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Assessment of the feeding value of South Dakota-grown field peas (*Pisum sativum* L.) for growing pigs[1,2]

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ABSTRACT: Four experiments were conducted to investigate the feeding value of South Dakota-grown field peas (*Pisum sativum* L.) for growing pigs. In Exp. 1, 96 pigs (initial BW = 22 ± 3.35 kg) were allotted to four treatment groups (four pigs per pen, six replicate pens per treatment) and fed growing (0.95% Lys) and finishing (0.68% Lys) diets containing 0, 12, 24, or 36% field peas (as-fed basis). There were no differences among the treatment groups in ADG, ADFI, or G:F. Likewise, there were no differences in backfat thickness or lean meat percent among treatment groups, but pigs fed diets containing 12, 24, or 36% field peas had greater ($P < 0.05$) loin depths than pigs fed the control diet. In Exp. 2, 120 pigs (initial BW = 7.8 ± 1.04 kg) were allotted to four treatment groups 2 wk after weaning. Pigs were then fed diets containing 0, 6, 12, or 18% field peas (as-fed basis) during the following 4 wk. There were five pigs per pen and six replicate pens per treatment. Results of the experiment showed no differences in ADG, ADFI, or G:F among treatment groups. In Exp. 3, apparent (AID) and standardized (SID) ileal digestibility coefficients of CP and AA in field peas and soybean meal were measured using six individually penned growing pigs (initial BW = 36.5 ± 2.1 kg) arranged in a repeated 3 × 3 Latin square design. The AID for Met, Trp, Cys, and Ser, and the SID for Met, Trp, and Cys were lower ($P < 0.05$) in field peas than in soybean meal; but for CP and all other AA, no differences in AID or SID were observed between the two feed ingredients. Experiment 4 was an energy balance experiment conducted to measure the DE and ME concentrations in field peas and corn. Six growing pigs (initial BW = 85.5 ± 6.5 kg) were placed in metabolism cages and fed diets based on field peas or corn and arranged in a two-period switch-back design. The DE values for field peas and corn (3,864 and 3,879 kcal/kg DM, respectively) were similar, but the ME of corn was higher ($P < 0.05$) than the ME of field peas (3,825 vs. 3,741 kcal ME/kg DM). The results from the current experiments demonstrate that the nutrients in South Dakota-grown field peas are highly digestible by growing pigs. Therefore, such field peas may be included in diets for nursery pigs and growing-finishing pigs in amounts of at least 18 and 36%, respectively, without negatively affecting pig performance.

Key Words: Amino acids, Digestibility, Energy, Field Peas, Pigs

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Introduction

Field peas (*Pisum sativum* L.) are grown in the upper Midwest, but they are usually not included in diets for swine. Instead, domestically grown field peas are most often consumed by other livestock species. Because of the high nutritional quality of pea protein, field peas may be a potential substitute for corn and soybean meal in diets for pigs. Indeed, field peas are often included in diets for swine in Australia, Canada, and Europe, and the nutritional value of field peas has been reported from numerous research experiments in those countries (Castell, 1990; Carrouée and Gatel, 1995; Stefanyshyn-Cote et al., 1998). However, very limited research has been conducted with field peas grown in the United States. Because of differences in climate, soil, varieties, and agronomic practices, domestically grown field peas may have different nutritional properties than the peas grown in other parts of the world. Therefore, there is a need for investigating the feeding value of domestically grown field peas for swine.

The objectives of the current experiments were to assess the feeding value of South Dakota-grown field

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

Period:	Growing				Finishing			
Item Field peas, %:	0	12	24	36	0	12	24	36
Ingredients, %								
Corn	72.65	64.37	56.05	47.69	81.99	72.99	65.83	58.51
Field peas	—	12.0	24.0	36.0	—	12.0	24.0	36.0
Soybean meal, 44%	23.0	19.0	15.0	11.0	15.0	11.75	6.6	1.5
Soybean oil	2.0	2.3	2.6	2.95	1.0	1.3	1.6	1.9
Limestone	0.90	0.85	0.85	0.85	0.75	0.75	0.75	0.75
Dicalcium phosphate	0.80	0.85	0.85	0.85	0.70	0.70	0.70	0.75
L-Lysine HCl	0.15	0.11	0.08	0.04	0.06	—	—	—
DL-Methionine	—	0.01	0.04	0.07	—	—	—	0.02
L-Threonine	—	0.01	0.02	0.03	—	—	—	0.03
L-Tryptophan	—	—	0.01	0.02	—	0.01	0.02	0.04
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Vitamin premix[a]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Micromineral premix[b]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Nutrients (calculated)								
ME, kcal/kg	3,384	3,384	3,383	3,384	3,365	3,364	3,366	3,364
Ca, %	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
P, %	0.5	0.5	0.5	0.5	0.45	0.45	0.45	0.45
CP, %	16.1	16.1	16.2	16.2	13.4	13.7	13.3	13.0
Arginine, %	1.01	1.08	1.14	1.21	0.79	0.87	0.91	0.94
Histidine, %	0.44	0.43	0.42	0.41	0.36	0.36	0.35	0.33
Isoleucine, %	0.66	0.65	0.64	0.63	0.53	0.53	0.50	0.48
Leucine, %	1.51	1.45	1.39	1.33	1.32	1.29	1.20	1.12
Lysine, %	0.95	0.95	0.95	0.95	0.68	0.68	0.68	0.68
Methionine, %	0.26	0.26	0.27	0.29	0.23	0.22	0.20	0.20
Methionine + cysteine, %	0.56	0.55	0.55	0.55	0.49	0.47	0.44	0.42
Phenylalanine, %	0.78	0.78	0.78	0.78	0.65	0.66	0.64	0.61
Phenylalanine + tyrosine, %	1.36	1.35	1.35	1.34	1.11	1.12	1.08	1.04
Threonine, %	0.61	0.61	0.61	0.61	0.50	0.50	0.50	0.50
Tryptophan, %	0.18	0.18	0.18	0.18	0.14	0.14	0.14	0.14
Valine, %	0.76	0.75	0.74	0.73	0.63	0.63	0.61	0.58

