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Characterization of the nutritional value of air-classified protein and starch fractions of field pea and zero-tannin faba bean in grower pigs[1]

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ABSTRACT: Most pulse (nonoilseed legume) seed flours can be fractionated rapidly and economically by air classification into protein and starch concentrates. The nutritional value of air-classified field pea and faba bean concentrates requires characterization to assess the feeding opportunity for pigs. Thus, the objectives were to characterize the apparent total tract digestibility (ATTD) of DM, OM, energy, starch, CP, fat, and ash; apparent ileal digestibility of CP and starch; standardized ileal digestibility (SID) of AA; and the SID AA, DE, and NE content of air-classified zero-tannin faba bean and field pea protein and starch concentrates in grower pigs. Pulse protein and starch concentrates were compared with soy protein concentrate and corn starch, respectively, as corresponding standards. The corn starch diet served as an N-free diet to correct for basal endogenous AA losses. In a Youden square design, 8 ileal-cannulated barrows (24.9 ± 2.3 kg of BW) were fed 6 diets over 7 periods at 3 times the maintenance DE requirement. Periods encompassed a 5-d diet acclimation, 3-d feces collection, and 3-d ileal digesta collection. The ATTD of GE was 2% greater ($P < 0.05$) for faba bean than soy and was intermediate for field pea protein (95.6, 93.7, and 94.9%, respectively). The ATTD of GE was 3.6% greater ($P < 0.05$) for corn and field pea than faba bean starch (96.2, 95.1, and 92.3%, respectively). The DE content of faba bean was 5.0% greater ($P < 0.05$) than for field pea or soy protein (4.47, 4.23, and 4.26 Mcal/kg, respectively). The DE content of faba bean and field pea was 1.7% greater ($P < 0.05$) than for corn starch (3.72, 3.77, and 3.68 Mcal/kg, respectively). The NE content was 5% greater ($P < 0.05$) for faba bean than field pea and soy protein (3.08, 2.94, and 2.92 Mcal/kg, respectively). The NE content for field pea starch was 2.0% greater ($P < 0.05$) than for corn starch and faba bean starch (2.68, 2.63, and 2.61 Mcal/kg, respectively). Protein concentrates had a 14 and 11% greater ($P < 0.05$) DE and NE content, respectively, than starch concentrates. The SID of Lys was 6.0% greater ($P < 0.05$) for faba bean and field pea protein than soy protein (95.5, 92.6, and 88.7%, respectively). The SID of Lys was 6.0% greater ($P < 0.05$) for faba bean than field pea starch. Nutrient digestibility and digestible nutrient profiles indicated that air-classified fractions of zero-tannin faba bean and field pea constitute concentrated sources of AA and energy for pigs with high nutritional demands.

Key words: air classification, amino acid, digestibility, energy, pig, pulse

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INTRODUCTION

Pulses include nonoilseed legume crops such as field pea, lentil, chickpea, and white bean (Rochfort and Panozzo, 2007). Pulses are commonly grown in Canada primarily for the export market as human food, but excess production, splits, and rejects are diverted to swine feeding. Faba bean is a novel pulse crop of interest because of its greater yield and atmospheric N fixation rate in comparison with field pea (Strydhorst et al., 2008), the local pulse standard in crop rotation to cereal grains.

Air classification is a fast and simple processing technique that separates light from heavy particles in pulse flour by using a stream of air (Vose et al., 1976). The high content of protein (20 to 30%) and starch (40 to 50%) and low lipid content of pulse seeds offers the

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possibility to fractionate and concentrate these main components, yielding high protein and starch concentrates as novel feedstuffs. Pulse concentrates may have functional food, feed, and bioindustrial applications because of the structural characteristics of the starch and protein (Sosulski and Youngs, 1979). The performance and nutrient digestibility of weaned pigs fed air-classified field pea protein concentrate was reported recently (Valencia et al., 2008). However, the digestible nutrient profiles of air-classified faba bean protein and starch concentrates have not been published.

