

JOURNAL OF ANIMAL SCIENCE

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J Anim Sci 2001. 79:1230-1239.

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Effects of dietary soy isoflavones on growth, carcass traits, and meat quality in growing-finishing pigs^{1,2}

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ABSTRACT: Two experiments were conducted to determine the effect of soy isoflavones on growth, meat quality, and carcass traits of growing-finishing pigs. In Exp. 1, 36 barrows (initial and final BW, 26 and 113 kg, respectively) were used and each treatment was replicated four times with three pigs each. The dietary treatments were 1) corn-soybean meal (C-SBM), 2) corn-soy protein concentrate (low isoflavones, C-SPC), or 3) C-SPC + isoflavones (isoflavone levels equal to those in C-SBM). Daily gain and ADFI were increased ($P < 0.10$) in pigs fed the C-SPC relative to pigs fed the C-SPC + isoflavone diet in the late finishing period; otherwise, growth performance was not affected ($P > 0.10$) by diet. Longissimus muscle area, 10th-rib fat depth, percentage muscling (National Pork Producers Council), 24-h pH and temperature, color, firmness-wetness, marbling, drip loss, and CIE L*, a*, and b* color values were not affected ($P > 0.10$) by diet. Dressing percentage, carcass length, weight and percentage of fat-free lean in ham and carcass, lean gain per day, lean:fat, and ham weight were increased ($P < 0.10$), and ham fat and percentage fat in ham and carcass were

decreased ($P < 0.10$) in pigs fed the C-SPC + isoflavone diet compared with pigs fed the C-SPC diet. Pigs fed the C-SPC + isoflavone diet had similar ($P > 0.10$) carcass traits as pigs fed the C-SBM diet, except carcass length, percentage ham lean and thaw loss were greater ($P < 0.10$), and total ham fat was less ($P < 0.10$) in pigs fed the C-SPC + isoflavone diet. In Exp. 2, 60 gilts (initial and final BW, 31 and 116 kg, respectively) were used, and each treatment was replicated five times with four pigs per replicate. The treatments were 1) C-SBM, 2) C-SBM + isoflavone levels two times those in C-SBM, and 3) C-SBM + isoflavone levels five times those in C-SBM. Daily feed intake was linearly decreased ($P < 0.10$) in the growing phase and increased ($P < 0.10$) in the late finishing phases as isoflavone levels increased; otherwise, growth performance was not affected ($P > 0.10$) by diet. Diet did not affect ($P > 0.10$) carcass traits; however, CIE a* and b* color scores and drip loss were decreased ($P < 0.06$) as isoflavone levels increased. Soy isoflavones decreased fat and increased lean in barrows when fed within the dietary concentrations found in typical C-SBM diets but not when fed to gilts at concentrations above those present in C-SBM diets.

Key Words: Carcass Quality, Growth, Isoflavones, Meat Quality, Pigs

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J. Anim. Sci. 2001. 79:1230–1239

Introduction

A large amount of research is being conducted to evaluate factors that affect lean and fat deposition in pigs. This research is stimulated by consumers who demand a product that is both lean and palatable.

Dietary components that recently have received attention for their action as phytoestrogens are soy isoflavones. Soy products are the most significant dietary sources of isoflavones (Barnes et al., 1994). Isoflavones are diphenolic compounds, which exist in unconjugated (aglycone) or conjugated forms (Kudou et al., 1991). The aglycone forms are daidzein, genistein, and glycitein. Isoflavones have structural and functional similarity to natural estrogens (Kurzer and Xu, 1997). They can weakly bind to estrogen receptors, causing competition between natural estrogens and isoflavones (Kelly et al., 1993). However, Martin et al. (1978) suggested that isoflavones may act as antiestrogens in the presence of high levels of endogenous estrogens. Because isoflavones may have hormonelike functions, they may play a role in affecting growth and carcass composition of pigs. Various estrogenic compounds

¹Approved for publication by the director of the Louisiana Agric. Exp. Sta. as manuscript no. 2000-11-0323.

²The authors thank Frederick LeMieux and the Louisiana State Univ. Agric. Center Swine Unit for assistance with the animals and Manuel Persica, John Carothers, Amy Guzik, LeAnn Johnston, Erin Shelton, Laura Camp, Neal Matthews, and Jason Shelton for assistance with data collection and laboratory analyses.

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Received July 24, 2000.

Accepted December 6, 2000.

when fed to or implanted into pigs reduce fat and increase muscling (Bidner et al., 1972; DeWilde and Lauwers, 1984; Plimpton and Teague, 1972). Similarly, Cook (1998) reported that supplemental isoflavones (1,585 mg/kg diet) increased growth rate and carcass muscle but did not affect carcass fat in pigs from 6 to 32 kg BW. Therefore, the objectives of our research were to determine the effect of soy isoflavones on growth performance, carcass traits, and meat quality in growing-finishing pigs.

Materials and Methods

General

Two experiments were conducted to evaluate isoflavones in growing-finishing pigs. Purebred Yorkshire and crossbred (Yorkshire × Landrace) pigs from the Louisiana State University Agricultural Center Swine Unit were used in these experiments. Pigs were allotted to treatments on the basis of weight, with ancestry equalized across treatments in randomized complete block designs. Pigs and feeders were weighed every 2 wk for calculation of ADG, ADFI, and gain:feed. Feed and water were provided on an ad libitum basis throughout both experiments. The materials and methods used in these experiments were approved by the Louisiana State University Animal Care and Use Committee.

Soybean meal (**SBM**), soy protein concentrate (**SPC**), and isoflavones were analyzed for aglycone (daidzein, genistein, and glycitein) concentrations by Central Soya Co., Inc. (Ft. Wayne, IN) using a modified method of Thiagarajan et al. (1998). The aglycone forms, daidzein, genistein, and glycitein, are the main forms of isoflavones (Kudou et al., 1991). The SBM contained 1.14 mg/g of total isoflavones, which consisted of 0.54 mg/g daidzein, 0.15 mg/g glycitein, and 0.45 mg/g genistein adjusted for aglycone content. The SPC contained 0.06 mg/g of total isoflavones, which consisted of 0.03 mg/g daidzein, 0 mg/g glycitein, and 0.03 mg/g genistein adjusted for aglycone content. The isoflavones contained 29.4 mg/g of total isoflavones, which consisted of 11.6 mg/g daidzein, 1.35 mg/g glycitein, and 16.4 mg/g genistein adjusted for aglycone content.