[a]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 5,000 IU; vitamin D_3, 500 IU; vitamin E, 44 IU; vitamin K_3, 2.2 mg; thiamin, 1.5 mg; riboflavin, 5 mg; pyridoxine, 2.0 mg; vitamin B_{12}, 0.025 mg; D-pantothenic acid, 13.2 mg; niacin, 25 mg; folic acid, 1.5 mg; biotin, 0.2 mg; choline, 1,250 mg.

[b]Provided the following quantities of minerals per kilogram of complete diet: Se, 0.30 mg as sodium selenite; I, 0.30 mg as potassium iodate; Cu, 25 mg as copper sulfate; Mn, 25 mg as manganese sulfate; Fe, 120 mg as iron sulfate; Zn, 125 mg as zinc oxide.

peas for growing pigs by measuring performance and carcass quality of growing pigs fed diets containing field peas and to measure digestibility coefficients of AA and energy in field peas.

Materials and Methods

General Procedures

Four experiments were conducted to assess the feeding value of field peas for growing pigs. The South Dakota State University Animal Care and Use Committee approved the experiments. Pigs used in each experiment were the offspring of Landrace × Yorkshire × Duroc sows mated to Hampshire × Duroc boars. In all four experiments, field peas (Carneval) grown and harvested in South Dakota in the year 2000 were used; Carneval is a smooth, white-flowered variety. Before mixing the experimental diets, the peas were ground through a hammer mill using a 4.7-mm screen.

Experiment 1

Ninety-six growing pigs (initial BW = 22.2 kg ± 3.35 kg) were allotted to one of four experimental groups based on BW, ancestry, and sex in a randomized complete block design. Pigs were housed four per pen with six replicate pens per treatment group in an environmentally controlled building. A two-hole feeder and a nipple drinker were installed in each pen. During the initial 50 d of the experiment, pigs were fed growing diets, whereas finishing diets were provided for the remaining 69 d. Pigs were slaughtered at a commercial abattoir at a weight of 109.9 ± 7.96 kg.

Four growing diets (0.95% Lys) and four finishing diets (0.68% Lys) were formulated (Table 1). In both the growing and the finishing diets, field peas were included at concentrations of 0, 12, 24, or 36% (as-fed basis). To maintain a constant concentration of indispensable AA across diets, crystalline Met, Thr, and Trp were added to the diets as the amount of field peas increased, and the amount of crystalline Lys was re-

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

Item	Phase: 1	2			
Field peas, %:	0	0	6	12	18
Ingredient composition, %					
Corn	51.7	64.92	60.92	56.92	52.91
Field peas	—	—	6.0	12.0	18.0
Soybean meal, 44%	18.5	25.0	23.0	21.0	19.0
Spray dried plasma protein	3.5	—	—	—	—
Dried whey powder	15.0	—	—	—	—
Fish meal	8.0	5.0	5.0	5.0	5.0
Soybean oil	2.0	3.0	3.0	3.0	3.0
Limestone	0.4	0.65	0.65	0.65	0.65
Dicalcium phosphate	0.15	0.85	0.85	0.85	0.85
L-Lysine·HCl	0.12	0.05	0.03	0.01	—
DL-Methionine	—	0.03	0.04	0.05	0.07
L-Threonine	0.03	—	0.01	0.01	0.01
L-Tryptophan	—	—	—	0.01	0.01
Salt	0.4	0.3	0.3	0.3	0.3
Vitamin premix[a]	0.1	0.1	0.1	0.1	0.1
Micro mineral premix[b]	0.1	0.1	0.1	0.1	0.1
Nutrients (calculated)					
ME, kcal/kg	3,400	3,435	3,427	3,420	3,412
CP, %	22.0	19.5	19.5	19.5	19.6
Ca, %	0.8	0.80	0.80	0.80	0.80
P, %	0.7	0.65	0.65	0.65	0.65
Arginine, %	1.44	1.23	1.30	1.30	1.42
Histidine, %	0.60	0.53	0.53	0.52	0.52
Isoleucine, %	0.91	0.81	0.80	0.80	0.80
Leucine, %	1.84	1.72	1.70	1.67	1.64
Lysine, %	1.50	1.16	1.15	1.15	1.16
Methionine, %	0.40	0.38	0.38	0.39	0.40
Methionine + cysteine, %	0.87	0.71	0.71	0.70	0.71
Phenylalanine, %	1.06	0.92	0.92	0.92	0.92
Phenylalanine + tyrosine, %	1.86	1.61	1.61	1.61	1.61
Threonine, %	0.99	0.75	0.75	0.75	0.75
Tryptophan, %	0.27	0.23	0.23	0.22	0.22
Valine, %	1.09	0.92	0.92	0.91	0.91

[a]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 5,000 IU; vitamin D_3, 500 IU; vitamin E, 44 IU; vitamin K_3, 2.2 mg; thiamin, 1.5 mg; riboflavin, 5 mg; pyridoxine, 2.0 mg; vitamin B_{12}, 0.025 mg; D-pantothenic acid, 13.2 mg; niacin, 25 mg; folic acid, 1.5 mg; biotin, 0.2 mg; choline, 1,250 mg.