Our hypothesis was that the air-classified protein and starch fractions of zero-tannin faba bean and field pea would have a similar nutritional value as feedstuffs to each other and to soybean protein concentrate (commonly used in pig starter diets) and to corn starch (a highly digestible source of starch), respectively. The objectives of this study were to characterize and compare the apparent total tract digestibility (**ATTD**) of DM, OM, energy, starch, CP, fat, and ash; the apparent ileal digestibility (**AID**) of CP and starch; the standardized ileal digestibility (**SID**) of AA; and the SID AA, DE, and NE content of these feedstuffs in grower pigs.

MATERIALS AND METHODS

The animal protocol for the study was approved by the University of Alberta Animal Care and Use Committee–Livestock and followed established principles (Canadian Council on Animal Care, 1993).

Ingredients, Processing, and Diets

A zero-tannin faba bean sample (var. Snowbird) was grown near Fort Saskatchewan (Alberta, Canada). The sample (Table 1), including the hull, was ground sequentially using a cracking mill (Ferrel-Ross, Bluffton, IN) and an Alpine Contraplex Wide Chamber Pin Mill (type A250, Alpine Aktiengesellschaft, Augsberg, Germany) until 97.5% of the flour reached a particle size of <100 μm at the POS Pilot Plant Corp. (Saskatoon, Saskatchewan, Canada). Subsequently, the flour was air classified using an Alpine Microplex Classifier (model 132MP, Aktiengesellschaft, Augsberg, Germany) at a rotor speed of 11,000 rpm and a feed rate of 32 kg of flour/h. In the process, the CP content was increased from 28% in the seed to 63% in the protein concentrate, and the starch content was enriched from 46% in the seed to 55% in the starch concentrate on a DM basis.

Air-classified field pea protein (Prestige) and starch (Probond; Table 1) were donated by Parrheim Foods (Saskatoon, Saskatchewan, Canada). Soy protein concentrate (Soycomil, Archer Daniels Midland Company, Decatur, IL) and native corn starch (Melojel, National Starch and Chemical Co., Bridgewater, NJ) were used as control protein and starch feedstuffs, respectively.

Analyzed nutrient values for the test ingredients (Table 1) and tabulated nutrient values (NRC, 1998) for soy protein concentrate and corn starch were used in diet formulation. The diets, except for the corn starch diet (N free), were formulated to provide 19% CP, 0.9% Ca, and 0.7% P (Table 2), and were not balanced for energy, fat, or AA content. In the 3 protein concentrate and faba bean starch concentrate diets, the test feedstuff was the sole provider of AA. Soy protein concentrate was added to the field pea starch concentrate diet to reach 19% CP. The diets were fortified with minerals and vitamins (NRC, 1998). Chromic oxide was added to the diets (0.38%, as fed) as the indigestible marker to calculate nutrient digestibility.

Experimental Design and Procedures

The experiment was conducted at the Swine Research and Technology Centre, University of Alberta (Edmonton, Alberta, Canada). Eight crossbred barrows (Large White × Duroc; Hypor, Regina, Saskatchewan, Canada; 24.9 ± 2.3 kg of BW) were surgically fitted with T-cannulas at the distal ileum. The study was designed as a Youden square with 6 diets fed to 8 pigs over 6 periods.

Pigs were housed in an environmentally controlled room that used negative pressure to ventilate. Lights were on from 0800 to 2200 h, and temperature was maintained at 22 ± 2.5°C. Individual pigs were housed in elevated pens that measured 1.52 × 2.46 × 1.14 m (width, length, height), ensuring freedom of movement. The pens were equipped with plastic flooring and the tubing walls were covered with plexiglass. Each pen was equipped with a plastic feeder attached to a front corner of the pen, and 2 nipple drinkers were located nearby.