Experiment 1

Thirty-six barrows with an average initial BW of 26 ± 2 kg were allotted to three dietary treatments. Each treatment was replicated with four pens of three pigs each. The treatment diets (Table 1) were 1) corn-soybean meal (**C-SBM**), 2) corn-SPC (**C-SPC**), or 3) **C-SPC** + isoflavones added to equal the level of isoflavones found in the C-SBM diet. Diets were formulated to have equal NE, and Diets 1 and 3 were equal in isoflavone content. The diets were formulated to provide 105% of the true ileal digestible amino acid re-

quirements of barrows with 350 g of lean gain per day, and the diets met or exceeded the other nutrient requirements of growing and finishing pigs (NRC, 1998). Diet formulations were based on the amino acid content of corn and SBM (NRC, 1998). The amino acid content of SPC was provided by Central Soya Co., Inc. (Ft. Wayne, IN; Table 3). True ileal digestibility of amino acids in SPC was calculated using the true digestibility coefficients of SPC (NRC, 1998). The amino acid content of the isoflavone product was not used in diet formulations in Exp. 1.

Pigs were fed the growing diets for 31 d, during which time they were housed in a totally enclosed building with 1.83- × 2.44-m pens and metal slotted floors. During both the early (28 d) and late (43 d) finishing periods, the pigs were housed in a curtain-sided building with 1.5- × 3.0-m pens and concrete slotted floors. The experimental period lasted 102 d. The average final BW was 113 kg.

Experiment 2

Sixty gilts with an initial body weight of 31 ± 5 kg were allotted to three dietary treatments. Each treatment was replicated with five pens of four gilts each. The treatment diets (Table 2) were 1) C-SBM, 2) C-SBM plus two times the isoflavone levels found in Diet 1 (2×), or 3) C-SBM plus five times the isoflavone levels found in Diet 1 (5×). Diets were formulated to have equal NE. They also were formulated to provide 105% of the true ileal digestible amino acid requirements of gilts with a lean gain of 350 g per day, and the diets met or exceeded the other nutrient requirements of growing and finishing pigs (NRC, 1998). Diet formulations were based on actual amino acid analysis of isoflavones (Table 3; AOAC, 1990) and on the amino acid content of corn and SBM (NRC, 1998). The diet formulations for Exp. 2 used the amino acid content of the isoflavone product. True ileal digestibility of amino acids in the isoflavone product was calculated using the true digestibility coefficients of SBM (NRC, 1998).

The pigs were housed in total confinement in 1.29- × 2.36-m pens with metal slotted floors for both the growing (28 d) and early finishing (35 d) periods. During the late finishing period (48 d), the pigs were kept in the same finishing facility as in Exp. 1. The experimental period lasted 111 d. The average final BW was 116 kg.

Plasma Collection and Analysis

Blood samples were taken near the end of the late finishing period in both experiments. The pigs in Exp. 1 had access to feed up to and throughout the time of bleeding, whereas pigs in Exp. 2 were held without feed for 16 h before bleeding. Blood was collected via the anterior vena cava and was placed in 7-mL tubes (Monoject, Sherwood Medical, St. Louis, MO) con-

Table 1. Composition of basal diets, as-fed basis (Exp. 1)^a

Ingredient	Growing		Early finishing		Late finishing	
	C-SBM	C-SPC	C-SBM	C-SPC	C-SBM	C-SPC
Corn	69.65	81.27	79.25	86.83	86.24	90.86
Soybean meal (47.5% CP)	23.97	—	15.60	—	9.54	—
Soy protein concentrate ^b	—	15.26	—	9.93	—	6.07
Dry fat ^c	3.00	—	1.96	—	1.19	—
Monocalcium phosphate	1.14	1.18	1.05	1.07	0.92	0.93
Limestone	1.12	1.17	0.96	0.99	0.93	0.95
Trace minerals ^d	0.10	0.10	0.10	0.10	0.10	0.10
Vitamins ^e	0.375	0.375	0.375	0.375	0.375	0.375
L-Lysine·HCl	0.10	0.10	0.15	0.15	0.15	0.15
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Selenium premix ^f	0.05	0.05	0.05	0.05	0.05	0.05
L-Threonine	—	—	0.01	—	—	—
L-Tryptophan	—	—	—	0.01	0.01	0.01
Isoflavone ^g	—	-/+	—	-/+	—	-/+
Calculated composition: ^h						
NE, kcal/kg	2,305	2,305	2,313	2,313	2,319	2,319
ME, kcal/kg	3,430	3,366	3,393	3,351	3,366	3,341
Crude fat, %	6.43	3.63	5.51	3.68	4.84	3.73
Crude protein, %	17.26	16.88	14.13	13.88	11.84	11.69
Lysine, %	0.87	0.87	0.70	0.70	0.55	0.55
TSAA, % ^a	0.53	0.53	0.44	0.45	0.39	0.39
Tryptophan, %	0.18	0.17	0.13	0.13	0.11	0.11
Threonine, %	0.55	0.60	0.45	0.48	0.36	0.38
Calcium, %	0.70	0.70	0.60	0.60	0.55	0.55
Phosphorous, %	0.60	0.60	0.55	0.55	0.50	0.50
Potassium, %	0.74	0.64	0.59	0.53	0.49	0.45
Isoflavone, mg/kg ⁱ	272.00	8.78	177.00	5.70	108.30	3.49

^aC-SBM = corn-soybean meal; C-SPC = corn-soy protein concentrate; TSAA = total sulfur amino acids.

^bProfine E, Central Soya Co., Inc., Fort Wayne, IN 46801.

^cFat Pak 100, Milk Specialties Co., Dundee, IL.

^dProvides the following per kilogram of diet: Zn, 127 mg; Fe, 127 mg; Mn, 20 mg; Cu, 12.7 mg; I, 0.80 mg, as zinc sulfate, ferrous sulfate, manganese sulfate, copper sulfate, calcium iodate, respectively, with calcium carbonate as the carrier.