[b]Provided the following quantities of minerals per kilogram of complete diet: Se, 0.30 mg as sodium selenite; I, 0.30 mg as potassium iodate; Cu, 25 mg as copper sulfate; Mn, 25 mg as manganese sulfate; Fe, 120 mg as iron sulfate; Zn, 125 mg as zinc oxide.

duced. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998). Feed was provided on an ad libitum basis, and water was available at all times.

Pig weights were recorded at the beginning of the experiment, at the end of the growing period, and at the conclusion of the experiment. Feed allotment to each pen was recorded daily, and feed remaining in the feeders was recorded each time pigs were weighed. At the end of the experiment, ADFI, ADG, and G:F were calculated for each pen and period and for the entire experimental period. At slaughter, hot carcass weight, backfat thickness, and loin muscle depth were recorded for each pig and the lean meat percent was calculated (NPB, 2000).

Data were analyzed by ANOVA using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). The model included treatment as the main effect. Linear and quadratic effects of the inclusion of field peas were analyzed using a contrast statement, and an alpha level of 0.05 was used to assess significance.

Experiment 2

Experiment 2 was conducted to investigate the effect of field pea-based diets on nursery pig performance during the third to the sixth week postweaning. One hundred twenty pigs were weaned at 21 ± 2 d of age. During the initial 14 d after weaning, pigs were fed a common 22% CP starter diet (Table 2). Two weeks after weaning, all pigs were weighed and randomly allotted to one of four experimental groups based on ancestry, sex, and BW in a randomized complete block design. The initial average BW was 7.8 ± 1.04 kg. There were six replicate pens per treatment group and five pigs per pen. Pigs were housed in an environmentally controlled nursery

Table 3. Ingredient composition of diets (as-fed basis), Exp. 3

Ingredient, %	Field pea diet	Soybean meal diet	N-free diet
Field peas	77.5	—	—
Soybean meal, 44%	—	37.5	—
Solka floc	—	—	5.0
Dextrose	5.0	5.0	5.0
Soybean oil	4.0	4.0	4.0
Chromic oxide	0.25	0.25	0.25
Dicalcium phosphate	1.65	2.0	3.2
Limestone	0.7	0.4	—
Salt	0.4	0.4	0.4
Vitamin premix[a]	0.1	0.1	0.1
Micromineral premix[b]	0.1	0.1	0.1
Cornstarch	10.30	50.25	81.95

[a]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 5,000 IU; vitamin D_3, 500 IU; vitamin E, 44 IU; vitamin K_3, 2.2 mg; thiamin, 1.5 mg; riboflavin, 5 mg; pyridoxine, 2.0 mg; vitamin B_{12}, 0.025 mg; D-pantothenic acid, 13.2 mg; niacin, 25 mg; folic acid, 1.5 mg; biotin, 0.2 mg; choline, 1,250 mg.

[b]Provided the following quantities of minerals per kilogram of complete diet: Se, 0.30 mg as sodium selenite; I, 0.30 mg as potassium iodate; Cu, 25 mg as copper sulfate; Mn, 25 mg as manganese sulfate; Fe, 120 mg as iron sulfate; Zn, 125 mg as zinc oxide.

building throughout the 4-wk experimental period. The initial temperature was set at 28°C and decreased by 1°C each week. A feeder was placed at the front gate of each pen and a nipple drinker was suspended at one side panel. An expanded-metal plastic-coated floor was provided in each pen. Throughout the experiment, pigs had free access to feed and water.

Four experimental diets were formulated to contain 0, 6, 12, or 18% field peas (as-fed basis), respectively (Table 2). For each 6% peas that were included in the diets, 2% soybean meal and approximately 4% corn were removed. Included in all diets were 5% fish meal and 3% soybean oil. Crystalline AA were included to balance the AA concentration of the diets to meet current requirement estimates (NRC, 1998). Minerals and vitamins were also included to meet or exceed current requirement estimates (NRC, 1998).

Individual pig weights were recorded at the beginning and at the end of the experimental period. The amount of feed provided in each feeder was recorded daily, and residual feed was weighed at the end of the experiment and subtracted from the total amount of feed supplied in the feeder to calculate total feed disappearance. Within each pen, ADG and ADFI were summarized at the end of the experiment, and G:F was calculated. Data were analyzed statistically using procedures similar to those outlined for Exp. 1.

