in the quality of rice milling, and different types of milling may result in different concentrations of starch from the endosperm in FFRB and DFRB (Juliano, 1983; Saunders, 1985; Rosniyana et al., 2007). The process used for extraction of oil from FFRB also affects the concentration of fat in DFRB because solvent extraction of fat results in less residual fat in DFRB compared with DFRB produced from mechanical extraction of fat (Saunders, 1985; Serna-Saldivar, 2010). Rice oil contains approximately 41% and 34% MUFA and PUFA, respectively (Juliano, 1983; Saunders, 1985; Faria et al., 2012), and the high concentration

of MUFA and PUFA and the presence of lipases and oxidases cause rapid oxidation of fat in FFRB if it is not stabilized immediately after production (Saunders, 1985; Rosniyana et al., 2009). Stabilization of FFRB is usually achieved by dry heating, extrusion, or cooking (Saunders, 1985; Chae and Lee, 2002; Faria et al., 2012; Thanonkaew et al., 2012). The FFRB used in this experiment was stabilized by heating to prevent oxidation of oil.

Growth Performance

To the best of our knowledge, no previous experiments have evaluated growth performance of pigs fed either FFRB or DFRB over the entire growing-finishing period, although data for the growing period (Warren and Farrell, 1990) or the finishing period (Chae and Lee, 2002; de Campos et al., 2006) have been reported. However, the present results indicate that responses to inclusion of FFRB or DFRB in diets for growing-finishing pigs are primarily related to the ME of the diets. Thus, the linear reduction in ADFI and the increased G:F that was observed as FFRB increased in the diets is likely a result of the greater ME in FFRB than in corn and soybean meal (Casas and Stein, 2017), which resulted in greater ME in the diets as FFRB inclusion increased. It is also possible that the greater concentration of fat in diets containing FFRB increased the digestibility of other nutrients (Cervantes-Pahm and Stein, 2008). Likewise, the increased ADFI and reduced G:F by pigs fed diets containing DFRB are likely a result of the reduced ME of DFRB compared with corn and soybean meal (Casas and Stein, 2017) with a subsequent reduction in ME of the diets as DFRB inclusion increased. Results obtained in this experiment are in agreement with results for growth performance of weanling pigs fed diets containing FFRB or DFRB (Casas and Stein, 2016b) and indicate that FFRB or DFRB does not affect ADG of pigs. However, due to differences in ME among FFRB, DFRB, corn, and soybean meal, ADFI and G:F will be affected by the inclusion of FFRB or DFRB in the diets.

Organ Weights, Carcass Characteristics, and Loin and Fat Quality

Weights of the organs observed in this experiment were less than reported from previous experiments (Casas et al., 2009; Boler et al., 2014), but in agreement with data reported by Overholt et al. (2016a). However, the weight of the organs such

as heart, liver, lungs, and kidneys depends on the BW of the pigs, whereas the weight of the stomach, small intestine, and large intestine is also influenced by feed intake and concentration of fiber in the diet (van Milgen and Noblet, 2003). Thus, the increased weight of the large intestine of pigs fed diets containing DFRB was likely a result of the greater feed intake by those pigs. Chae and Lee (2002) reported no effects on carcass yield or back fat thickness of feeding diets containing 20% FFRB compared with pigs fed a control diet containing DFRB, corn, and animal fat, and data from this experiment are in agreement with this observation.

The proximate composition of LM that was determined in this experiment concurs with data from previous studies (Kim et al., 2008; Boler et al., 2014). However, the decrease in the concentration of fat in LM that was observed in this experiment as FFRB or DFRB was included in the diets is in contrast with previous data indicating an increased concentration of fat in cuts from forelegs of pigs fed diets containing 30% FFRB (de Campos et al., 2006). Differences in lipid and carbohydrate metabolism in the muscle fibers of the LM compared with forelegs muscle may explain the difference between this study and previous data (Leseigneur-Meynier and Gandemer, 1991; Monziols et al., 2007). Likewise, no effects on pH of loin chops were reported as FFRB was added to diets for finishing pigs (de Campos et al., 2006) and a similar observation was made in this experiment. Thus, it appears that FFRB or DFRB may be included in diets for growing-finishing pigs without influencing carcass characteristics or LM quality.

Fatty Acid Profile of Belly Adipose Tissues

The belly represents 12.0% to 16.7% of the carcass weight of pigs and is the most valuable cut in the United States because of the high value of bacon (Soladoye et al., 2015). The quality of the belly is influenced by concentration and composition of dietary fat (Rosenvold and Andersen, 2003; Wood et al., 2008). Greater concentration of unsaturated fatty acids results in softer bellies, reduced slicing efficiency, and shorter shelf life (Kloareg et al., 2007; Soladoye et al., 2015). However, for health reasons, consumers prefer less saturated fat and more unsaturated fatty acids (Shackelford et al., 1990; Webb and O'Neill, 2008).

Values for belly weight, length, and thickness observed in this experiment are within the range of previous data (Overholt et al., 2016b). The drop in the flop distance observed when pigs were fed diets containing

30% FFRB or DFRB is likely a result of the greater concentrations of PUFA in the adipose tissue.

The concentration of fat in FFRB is greater than in corn and DFRB, and increased inclusion of FFRB in the diets, therefore, increased the concentration of fat and total concentration of fatty acids in the bellies. Pigs are able to synthesize SFA and MUFA *de novo*, but they do not synthesize PUFA (Shackelford et al., 1990; Kloareg et al., 2007). As a consequence, even though diets had different concentrations of crude fat, the concentration of fat in the bellies was not different. *De novo* synthesis of fat is likely the reason pigs fed diets containing DFRB had a greater concentration of SFA and MUFA, specifically C18:0 and C18:1, compared with pig fed FFRB. However, because FFRB contains more C18:2 and C18:3, the adipose tissue of pigs fed diets FFRB had increased concentration of PUFA. Results observed in this experiment concur with data reported by de Campos et al. (2006) for pigs fed diets containing 30% FFRB.

In conclusion, 30% FFRB included in diets for growing-finishing pigs may improve G:F of pigs without affecting carcass characteristics or LM quality with the exception that concentration of PUFA in bellies will increase. However, inclusion of DFRB in diets will reduce G:F without affecting LM quality or composition of the bellies. The differences in results between FFRB and DFRB are primarily a consequence of differences in ME and in the concentration of fat between FFRB and DFRB.

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