^eProvides the following per kilogram of diet: vitamin A, 8,267 IU; vitamin D, 2,480 IU; vitamin E, 66 IU; menadione (as menadione pyrimidinol bisulfite complex) 6.2 mg; riboflavin, 10 mg; Ca-D-pantothenic acid, 37 mg; niacin, 66 mg; vitamin B₁₂, 45 µg; D-biotin, 331 µg; folic acid, 2.5 mg; pyridoxine, 3.31 mg; thiamin, 3.31 mg; and vitamin C, 83 µg.

^fProvides 0.3 mg of Se per kilogram of diet.

^gIsoflavone was added at 0.90, 0.58, 0.36% in the growing, early finishing, and late finishing periods, respectively, to provide isoflavone levels equal to those in the C-SBM diet.

^hAmino acid values are on a true ileal digestibility basis and were calculated using NRC (1998) values for corn and soybean meal. Amino acid, ME, and NE values for soy protein concentrate were provided by Central Soya Co., Inc. (Ft. Wayne, IN). True digestibility of soy protein concentrate was calculated using digestibility coefficients from NRC (1998).

ⁱIsoflavone values are for the diets with no added isoflavones. They are the sum of the aglycone forms (daidzein, genistein, and glycitein) and were determined by Central Soya Co., Inc.

taining 17.5 mg of sodium fluoride and 14.0 mg of potassium oxalate. After collection, blood samples were refrigerated at 8°C for 2 h and then centrifuged for 45 min at 1,500 × g at 4°C. Plasma was collected after centrifugation, and samples were frozen in racks at -15°C in a freezer until analysis. Urea N was determined by the methods of Laborde et al. (1995). Nonesterified fatty acid concentrations were determined with the enzymatic-colorimetric procedure (NEFA-C Kit, ACS-ACOD Method; Waco Chemicals USA, Inc., Richmond, VA) described by McCutcheon and Bauman (1986). Samples also were analyzed for glucose (Exp. 1, Sigma Kit # 510-6, ACS-ACOD Method; Sigma Chemical Company, St. Louis, MO) and insulin (Exp. 1, Coat-a-Count; Diagnostic Products Corp., Los

Angeles, CA). The intraassay CV for insulin determined with a porcine plasma pool was 5.0%. Luteinizing hormone concentrations also were analyzed on samples collected in Exp. 1 by the methods of Thompson et al. (1985). The intraassay CV for LH using a porcine plasma pool was 6.0%.

Carcass Evaluation

At the termination of the experiments, all (Exp. 1) or 30 pigs (Exp. 2; two pigs per pen) were slaughtered in a commercial facility, and hot carcass weights were collected. Following a 24-h chill at 2°C, midline backfat thickness at the first-rib, last-rib, and last-lumbar vertebrae, and carcass length were collected at the com-

Table 2. Composition of basal diets, as-fed basis (Exp. 2)^a

Ingredient	Growing	Early finishing	Late finishing
Corn	69.63	72.95	80.17
Soybean meal (47.5% CP)	23.98	21.01	13.92
Dry fat ^b	3.00	3.00	3.00
Monocalcium phosphate	1.14	0.96	0.85
Limestone	1.12	0.96	0.92
Trace minerals ^c	0.10	0.10	0.10
Vitamins ^d	0.375	0.375	0.375
L-Lysine·HCl	0.10	0.10	0.10
Salt	0.50	0.50	0.50
Selenium premix ^e	0.05	0.05	0.05
L-Threonine	—	—	0.003
Isoflavone ^f	-/+	-/+	-/+
Calculated composition ^g			
NE, kcal/kg	2,305	2,324	2,354
ME, kcal/kg	3,300	3,300	3,000
Crude fat, %	6.43	6.47	6.54
Crude protein, %	17.27	16.13	13.36
Lysine, %	0.87	0.80	0.62
TSAA, % ^a	0.52	0.49	0.43
Tryptophan, %	0.18	0.16	0.12
Threonine, %	0.55	0.52	0.42
Calcium, %	0.70	0.60	0.55
Phosphorous, %	0.60	0.55	0.50
Isoflavone, mg/kg ^h	246.20	215.70	142.90

^aC-SBM = corn-soybean meal; TSAA = total sulfur amino acids.

^bFat Pak 100, Milk Specialties Co., Dundee, IL.

^cProvides the following per kilogram of diet: Zn, 127 mg; Fe, 127 mg; Mn, 20 mg; Cu, 12.7 mg; I, 0.80 mg, as zinc sulfate, ferrous sulfate, manganese sulfate, copper sulfate, calcium iodate, respectively, with calcium carbonate as the carrier.

^dProvides the following per kilogram of diet: vitamin A, 8,267 IU; vitamin D, 2,480 IU; vitamin E, 66 IU; menadione (as menadione pyrimidinol bisulfite complex) 6.2 mg; riboflavin, 10 mg; Ca-D-pantothenic acid, 37 mg; niacin, 66 mg; vitamin B₁₂, 45 µg; D-biotin, 331 µg; folic acid, 2.5 mg; pyridoxine, 3.31 mg; thiamin, 3.31 mg; and vitamin C, 83 µg.

^eProvides 0.3 mg of Se per kilogram of diet.

^fIsoflavone was added at 0.85 and 3.40, 0.75 and 2.98, 0.49 and 1.98% in the growing, early finishing, and late finishing periods, respectively, to provide two or five times the isoflavone levels of those in the C-SBM diet.

^gAmino acid values are on a true ileal digestibility basis and were calculated using NRC (1998) values for corn and soybean meal. Isoflavone product was analyzed for amino acid content, and the true ileal digestibility coefficients for soybean meal (NRC, 1998) were used to calculate true ileal digestible content.

^hIsoflavone values are for the diets with no added isoflavones. They are the sum of the aglycone forms (daidzein, genistein, and glycitein) and were determined by Central Soya Co., Inc.