Experiment 3

Experiment 3 was designed to measure apparent (**AID**) and standardized (**SID**) ileal digestibility coefficients for AA in field peas and soybean meal by growing pigs. Six barrows (initial BW = 36.5 ± 2.1 kg) were equipped with a T-cannula in the distal ileum using

Table 4. Analyzed nutrient composition of diets (as-fed basis), Exp. 3

Nutrients, %	Field pea diet	Soybean meal diet	N-free diet
CP	16.85	17.10	—
Ca[a]	0.7	0.7	0.7
P[a]	0.6	0.6	0.6
Indispensable AA			
Arginine	1.23	1.04	—
Histidine	0.37	0.40	—
Isoleucine	0.65	0.68	—
Leucine	1.24	1.18	—
Lysine	1.15	0.96	—
Methionine	0.21	0.30	—
Phenylalanine	0.80	0.77	—
Threonine	0.81	0.87	—
Tryptophan	0.11	0.20	—
Valine	0.70	0.68	—
Dispensible AA			
Alanine	0.69	0.65	—
Aspartic acid	1.69	1.69	—
Cysteine	0.19	0.19	—
Glutamic acid	2.48	2.66	—
Glycine	0.61	0.60	—
Proline	0.65	0.74	—
Serine	0.47	0.51	—
Tyrosine	0.55	0.55	—

[a]Values for Ca and P were calculated rather than analyzed.

procedures adapted from Stein et al. (1998). Following the surgery, pigs were housed individually in 1.2- × 1-m pens in an environmentally controlled building. Room temperature was set at 22°C. A feeder and a nipple drinker were installed in each pen.

Three diets were prepared (Tables 3 and 4). Diet 1 contained field peas at a concentration of 77.5% (as-fed basis), whereas Diet 2 contained soybean meal in the amount of 37.5% (as-fed basis). Field peas and soybean meal were the only AA-containing ingredients in these diets. Diet 3 was a protein-free diet. Dextrose and soybean oil were included in all diets at 5% and 4%, respectively. Chromic oxide (0.25%) was included in all diets as an inert marker. Solka floc, a synthetic source of fiber, was included in Diet 3 (5%), and vitamins and minerals were included in all diets at concentrations that met or exceeded requirement estimates for growing pigs (NRC, 1998). Feed was supplied in amounts equal to three times the maintenance energy requirement (i.e., 106 kcal ME/kg$^{0.75}$) for the pigs and divided into two daily meals. Water was available at all times.

Pigs were arranged in a repeated 3 × 3 Latin square design with animals and periods making up the rows and the columns, respectively. Each experimental period lasted 7 d. The initial 5 d of each period were used as an adaptation to the diet, whereas the remaining 2 d were used for digesta collections in 12-h periods as described by Stein et al. (1999). Briefly, a plastic bag was attached to the cannula barrel and digesta flowing into the bag were collected. Bags were removed whenever they were filled with digesta, or at least once every

30 min, and immediately frozen at −20°C to prevent bacterial degradation of the digesta proteins.

At the end of the experiment, samples were thawed, mixed within animal and diet, and a subsample was taken for chemical analysis. All digesta samples were freeze-dried and finely ground before chemical analysis. Dry matter and Kjeldahl N were analyzed in duplicate samples of digesta and diets (AOAC, 2000). Amino acids were analyzed in duplicate samples on a Chrom-tech HPLC AA analyzer, using ninhydrin for postcolumn derivatization and norleucine as the internal standard (AOAC, 2000). Before analysis, samples were flushed with N and hydrolyzed with 6 *N* HCl for 24 h at 110°C. Methionine and Cys were determined as methionine sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis. Tryptophan was determined after alkaline hydrolysis for 22 h at 110°C. The chromium concentration of diets and digesta samples were determined by atomic spectrophotometry as described by Williams et al. (1962).

The AID for AA in field peas and soybean meal were calculated using Eq. [1] (Stein et al., 1999):

$$AID = \{100 - [(AAd/AAf) \times (Crf/Crd)]\} \times 100 \quad [1]$$

where AID is the apparent ileal digestibility of an AA (%), AAd is the AA concentration in the ileal digesta DM, AAf is the AA concentration in the feed DM, Crf is the chromium concentration in the feed DM, and Crd is the chromium concentration in the ileal digesta DM. The AID for CP was calculated using the same equation.

The basal endogenous loss (**EAL**) to the distal ileum of each AA was determined based on the flow obtained after feeding the protein-free diet using Eq. [2] (Stein et al., 2001):

$$EAL = [AAd \times (Crf/Crd)] \quad [2]$$

where EAL is the basal endogenous loss of an AA (g/kg of DMI), AAd is the concentration of that AA in the digesta DM, Crf is the chromium concentration in the feed DM, and Crd is the chromium concentration in the ileal digesta DM. The basal endogenous flow of CP was determined using the same equation.

By correcting the AID for the EAL for each AA, standardized ileal AA digestibility coefficients (**SID**) were calculated for each diet using Eq. [3] (Stein et al., 2001):

$$SID = [AID + (EAL/AAf)] \quad [3]$$

where SID is the standardized ileal digestibility coefficient (%). The SID for CP was determined using the same equation.

Data were analyzed statistically using the MIXED procedure of SAS (Littell et al., 1996). An analysis of variance was conducted with diets as the main effect. Treatment means were separated using the LSMEANS statement and the PDIFF option of PROC MIXED. An alpha level of 0.05 was used to assess significance between treatment means.

Table 5. Diet composition (as-fed basis), Exp. 4

Item	Field pea diet	Corn diet
Ingredients, %		
Corn	—	97.29
Field peas	97.68	—
Dicalcium phosphate	1.96	2.27
Salt	0.16	0.24
Vitamin premix[a]	0.10	0.10
Micromineral premix[b]	0.10	0.10
Nutrients (analyzed)		
GE, kcal/kg	4,011	4,088
CP, %	21.7	8.7

[a]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 5,000 IU; vitamin D_3, 500 IU; vitamin E, 44 IU; vitamin K_3, 2.2 mg; thiamin, 1.5 mg; riboflavin, 5 mg; pyridoxine, 2.0 mg; vitamin B_{12}, 0.025 mg; D-pantothenic acid, 13.2 mg; niacin, 25 mg; folic acid, 1.5 mg; biotin, 0.2 mg; choline, 1,250 mg.