Table 3. Amino acid analysis, as-fed basis^a

Amino acid, %	Isoflavone	Soy protein concentrate
Arginine	1.95	5.08
Cysteine	0.59	0.99
Histidine	0.76	1.78
Isoleucine	1.33	2.96
Leucine	2.35	5.39
Lysine	1.50	4.34
Methionine	0.40	0.95
Phenylalanine	1.62	3.36
Tyrosine	1.08	2.38
Threonine	1.15	2.85
Tryptophan	0.44	0.92
Valine	1.48	3.36

^aThe isoflavone product was analyzed in our laboratory for total amino acid content. Values for soy protein concentrate were provided by Central Soya Co., Inc.

mercial facility. Average backfat thickness was determined by averaging the first-rib, last-rib, and last-lumbar vertebral measurements.

The ham and loin sections (8th to 11th ribs) from the left side of each carcass were collected and transported to the Louisiana State University Agricultural Center Meats Laboratory for further analysis. Ham weight was recorded, and butt fat thickness was measured from the interior edge of the subcutaneous fat, beneath the femur, on a straight line to the outer skin surface and perpendicular to the outer skin surface. The ham was evaluated by total-body electrical conductivity (**TOBEC**; Model MQI-27; Meat Quality Inc., Springfield, IL) analysis for calculation of fat-free lean and fat content in the total carcass and for fat-free lean and fat content in the ham (Higbie, 1997). Fat-free lean in the carcass was calculated using the following equation: $([-2.136 + \{0.138 \times \text{carcass length (cm)}\} + \{0.365 \times \text{peak ham TOBEC value}\} - \{0.254 \times \text{temperature C}\}] \times 2)$; ($R^2 = 0.94$). Percentage lean in the carcass

was calculated as $([\text{fat-free lean} \div \text{hot carcass weight (kg)}] \times 100)$. Total fat in the carcass was calculated using the following equation: $([-6.754 + \{0.262 \times \text{hot carcass weight (kg)}\} + \{0.200 \times \text{peak ham TOBEC value}\} + \{2.139 \times \text{butt fat thickness (cm)}\}] \times 2)$; ($R^2 = 0.91$). Percentage fat in the carcass was calculated as $([\text{total fat (kg)} \div \text{hot carcass weight (kg)}] \times 100)$. Lean gain per day was calculated using $([\text{fat-free lean (kg)} - \text{initial lean (kg)}] \div \text{number of days on trial})$. Initial lean was determined using the equation of Brannaman et al. (1984): $(-1.59 + [0.44 \times \text{initial BW (kg)}])$. Fat-free ham lean was calculated using the following equation: $(2.738 + [0.121 \times \text{peak ham TOBEC value}] - [0.089 \times \text{temperature C}])$; ($R^2 = 0.95$). Percentage ham lean was calculated as $([\text{fat-free ham lean (kg)} \div \text{ham weight (kg)}] \times 100)$. Total ham fat was determined using the following equation: $(-2.392 - [0.090 \times \text{peak ham TOBEC value}] + [0.671 \times \text{ham weight (kg)}] + [0.072 \times \text{temperature C}])$; ($R^2 = 0.84$). Percentage ham fat was calculated as $([\text{total ham fat (kg)} \div \text{ham weight (kg)}] \times 100)$. Percentage muscling was determined with the equation described by the NPPC (1991), which uses a 5% estimation for intramuscular fat and compensates for unequal body weights.

Twenty-four-hour pH and temperature measurements were taken between the 10th and 11th ribs approximately 24 h after slaughter (Exp. 1 only). A handheld pH meter (Model 2000; VWR Scientific Products Co., South Plainfield, NJ) equipped with a spear-tipped electrode (Catalog # P-05658-60; Cole-Parmer Instrument Co., Vernon Hills, IL) was used for determining the pH of the longissimus muscle. Longissimus muscle area was determined by tracing the longissimus muscle surface area at the 10th rib using acetate paper. The tracing was then measured and area determined by using a compensating polar planimeter. Tenth-rib backfat thickness was determined by measuring the fat thickness at the 10th rib, three-quarters of the lateral length of the longissimus muscle perpendicular to the outer skin surface. Following tracing, the pork quality scores (color, marbling, and firmness-wetness) were determined according to the guidelines of the NPPC (1991) using the interface of the longissimus muscle at the 10th rib. The CIE L^* , a^* , and b^* values also were obtained from the 10th-rib longissimus muscle after a 15-min bloom using a Minolta chromameter CR-300 (Minolta Camera Co., Japan, illuminant D65 and 0° ; Exp. 1) and a Minolta spectrophotometer (Model CM-508d; Minolta Corp., Ramsey, NJ 07446; Exp. 2). The 10th-rib chop was removed from the loin section, deboned, cleaned of any adhering intermuscular fat, and weighed for 24-h drip loss determination by a suspension method. The chops were weighed, and then suspended on a hook and line in a 10.8- \times 21.6-cm Whirl-Pak sample bag. Next, the chops were stored for 24 h at 2°C and then weighed again. Drip loss was calculated as $([\text{initial wt.} - \text{final wt. of drip chop}] \div \text{initial wt.}] \times 100)$.

In Exp. 1, the longissimus muscle that was used to determine drip loss was frozen in vacuum bags until cooking loss and shear force could be determined. Thaw loss was calculated for each chop. Chops were thawed at 2°C for 18 h. Each chop was then removed from the bag, blotted with paper towels, and weighed to determine the blotted chop weight. Thaw loss was calculated by the equation $([\text{final wt. of drip chop (g)} - \text{blotted chop weight (g)}] \div \text{initial chop weight (g)}) \times 100$. Total loss for Exp. 1 was calculated as the sum of drip, thaw, and cooking losses.

In Exp. 2, the longissimus muscle that was used to determine drip loss was used immediately following drip loss to determine cooking loss and shear force. Total loss for Exp. 2 was calculated as the sum of drip and cooking losses. Cooking loss and shear force for both experiments followed the procedures described by Boleman et al. (1995).

Statistical Analysis

Data were analyzed by analysis of variance procedures appropriate for randomized complete block designs (Steel and Torrie, 1980) using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). In Exp. 1, growth and carcass data were analyzed by the PDIF option. Carcass data were analyzed with mean final body weight as a covariate, and 24-h temperature was used as a covariate for the 24-h pH measurements (Exp. 1). In Exp. 2, growth and carcass data were analyzed using linear and quadratic contrast statements appropriate for unequally spaced treatments. Final body weight was not used as a covariate for the carcass data because it was not significant ($P > 0.10$). The pen of pigs was the experimental unit for all data.

Results

Experiment 1

Growth Performance. Average daily gain and ADFI were not affected ($P > 0.10$) by diet during the growing, early finishing, or overall periods (Table 4). However, ADG and ADFI were increased ($P < 0.10$) in pigs fed C-SPC relative to pigs fed C-SPC + isoflavones during the late finishing period. Gain:feed was not affected ($P > 0.10$) by diet during any period.

Plasma Metabolites. Glucose, NEFA, urea N, and LH concentrations were not affected ($P > 0.10$) by diet (Table 4). Pigs fed C-SBM had higher insulin concentrations and insulin:glucose ($P < 0.10$) than the pigs fed either the C-SPC or C-SPC + isoflavone diets.

Carcass Traits. Pigs fed the C-SPC + isoflavone diet had an increased ($P < 0.10$) dressing percentage, carcass length, weight and percentage of fat-free lean in carcass and ham, lean gain per day, and lean:fat but decreased ($P < 0.10$) ham fat and percentage fat in carcass and ham relative to the pigs fed C-SPC (Table 5). Pigs fed the C-SPC + isoflavone or the C-SBM diets

Table 4. Effect of isoflavone on growth performance (Exp. 1)^a

Item	C-SBM	C-SPC	C-SPC +ISF	Pooled SEM
Growing (31 d)				
Daily gain, kg	0.75	0.76	0.74	0.03
Daily feed, kg	1.96	1.98	1.89	0.11
Gain:feed	0.38	0.39	0.40	0.01
Early finishing (28 d)				
Daily gain, kg	1.05	0.96	0.99	0.05
Daily feed, kg	3.29	3.01	3.07	0.16
Gain:feed	0.32	0.32	0.32	0.02
Late finishing (43 d)				
Daily gain, kg	0.81 ^{bc}	0.88 ^b	0.75 ^c	0.04
Daily feed, kg	3.43 ^{bc}	3.46 ^b	3.08 ^c	0.13
Gain:feed	0.24	0.26	0.25	0.01
Overall				
Daily gain, kg	0.86	0.87	0.82	0.04
Daily feed, kg	2.93	2.89	2.67	0.11
Gain:feed	0.30	0.30	0.31	0.01
Plasma metabolites				
Glucose, mmol/L	5.04	5.01	5.08	0.19
Insulin, μ U/mL	16.21 ^b	10.31 ^c	10.40 ^c	2.05
Insulin:glucose	3.14 ^b	2.09 ^c	2.04 ^c	0.30
NEFA, μ Eq/L	139.8	141.0	141.4	5.9
Urea N, mmol/L	1.67	1.59	1.42	0.18
LH, ng/mL	0.25	0.24	0.21	0.08

^aData are means of four replicates of three pigs per replicate. Average initial and final body weight were 26 and 113 kg, respectively. The growth trial lasted 102 d. C-SBM = corn-soybean meal; C-SPC = corn-soy protein concentrate; C-SPC + ISF = corn-soy protein concentrate plus isoflavone equal to the level found in the C-SBM diet.

^{b,c}Means with different superscripts differ ($P < 0.10$).

had similar ($P > 0.10$) carcass traits, except carcass length and percentage ham lean were greater ($P < 0.10$) and total ham fat was less ($P < 0.10$) in pigs fed the C-SPC + isoflavones. Longissimus muscle area, 10th-rib backfat, average backfat, percentage muscling, kilograms of lean (NPPC, 1991), and total fat were not affected ($P > 0.10$) by dietary treatment.

Pork Quality. Twenty-four hour pH, 24-h temperature, NPPC pork quality scores, CIE L*, a*, and b* color scores, 24-h drip loss, cooking loss, and shear force were not affected ($P > 0.10$) by diet (Table 6). The longissimus muscle from pigs fed C-SPC + isoflavones had increased ($P < 0.06$) thaw loss relative to those from pigs fed C-SBM or C-SPC diets.

Experiment 2

Growth Performance and Carcass Traits. Average daily gain and gain:feed were not affected ($P > 0.10$) by diet in the growing, early finishing, late finishing, or overall periods (Table 7). However, ADFI was decreased (linear, $P < 0.09$) in the growing period but increased (linear, $P < 0.10$) in the late finishing period by increasing levels of isoflavones. Average daily feed intake was not affected ($P > 0.10$) during the early finishing or overall periods. Dietary isoflavones did not affect ($P > 0.10$) any of the carcass traits measured (Table 8).

Plasma Metabolites. Nonesterified fatty acid concentrations (Table 7) were increased by the 2 \times level of isoflavones but decreased by the 5 \times level (quadratic, $P < 0.02$). The isoflavones did not affect plasma urea N levels ($P > 0.10$).

Pork Quality. The NPPC (1991) pork quality scores, CIE L*, cooking loss, 24-h drip loss, total loss, and shear force were not affected ($P > 0.10$) by dietary treatment. The CIE a* and b* color scores ($P < 0.10$) were decreased linearly as isoflavones increased (Table 9).