[b]Provided the following quantities of minerals per kilogram of complete diet: Se, 0.30 mg as sodium selenite; I, 0.30 mg as potassium iodate; Cu, 25 mg as copper sulfate; Mn, 25 mg as manganese sulfate; Fe, 120 mg as iron sulfate; Zn, 125 mg as zinc oxide.

Experiment 4

Experiment 4 was conducted with the objectives of measuring the DE and ME concentrations in field peas and comparing these values to the DE in yellow dent corn. Six growing barrows (initial BW = 85.5 ± 6.5 kg) were placed in metabolism cages and arranged in a two-period switch-back design. Two diets based on field peas or corn were formulated (Table 5) according to procedures appropriate for measuring energy digestibility using the direct method (Adeola, 2001). The daily amount of feed provided per pig was calculated as 2.5 times the maintenance energy requirement and was divided into two equal meals. Water was available to the pigs at all times. Each of the two periods lasted 12 d. After an adaptation period of 5 d, ferric oxide (0.1%) was included in the morning meal on d 6 and the collection of urine was initiated. Urine was collected over a preservative of 6 *N* sulfuric acid added to collection buckets placed under the metabolism cages. Fecal collections were initiated when the marker had passed through the pigs. The daily collections of feces were frozen at −20°C. The daily collections of urine were weighed and mixed, and a 20% subsample was frozen at −20°C. In the morning meal on d 11, ferric oxide was again included in the diet and the urine collections were discontinued. Fecal collections continued until the marker had passed through the pigs. At the end of the experiment, fecal and urine samples were thawed and mixed within animal and diet, and a subsample was taken for chemical analysis. Samples were dried in a forced-air oven and finely ground before analysis. Fecal, urine, and feed samples were analyzed in duplicate for DM and Kjeldahl N (AOAC, 2000). Gross energy was

Table 6. Growth performance and carcass characteristics of growing and finishing pigs fed diets containing graded levels of field peas, Exp. 1[a]

Response Field peas, %:	0	12	24	36	SEM	*P*-value Linear effect	*P*-value Quadratic effect
Average initial BW, kg	22.3	22.2	22.1	22.2	1.48	0.98	0.96
Average final BW, kg	109.0	111.8	111.2	107.8	3.41	0.78	0.38
ADG, g	729	752	748	719	25	0.76	0.31
ADFI, kg (as-fed basis)	2.13	2.22	2.23	2.13	0.08	0.97	0.22
G:F	0.34	0.34	0.34	0.34	0.008	0.62	0.76
Carcass weight, kg	83.5	88.5	87.8	85.3	1.97	0.57	0.06
Backfat, mm	18.4	18.0	20.3	19.7	0.93	0.16	0.90
Loin depth, cm	6.60	7.03	6.95	7.02	0.07	0.001	0.01
Lean, %	54.7	55.5	54.8	55.1	0.34	0.83	0.45

[a]Each mean represents six pens with four pigs per pen.

analyzed in triplicate samples using bomb calorimetry (Parr Instruments, Moline, IL). Following chemical analysis, the amount of energy lost in feces and urine was calculated, and the amount of DE and ME in each of the two diets was calculated using the direct approach (Adeola, 2001). By correcting the energy concentrations in the diets for the non-energy-containing feed ingredients, the amount of energy in each of the two feed ingredients was calculated. By further correcting these values for the DM concentrations in the field peas and corn (91.07% and 89.44%, respectively), the energy concentration in the ingredient DM was estimated. The total-tract N digestibility and N retention for each diet were calculated as well. Results obtained for each diet were compared statistically using procedures similar to those used in Exp. 3.

Results

In Exp. 1, there were no differences in ADFI, ADG, or G:F among treatment groups (Table 6). This was true for the growing period (data not shown), the finishing period (data not shown), and overall for the entire experimental period. At slaughter, there were no differences among treatment groups in the average backfat thickness or the percentage of lean meat. However, pigs fed diets containing 12, 24, or 36% field peas had larger loin depths than pigs fed the control diet (linear and quadratic effect; $P < 0.01$).

The ADG of pigs in Exp. 2 were 423, 436, 433, and 407 g for pigs fed diets containing 0, 6 12, or 18% field peas, respectively (Table 7). These numbers were not different. Likewise, there were no differences in ADFI or G:F among treatment groups.

The AID and SID for CP and AA in field peas and soybean meal are presented in Table 8. For Met, Trp, Cys, and Ser, higher ($P < 0.05$) AID were found in soybean meal than in field peas. The same was true for the SID for Met, Trp, and Cys. However, for CP and for all other AA, no differences between the two feed ingredients in AID or SID were found, although a trend for a higher AID and SID for Thr in soybean bean meal than in field peas was observed ($P = 0.06$ and 0.08, respectively).

Results from Exp. 4 are presented in Table 9. The calculated concentration of DE in the pea-based diet was 3,437 kcal/kg, whereas the DE in the corn-based diet was 3,376 kcal/kg. These numbers were not different. After adjusting for the nonenergy components of the diets, the DE in field peas and corn was calculated (3,519 and 3,470 kcal/kg, respectively). These values correspond to 3,864 and 3,879 kcal DE/kg DM for field peas and corn, respectively, and they did not differ. Pigs fed the pea-based diet had a higher ($P < 0.001$) loss of energy in urine than had the pigs fed the corn-based diet, but the calculated concentration of metabolizable energy was not different between the pea- and the corn-based diets (3,328 and 3,329 kcal/kg, respectively).

Table 7. Growth performance of nursery pigs fed diets containing field peas, Exp. 2[a]

Response Field peas, %:	0	6	12	18	SEM	*P*-value Linear effect	*P*-value Quadratic effect
Average initial BW, kg	7.81	7.81	7.79	7.79	0.68	0.98	0.99
Average finished BW, kg	19.65	20.02	19.90	19.17	1.33	0.79	0.68
ADG, g	423	436	433	407	25	0.64	0.44
ADFI, kg (as-fed basis)	0.66	0.66	0.70	0.64	0.05	0.91	0.54
G:F	0.62	0.64	0.62	0.64	0.015	0.66	0.67

[a]Each mean represents six observations with five pigs per pen.

Table 8. Apparent (AID) and standardized (SID) ileal digestibility coefficients (%) of amino acids in field peas and soybean meal by growing pigs, Exp. 3[a,b,c]

Procedure:	AID				SID			
Item / Diet:	Field peas	Soybean meal	SEM	P-value	Field peas	Soybean meal	SEM	P-value
CP	68.3	72.8	1.93	0.13	79.9	84.5	1.86	0.11
Indispensable AA								
Arginine	88.6	87.9	0.88	0.61	92.8	93.0	0.79	0.85
Histidine	81.8	83.6	1.21	0.37	88.3	89.7	1.19	0.42
Isoleucine	74.9	78.0	1.30	0.13	83.4	86.3	1.35	0.17
Leucine	79.8	79.8	1.05	0.99	85.7	86.1	1.14	0.81
Lysine	83.7	83.1	1.05	0.68	88.1	88.4	1.10	0.84
Methionine	64.7	79.7	1.75	0.001	77.9	89.1	2.58	0.01
Phenylalanine	81.7	81.4	0.92	0.80	86.9	86.9	0.98	0.99
Threonine	71.6	77.7	2.02	0.06	80.2	85.9	2.04	0.08
Tryptophan	61.2	74.7	2.11	0.001	75.4	83.6	2.35	0.03
Valine	66.2	70.2	1.67	0.13	78.2	82.7	1.78	0.11
Dispensible AA								
Alanine	66.4	69.2	1.86	0.32	77.5	81.1	1.83	0.19
Aspartic acid	76.6	76.6	1.14	1.0	83.2	83.3	1.1	0.94
Cysteine	53.7	70.0	3.13	0.004	67.3	83.9	3.19	0.004
Glutamic acid	81.4	81.0	1.24	0.82	87.3	86.6	1.14	0.67
Glycine	56.9	58.6	4.31	0.79	78.4	80.8	3.68	0.65
Proline	43.1	46.7	9.78	0.80	97.2	95.1	11.27	0.90
Serine	62.5	70.0	2.12	0.03	76.1	82.8	2.18	0.06
Tyrosine	77.3	79.7	1.12	0.17	84.7	87.2	1.25	0.19

[a]AID = {100 − [(CP or AA in digesta DM/CP or AA in feed DM) × (chromium in feed DM/chromium in digesta DM)]} × 100%.

[b]SID = [AID + (endogenous losses/intake)] × 100%. Endogenous losses determined after feeding the N-free diet as the following quantities (g/kg DMI): CP, 21.4; arginine, 0.57; histidine, 0.26; isoleucine, 0.60; leucine, 0.80; lysine, 0.55; methionine, 0.30; phenylalanine, 0.46; threonine, 0.76; tryptophan, 0.17; valine, 0.91; alanine, 0.83; aspartic acid, 1.21; cysteine, 0.28; glutamic acid, 1.59; glycine, 1.42; proline, 3.83; serine, 0.69; tyrosine, 0.44.

[c]Data are means of six observations.

After adjusting the two diets for the ingredient content and the ingredient DM, the ME in field peas was calculated at 3,741 kcal/kg DM. This value was lower ($P < 0.05$) than the calculated ME for corn (3,825 kcal/kg DM).

The apparent total-tract N digestibility was higher ($P < 0.05$) for field peas than for corn (93 vs. 89%) and the amount of N absorbed over the 5-d collection period was much higher ($P < 0.001$) when pigs were fed the pea-based diet rather than the corn-based diet (346 vs.

Table 9. Energy and nitrogen balance in field peas and corn, Exp. 4[a,b]

Item	Field peas	Corn	SEM	P-value
GE consumed, kcal	42,367	39,247	1,230	0.10
N intake, g	373	137	8	0.001
GE lost in feces, kcal	2,499	3,009	287	0.24
GE lost in urine, kcal	1,251	509	85	0.001
N lost in feces, g	28	15	3	0.02
N lost in urine, g	182	24	5	0.001
Apparent DE in diet, kcal	3,437	3,376	24	0.10
Apparent digestibility coefficient, energy, %	94.1	92.3	0.65	0.08
Apparent DE in ingredient, kcal	3,519	3,470	24	0.18
Apparent DE in ingredient DM, kcal	3,864	3,879	27	0.68
ME in diet, kcal	3,328	3,329	22	0.98
ME in ingredient, kcal	3,407	3,421	22	0.66
ME in ingredient DM, kcal	3,741	3,825	24	0.04
N absorbed, g	346	122	8	0.001
N retained, g	163	88	9	0.001
N retention, %	44	65	6	0.04
Apparent total-tract N digestibility, %	93	89	0.9	0.03

[a]Data represent total intake and output over the 5-d experimental period.