Discussion

The effects of soy isoflavones on weight gain, feed intake, and feed efficiency are somewhat variable. Winters and Banz (1997) reported that supplemental isoflavones increased weight gain in female rats with no change in feed efficiency. However, weight gain and feed efficiency were decreased in male rats fed a similar diet (Winters and Banz, 1997). Cook (1998) reported that supplemental soy isoflavones (0 or 1,585 mg/kg) increased ADG in gilts from 6 to 30 kg BW. However, in a second study, Cook (1998) reported that dietary genistein (one form of isoflavones; 0, 200, 400, 600, or 800 mg/kg) did not affect ADG in barrows from 5 to 28 kg BW. A decrease in ADG and ADFI was seen in Sprague-Dawley rats fed a C-SPC diet supple-

Table 5. Effect of isoflavone on carcass characteristics (Exp. 1)^a

Item	C-SBM	C-SPC	C-SPC + ISF	Pooled SEM	Covariate ^b	$P > F^b$
Final body weight, kg	113.42	114.23	110.02			
Carcass lean and fat measurements						
LMA, cm ²	42.12	41.46	42.00	1.21	NS	NS
Tenth-rib backfat, cm	2.03	2.16	2.08	0.10	0.03	NS
Average backfat, cm	2.93	2.92	2.66	0.11	NS	NS
Carcass length, cm	78.89 ^e	78.26 ^e	79.86 ^f	0.33	0.01	0.10
Dressing percentage	75.85 ^{ef}	75.28 ^e	76.06 ^f	0.27	NS	0.10
Ham weight, kg	10.42 ^e	9.86 ^f	10.36 ^e	0.12	0.01	0.04
Butt fat thickness, cm	1.49	1.65	1.51	0.09	0.06	NS
TOBEC ^c						
Carcass						
Fat-free lean, kg	40.57 ^e	37.55 ^f	42.05 ^e	1.00	0.04	0.09
Percentage lean	47.40 ^e	44.47 ^f	48.99 ^e	1.01	NS	0.10
Total fat, kg	22.14	24.06	21.89	0.75	0.01	NS
Percentage fat	25.99 ^e	28.35 ^f	25.45 ^e	0.75	0.05	0.08
Lean:fat	1.88 ^e	1.61 ^f	1.99 ^e	0.08	NS	0.07
Lean gain per day, g	302.5 ^e	273.0 ^f	316.0 ^e	10.19	0.04	0.10
Ham						
Fat-free ham lean, kg	6.51 ^{ef}	6.04 ^e	6.72 ^f	0.17	0.05	0.04
Percentage ham lean	62.34 ^e	61.32 ^e	64.63 ^f	0.78	NS	0.10
Total ham fat, kg	2.26 ^e	2.28 ^e	2.07 ^f	0.06	0.01	0.09
Percentage ham fat	21.83 ^{ef}	23.10 ^e	20.12 ^f	0.72	0.08	0.04
NPPC ^d						
Percentage muscling	53.08	52.46	52.98	0.56	0.02	NS
Kilograms of lean	45.27	44.32	45.15	0.59	0.01	NS

^aData are means of four replicates of three pigs per replicate. All data were analyzed with final body weight as a covariate. Average final body weight was 113 kg. C-SBM = corn-soybean meal; C-SPC = corn-soy protein concentrate; C-SPC + ISF = corn-soy protein concentrate plus isoflavone equal to the level found in the C-SBM diet; LMA = longissimus muscle area.

^bActual probability values of the means reported. NS = not significant, $P > 0.10$.

^cCalculated using TOBEC analysis with equations from Higbie (1997).

^dCalculated using the equation described by the NPPC (1991), which uses 5% estimation for intramuscular fat and compensates for unequal body weights.

^{e,f}Means with different superscripts differ ($P < 0.10$).

Table 6. Effect of isoflavone on pork quality (Exp. 1)^a

Item	C-SBM	C-SPC	C-SPC + ISF	Pooled SEM
pH and temperature				
24-h pH ^b	5.46	5.48	5.45	0.03
24-h temperature, C ^b	10.24	10.04	9.59	0.53
NPPC pork quality				
Color	2.13	2.34	2.29	0.19
Firmness-wetness	2.34	2.46	2.23	0.12
Marbling	1.27	1.33	1.44	0.17
CIE color score				
Longissimus muscle				
L*	56.45	56.40	57.38	0.94
a*	16.39	16.05	16.06	0.31
b*	7.93	7.21	7.42	0.38
Drip loss, %	3.05	2.43	2.48	0.46
Thaw loss, %	11.69 ^c	11.81 ^c	12.68 ^d	0.27
Cooking loss, %	17.57	17.96	18.13	1.59
Total loss, %	32.31	32.20	33.28	2.07
Shear force, kg	3.84	3.38	3.73	0.23

^aData are means of four replicates of three pigs per replicate. C-SBM = corn-soybean meal; C-SPC = corn-soy protein concentrate; C-SPC + ISF = corn-soy protein concentrate plus isoflavone equal to the level found in the C-SBM diet.

^bThe pH and temperature measurements were taken in the longissimus muscle between the 10th and 11th ribs. Twenty four-hour temperature was used as a covariate for pH measurements.

^{c,d}Means with different superscripts differ ($P < 0.10$).

Table 7. Effect of isoflavone on growth performance (Exp. 2)^{a,b}

Item	C-SBM	C-SBM + 2× ISF	C-SBM + 5× ISF	Pooled SEM
Growing (28 d)				
Daily gain, kg	0.82	0.82	0.80	0.03
Daily feed, kg ^b	2.25	2.19	2.14	0.04
Gain:feed	0.37	0.38	0.39	0.01
Early finishing (35 d)				
Daily gain, kg	0.75	0.71	0.73	0.02
Daily feed, kg	2.16	2.17	2.29	0.11
Gain:feed	0.35	0.33	0.32	0.01
Late finishing (48 d)				
Daily gain, kg	0.75	0.77	0.79	0.03
Daily feed, kg ^b	2.69	2.85	2.98	0.10
Gain:feed	0.28	0.27	0.27	0.02
Overall (111 d)				
Daily gain, kg	0.77	0.76	0.77	0.02
Daily feed, kg	2.45	2.47	2.54	0.07
Gain:feed	0.32	0.31	0.31	0.01
Plasma metabolites				
NEFA, $\mu\text{Eq/L}^c$	424.92	654.65	298.03	76.50
Urea N, mmol/L	3.80	4.01	3.63	0.17

^aData are the mean of five replicates of four pigs per replicate. Average initial and final body weight were 31 and 116 kg, respectively. The growth trial lasted 111 d. C-SBM = corn-soybean meal; C-SBM + 2× ISF = corn-soybean meal plus two times the isoflavone level found in the C-SBM diet; C-SBM + 5× ISF = corn-soybean meal plus five times the isoflavone level found in the C-SBM diet.

^bLinear, $P < 0.10$.