[b]Data represent means of six observations per treatment.

122 g). Therefore, pigs fed the pea-based diet retained more ($P < 0.001$) N than did pigs fed the corn-based diet (163 vs. 88 g). However, pigs fed the pea-based diet also lost more ($P < 0.001$) N in the urine compared with pigs fed the corn-based diet. As a consequence, the retention of N as a percentage of N intake was lower ($P < 0.05$) in pigs fed the pea-based diet compared with pigs fed the corn-based diet (44 and 65%, respectively).

Discussion

Growth Performance and Carcass Characteristics

In diets for growing and finishing pigs, the inclusion of up to 40% field peas has been reported to not affect pig performance (Carrouée and Gatel, 1995; Thacker and Racz, 2001). In a previous experiment using South Dakota-grown field peas, no decrease in pig performance was observed on the addition of up to 18% field peas in the growing period and 36% field peas in the finishing period (Stein et al., 2002). Thus, results of the current study showing no adverse effects on growth rate or feed conversion of the inclusion of 36% field peas concur with published reports. It should, however, be noted that in the French research as well as in the present experiments, all diets containing field peas were balanced for indispensable AA, ensuring that deficiencies of Met, Thr, or Trp did not limit performance by pigs fed these diets.

Pigs fed diets containing 12, 24, or 36% field peas had increased loin depths compared with pigs fed the control diet. This response was unexpected, but in our previous experiment involving pigs fed 0, 12, 24, or 36% field peas in the finishing period and half that amount in the growing period, a similar observation was reported (Stein et al., 2002). In both experiments, the increase in loin depth did not increase the percentage of lean meat. We do not have an explanation for this observation.

The results of the current investigation indicate that field peas can be included in diets for weanling pigs from 2 wk after weaning in the amount of at least 18% without decreasing pig performance. Inclusion of extruded field peas at 20% in nursery diets during the initial 28 d after weaning was previously accomplished without negatively affecting pig performance (Landblom and Poland, 1998). In French experiments, a 30% inclusion of field peas in diets for nursery pigs from 6 d postweaning did not affect pig performance (Carrouée and Gatel, 1995), whereas an inclusion level of 40% in nursery diets reduced pig growth rate by 8% (Jondreville et al., 1992). Thus, the response obtained in the current study agrees well with previous observations in the United States and in France.

Overall, the results from the two growth performance experiments document that South Dakota-grown field peas can be included in diets for nursery pigs from the third week after weaning, and in diets for growing and finishing pigs, without negatively affecting pig performance. Diets containing field peas must, however, be balanced for all indispensable AA. At the inclusion levels used in the current experiments, most of the soybean meal was replaced in the finishing diet, but there was some soybean meal included in the nursery and the grower diets. Future research is needed to determine whether nursery pigs and growing pigs can tolerate higher inclusion rates of field peas than what were used in the present experiments.

Amino Acid Digestibility

The AID for most AA in field peas were close to the values measured in soybean meal, indicating that the protein in the two feed ingredients has a similar digestibility; however, in contrast to soybean meal, low AID in field peas was observed for Met, Trp, and Cys. A relatively low digestibility of Thr was also observed. Previously, low AID for these same AA have been reported for European varieties of field peas (Leterme et al., 1990; Le Guen et al., 1995; Grala et al., 1999) and for Australian varieties (van Barneveld and Batterham, 1994; Mariscal-Landin et al., 2002). Low AID for Met, Thr, and Cys were also reported in Canadian varieties of field peas by Fan et al. (1994b) and by Fan and Sauer (1995). The AID for Trp was not reported in these experiments. However, Fan and Sauer (1999) measured the AID of AA from six Canadian varieties of field peas and reported that the AID for Trp was the lowest among the indispensable AA for all varieties whereas Met and Thr were second or third lowest. The AID for Cys was the lowest among the dispensable AA for all six varieties. Thus, it can be concluded that the AID for Met, Thr, Trp, and Cys is low in protein from European and Canadian varieties of field peas. Results from the current experiment indicate that this is also the case for South Dakota-grown field peas.

It has been suggested that the reason why Thr, Trp, and the sulfur-containing AA (**SAA**) are poorly digested in field peas compared with other feed ingredients is that pea protein contains albumin, which has a relatively low digestibility. Albumin has a high concentration of Thr, Trp, and SAA, and consequently, an overall low digestibility for these AA is observed (Le Guen et al., 1995). Another contributing factor to the low AID for Cys and Trp in field peas is that the concentration of these AA in pea protein is relatively low. Because of the contribution of endogenous amino acids, a low dietary concentration of an AA tends to result in a low AID for this AA (Fan et al., 1994a). The digestibility of Met may be decreased because of the presence of bulky AA next to Met in pea protein (Canibe and Eggum, 1997). This in turn causes steric hindrances in these peptides that decrease the effectiveness of the enzymatic hydrolysis in the small intestine.

The low digestibility of the SAA and Thr and Trp has an important implication for practical feed formulation because the digestible amounts of these AA easily become limiting for pig performance. In particular, if field peas are included in corn-based diets, Trp may become the first-limiting AA because corn protein also has a low concentration of Trp. Thus, it is important that diets containing field peas be formulated on the basis of digestible amounts of all indispensable AA.