^cQuadratic, $P < 0.02$.

mented with 0, 431, 862, or 1,724 mg/kg soy isoflavones (Cook, 1998). In our studies, overall growth performance was not affected by soy isoflavones.

Banz et al. (1997) reported that diets high in isoflavones reduced the insulin:glucose ratio of rats, resulting in leaner rats. In our data, barrows fed the diets with SPC (regardless of isoflavone) had decreased plasma insulin with no change in plasma glucose, resulting in a decrease in insulin:glucose. These changes were not related to changes in muscling or fatness. One possible explanation for the decrease in plasma insulin in pigs fed SPC could be the lower level of crude fat in these diets compared with the C-SBM diet. High-fat diets have been shown to decrease insulin sensitivity and increase plasma insulin levels (Blazquez and Quijada, 1968).

There has been very little research conducted on the effect of isoflavones on carcass characteristics or meat quality in pigs. Cook (1998) reported that the combined weight of four red muscles or four white muscles were not affected by dietary genistein in pigs from 5 to 28 kg BW. However, Cook (1998) also showed that percentage of carcass muscle was increased, but percentage of carcass fat was not affected in pigs from 6 to 30 kg BW. Our results from Exp. 1 support the latter results of Cook (1998). Percentage of muscling was increased when isoflavones were included in the diet, whereas fat percentages were decreased. In Exp. 2, however, carcass traits were not affected by additional isoflavones in the diet above levels normally found in typical C-SBM diets. These data suggest that isofla-

vones affect carcass composition in pigs, but the effective dietary level is at or below the level of isoflavones commonly found in C-SBM diets, or that isoflavones are efficacious in barrows and not gilts.

One possible explanation for the decrease in leanness of pigs fed the C-SPC diet in Exp. 1 with low levels of isoflavones is that isoflavones have estrogenic activity and can act as a hormone (Reinli and Block, 1996). Additionally, barrows fed or implanted with estrogenic hormones seem to respond more than gilts. DeWilde and Lauwers (1984) reported that barrows implanted with estradiol-17 β + trenbolone had improved feed conversion and 23% less fat content than littermate barrows receiving only a control diet. Similarly, Plimpton and Teague (1972) reported an increase in longissimus muscle area, yield of lean cuts, and carcass length in barrows fed diethylstilbestrol and methyltestosterone compared with control barrows. Bidner et al. (1972) reported that backfat was decreased and ADG tended to be decreased in barrows fed diethylstilbestrol plus methyltestosterone compared with barrows fed a control diet. Although feed conversion was not affected in barrows fed the C-SPC diet in Exp. 1, our carcass characteristics agree with these studies.

The data with gilts is much less conclusive. DeWilde and Lauwers (1984) reported no difference in carcass composition in gilts implanted with estradiol-17 β + testosterone compared with control gilts. However, ADG was increased in the gilts implanted with estradiol-17 β + testosterone. Furthermore, Martinez et al.

Table 8. Effect of isoflavone on carcass characteristics (Exp. 2)^{a,b}

Item	C-SBM	C-SBM + 2× ISF	C-SBM + 5× ISF	Pooled SEM
Final body weight, kg	115.17	116.29	117.03	
Carcass lean and fat measurements				
LMA, cm ²	55.08	57.02	53.32	3.10
Tenth-rib backfat, cm	1.51	1.41	1.47	0.14
Average backfat, cm	2.23	2.28	2.13	0.12
Carcass length, cm	81.53	82.80	81.91	0.74
Dressing percentage	74.94	75.19	74.98	0.43
Ham weight, kg	10.84	11.01	10.78	0.27
Butt fat thickness, cm	1.15	1.15	1.05	0.12
TOBEC ^c				
Carcass				
Fat-free lean, kg	47.88	47.62	46.29	2.65
Percentage lean	54.58	53.82	52.64	2.21
Lean gain per day, g	348.39	346.88	335.82	25.57
Total fat, kg	17.90	18.88	18.64	1.43
Percentage fat	20.61	21.18	21.15	1.51
Lean:fat	2.96	2.60	2.61	0.31
Ham				
Fat-free ham lean, kg	7.60	7.50	7.32	0.42
Percentage ham lean	69.68	67.94	67.71	2.50
Total ham fat, kg	1.65	1.84	1.79	0.19
Percentage ham fat	15.56	16.77	16.72	1.99
NPPC ^d				
Percentage muscling	58.82	59.77	58.34	1.26
Kilograms of lean	51.43	52.78	51.28	1.77

^aData are the means of five replicates of two pigs per replicate. C-SBM = corn-soybean meal; C-SBM + 2× ISF = corn-soybean meal plus two times the isoflavone level found in the C-SBM diet; C-SBM + 5× ISF = corn-soybean meal plus five times the isoflavone level found in the C-SBM diet; LMA = longissimus muscle area.

^bNo significant effects ($P > 0.10$).

^cCalculated using TOBEC analysis with equations from Higbie (1997).

^dCalculated using the equation described by the NPPC (1991), which uses a 5% estimation for intramuscular fat and compensates for unequal body weights.

(1992) reported that backfat was not affected when gilts were implanted with trenbolone acetate compared with unimplanted gilts. However, Bidner et al. (1972) reported that backfat thickness was decreased

and ADG tended to be increased in gilts fed diethylstilbestrol plus methyltestosterone. In Exp. 2, the addition of isoflavones did not improve growth or the carcass characteristics of gilts. This lack of response in

Table 9. Effect of isoflavone on pork quality (Exp. 2)^a

Item	C-SBM	C-SBM + 2× ISF	C-SBM + 5× ISF	Pooled SEM
NPPC pork quality				
Color	1.80	2.00	2.25	0.30
Firmness-wetness	2.05	2.20	2.20	0.23
Marbling	1.10	1.20	1.35	0.13
CIE color score				
Longissimus muscle				
L*	58.88	57.90	53.38	2.38
a ^{*b}	6.73	5.74	4.88	0.39
b ^{*b}	13.37	12.63	11.25	0.67
Drip loss, %	4.65	2.97	2.91	0.69
Cooking loss, %	24.05	23.17	24.28	0.81
Total loss, %	28.69	26.13	27.19	1.03
Shear force, kg	4.26	4.23	4.12	0.14

^aData are means of five replicates of two pigs per replicate. C-SBM = corn-soybean meal; C-SBM + 2× ISF = corn-soybean meal plus two times the isoflavone level found in the C-SBM diet; C-SBM + 5× ISF = corn-soybean meal plus five times the isoflavone level found in the C-SBM diet.