The SID for AA in soybean meal calculated in this experiment are within the range of SID reported in other experiments (NRC, 1998; Stein et al., 2001; van Kempen et al., 2002). To the best of our knowledge, SID have never previously been reported for field peas grown in North America. However, owing to an assumed improved additivity of digestibility coefficients in mixed diets, SID will likely be used in diet formulations in the future (Mosenthin et al., 2000; Jansman et al., 2002). Therefore, SID for AA are needed for all feed ingredients used in mixed diets for swine. The SID for AA in field peas reported in this experiment are slightly higher than the values reported for European and Australian varieties (Leterme et al., 1990; Grosjean et al., 2000; Mariscal-Landin et al., 2002). However, SID are affected by the amount of trypsin inhibitors present in the peas (Grosjean et al., 2000). Although all white-flowered field peas contain relatively low concentrations of trypsin and chymotrypsin inhibitors, differences between varieties exist (Stefanyshyn-Cote et al., 1998). Concentrations of trypsin and chymotrypsin inhibitors were not measured in the field peas used in the current experiments, but, based on the SID that were measured, it can be speculated that the concentrations of these factors were low.

Energy Balance

The direct method was used to estimate the amounts of DE and ME in field peas and in corn. Using this procedure, experimental diets containing only the test feed ingredients and vitamins and minerals are formulated and all the energy in the diet is supplied by the test feed ingredient (Adeola, 2001). This method has been used to measure DE and ME values in different samples of corn (Carr et al., 1995; Adeola and Bajjalieh, 1997; Snow et al., 1998) but has not previously been used to measure the digestibility of energy in field peas. An alternative procedure is to use the difference method, in which diets consisting of the test feed ingredient and an energy-containing basal diet are used. However, if interactions in the energy digestibility occur between the test feed ingredient and the basal diet, then the estimation of energy digestibility in the test feed ingredient may be inaccurate. It has been suggested that the digestibility of nonstarch polysaccharides in field peas interacts with the digestibility in cereal grains (Goodlad and Mathers, 1991). Whether this interaction results in significant changes in energy digestibility or not remains to be seen, but, to avoid this interaction, the direct method was used in the current experiment.

The DE and ME values for corn measured in this experiment correspond well with published values, but the DE and the ME values for field peas are slightly higher than recently published values (Patience et al., 1995; NRC, 1998). However, Zijlstra et al. (1998) measured the energy digestibility in 11 varieties of Canadian-grown field peas and reported a mean DE value of 3,476 kcal/kg. This value corresponds to 3,862 kcal/kg DM. The DE in 19 European varieties of field peas averaged 16.34 MJ/kg DM, which corresponds to 3,904 kcal DE/kg DM (Grosjean et al., 1998). Both of these numbers are close to the DE that was calculated in this experiment (3,864 kcal DE/kg DM).

The total-tract digestibility coefficient for energy in field peas was 94%. Previously, digestibility coefficients between 87 and 90% have been reported (Fan et al., 1994b; Grosjean et al., 1998). It is not clear why a higher digestibility coefficient was observed in this experiment as compared with the previous experiments, but as indicated above, the total amount of DE in field peas corresponds well with numbers obtained in previous experiments.

Because the total-tract digestibility of energy in field peas is comparable to corn, it can be assumed that growing pigs have the ability to effectively digest the carbohydrate fraction in field peas. The carbohydrate fraction in field peas contains higher concentrations of compounds that are resistant to digestion by mammalian enzymes in the small intestine (i.e., α-galactosides, resistant starch, and soluble and insoluble nonstarch polysaccharides) than the carbohydrate fraction in corn and other cereal grains (Canibe and Bach Knudsen, 1997). Therefore, the ileal carbohydrate digestibility for field peas is relatively low; however, because of extensive fermentation in the hindgut of the pigs, most of these components are fermented before the distal colon. Thus, they contribute to the energy status of the pig via the production of short-chain fatty acids that can be absorbed from the cecum and the colon (Canibe et al., 1997).

The amount of ME in a feed ingredient is calculated by subtracting the urinary energy from the amount of digestible energy (Adeola, 2001). Pigs fed the pea-based diet in this experiment lost more than twice the energy in the urine than pigs fed the corn-based diet. This may have been caused by the higher CP concentration of the pea-based diet relative to the corn-based diet (21.5 vs. 8%). As a consequence, the pigs fed the pea-based diet absorbed more protein than their estimated needs and the excesses were excreted in the urine as indicated by much higher urinary N excretions from these pigs than from pigs fed the corn-based diet. Higher N excretion in turn contributed to an elevation of the energy in the urine. However, the ME values for field peas measured in this experiment are higher than previous estimates (Patience et al., 1995; NRC, 1998). This is true in absolute numbers as well as when the ME is expressed as a percentage of the DE. Therefore, the losses of energy in urine appear not to have invalidated the results obtained in the experiment.

In conclusion, results of the present experiment suggest DE and ME values for South Dakota-grown field peas of 3,864 and 3,741 kcal/kg DM, respectively. These numbers are comparable to recent values reported for Canadian- and European-grown field pea varieties. The energy concentration in field peas is almost identical to the energy concentration in corn, thus eliminating the need for making energy adjustments in diets containing field peas.

Implications

South Dakota-grown field peas can be included in diets for nursery pigs in the amount of at least 18%, whereas 36% can be included in diets for growing and finishing pigs. At these inclusion levels, pig performance will not be negatively affected, provided that the diets containing field peas are balanced for their contents of digestible Met, Thr, and Trp. South Dakota-grown field peas have digestibility coefficients for most AA comparable to those in soybean meal, whereas the energy concentration is similar to corn.

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