^bLinear, $P < 0.10$.

gilts could be because of their gender, or as suggested before, that the efficacious level of isoflavones is somewhere below the level present in typical C-SBM diets.

Implications

Soy isoflavones decrease fat and increase lean in growing-finishing barrows, but not at levels above those normally found in corn-soybean meal diets. These data suggest that supplemental isoflavone levels above those found in corn-soybean meal diets will not be beneficial to producers to improve animal performance, carcass characteristics, or meat quality.

Literature Cited

- AOAC. 1990. Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA.
- Banz, W. J., M. P. Williams, J. A. Greer, S. R. Reed, G. A. Byassee, D. A. Lightfoot, and T. A. Winters. 1997. The effects of soy protein and soy phytoestrogens on symptoms associated with cardiovascular disease in rats. In: Proc. Symp. on Phytoestrogen Research Methods: Chemistry, Analysis, and Biological Properties. Tuscon, AZ. Poster #23.
- Barnes, S., M. Kirk, and L. Coward. 1994. Isoflavones and their conjugates in soy foods: extraction conditions and analysis by HPLC—Mass spectrometry. *J. Agric. Food Chem.* 42:2466–2474.
- Bidner, T. D., R. A. Merkel, and E. R. Miller. 1972. Effect of a combination of diethylstilbestrol and, methyltestosterone on performance, carcass traits, serum, and muscle characteristics of pigs. *J. Anim. Sci.* 35:525–533.
- Blazquez, E., and C. L. Quijada. 1968. The effect of a high-fat diet on glucose, insulin sensitivity, and plasma insulin in rats. *J. Endocrinol.* 42:489–494.
- Boleman, S. J., S. L. Boleman, T. D. Bidner, K. W. McMillin, and C. J. Monelzun. 1995. Effects of *postmortem* time of calcium chloride injection on beef tenderness and drip, cooking, and total loss. *Meat Sci.* 39:35–41.
- Brannaman, J. L., L. L. Christian, M. F. Rothschild, and E. A. Kline. 1984. Prediction equations for estimating lean quantity in 15- to 50-kg pigs. *J. Anim. Sci.* 59:991–996.
- Cook, D. R. 1998. The effect of dietary soybean isoflavones on the rate and efficiency of growth and carcass muscle content in pigs and rats. Ph.D. dissertation. Iowa State Univ., Ames.
- DeWilde, R. O., and H. Lauwers. 1984. The effect of parenteral use of estradiol, progesterone, testosterone, and trenbolone on growth and carcass composition in pigs. *J. Anim. Sci.* 59:1501–1509.
- Higbie, A. D. 1997. Prediction of swine body composition by total body electrical conductivity (TOBEC). M.S. thesis. Louisiana State Univ., Baton Rouge.
- Kelly, G. E., C. Nelson, M. A. Waring, G. E. Joannou, and A. Y. Reeder. 1993. Metabolites of dietary (soya) isoflavones in human urine. *Clin. Chim. Acta* 223:9–22.
- Kudou, S., Y. Fleury, D. Welti, D. Magnolato, T. Uchida, K. Kitamura, and K. Okubo. 1991. Malonyl isoflavone glycosides in soybean seeds (*glycine max* MERRILL). *Agric. Biol. Chem.* 55:2227–2233.
- Kurzer, M. S., and X. Xu. 1997. Dietary phytoestrogens. *Annu. Rev. Nutr.* 17:353–381.
- Laborde, C. J., A. M. Chapa, D. W. Burleigh, D. J. Salgado, and J. M. Fernandez. 1995. Effects of processing and storage on the measurement of nitrogenous compounds in ovine blood. *Small Rum. Res.* 17:159–166.
- Martin, P. M., K. B. Horowitz, D. S. Ryan, and W. L. McGuire. 1978. Phytoestrogen interaction with estrogen receptors in human breast cancer cells. *J. Endocrinol.* 103:1860–1867.
- Martinez, M., C. López-Bote, G. Sancho, and J. Ventanas. 1992. Effects of trenbolone acetate on swine carcass characteristics and backfat composition. *Can. J. Anim. Sci.* 72:969–972.
- McCutcheon, S. N., and D. E. Bauman. 1986. Effect of chronic growth hormone treatment on responses to epinephrine and thyrotropin-releasing hormone in lactating cows. *J. Dairy Sci.* 69:44–51.
- NPPC. 1991. Procedures to Evaluate Market Hogs. 3rd ed. National Pork Producers Council, Des Moines, IA.
- NRC. 1998. Nutrient Requirements of Swine. 10th ed. National Academy Press, Washington, DC.
- Plimpton, R. F., Jr., and H. S. Teague. 1972. Influence of sex and hormone treatment on performance and carcass composition of swine. *J. Anim. Sci.* 35:1166–1175.
- Reinli, K., and G. Block. 1996. Phytoestrogen content of foods—a compendium of literature values. *Nutr. Cancer* 26:123–148.
- Steel, R. G. D., and J. H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. 2nd ed. McGraw-Hill, New York.
- Thiagarajan, D. G., M. R. Bennink, L. D. Bourquin, and F. A. Kavas. 1998. Prevention of precancerous colonic lesions in rats by soy flakes, soy flour, genistein, and calcium. *Am. J. Clin. Nutr.* 68:1394S–1399S.
- Thompson, D. L., Jr., L. L. Southern, R. L. St. George, L. S. Jones, and F. Garza, Jr. 1985. Active immunization of prepubertal boars against testosterone: testicular and endocrine responses at 14 months of age. *J. Anim. Sci.* 61:1498–1504.
- Winters, T. A., and W. J. Banz. 1997. Soy phytoestrogens and mammalian physiology: Preliminary results. Available at: <http://www.siu.edu/~tw3a/soypro2.htm>. Accessed Aug. 13, 1998.

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