Pigs were fed at 3 times maintenance (3 × 110 kcal of DE/kg of $BW^{0.75}$; NRC, 1998). The daily feed allowance was divided into 2 meals of equal size offered at approximately 0800 and 1600 h; pigs had free access to water. The 11-d experimental periods consisted of a 5-d diet adaptation, followed sequentially by a 3-d collection of feces and a 3-d collection of ileal digesta. Feces were continuously collected for 72 h by using plastic bags attached to the pig around the anus with a ring system (Van Kleef et al., 1994). Digesta was collected for 12 h from 0800 h by using bags containing 15 mL of 5% formic acid attached to the opened cannula barrel. Collected digesta and feces were pooled by pig within period and frozen at −20°C. Before analyses, feces and digesta were thawed, homogenized, subsampled, and lyophilized. Ingredients, diets, feces, and digesta were ground in a Wiley mill (Thomas-Wiley, Philadelphia, PA) through a 1-mm screen.

Chemical Analyses

Ingredients, diets, digesta, and feces were analyzed for DM by drying at 135°C in an airflow-type oven for 2 h (method 930.15; AOAC, 2003) and CP was analyzed using an N Analyzer (TruSpec CN Determinator, Leco Corp., St. Joseph, MI). Chromic oxide content of diets,

Table 1. Analyzed nutrient content of the experimental ingredients (as-is basis)[1]

	Protein concentrate			Starch concentrate		
Item	Soy	Faba bean	Field pea	Faba bean	Field pea	Corn
Moisture, %	8.52	6.44	7.45	7.54	8.04	10.4
GE, Mcal/kg	4.50	4.73	4.47	4.03	3.95	3.71
CP, %	67.7	63.0	46.5	18.4	7.56	0.76
Crude fiber, %	3.26	0.55	0.92	8.61	0.86	0.12
Ether extract, %	0.35	3.26	2.58	0.96	0.54	0.16
Ca, %	0.36	0.12	0.08	0.13	0.03	0.02
P, %	0.76	0.82	0.75	0.27	0.15	0.02
Ash, %	5.39	5.70	4.87	2.44	1.19	0.08
Starch, %	1.42	1.30	10.7	46.1	68.9	83.1
Amylose, %	—	0.44	3.42	14.5	19.7	—
Amylopectin, %	—	0.86	7.28	31.6	49.2	—
Tannin, %	0.45	1.20	0.75	0.60	0.20	—
TIA,[2] mg/g	<0.50	4.50	4.50	1.30	0.50	—
Indispensable AA, %						
Arg	5.03	5.47	3.87	1.43	0.55	0.02
His	1.73	1.58	1.11	0.46	0.17	0.01
Ile	3.06	2.58	1.98	0.74	0.29	0.02
Leu	5.30	4.77	3.40	1.32	0.49	0.06
Lys	4.31	4.18	3.54	1.21	0.54	0.02
Met	0.93	0.45	0.42	0.13	0.07	0.01
Phe	3.44	2.74	2.30	0.76	0.33	0.03
Thr	2.58	2.20	1.63	0.63	0.28	0.01
Trp	0.92	0.63	0.46	0.16	0.07	0.03
Val	3.26	2.82	2.20	0.83	0.34	0.02
Dispensable AA, %						
Ala	2.90	2.51	1.95	0.76	0.33	0.03
Asp	7.60	6.70	5.17	2.06	0.86	0.04
Cys	0.85	0.70	0.58	0.24	0.14	0.01
Glu	11.89	10.20	7.29	2.91	1.40	0.10
Gly	2.78	2.50	1.89	0.81	0.36	0.01
Ser	2.97	3.00	1.89	0.76	0.32	0.02
Tyr	2.37	2.11	1.54	0.53	0.20	0.01
All AA,[3] %	65.50	57.91	43.13	16.55	7.09	0.47

[1]Tabulated nutrient content for soy protein concentrate and corn starch (NRC, 1998) were used in diet formulation because these analysis results were not available then for soy protein concentrate and corn starch.

[2]Trypsin inhibitor activity.

[3]Sum of AA analyzed for the ingredients.

digesta, and feces was analyzed with a spectrophotometer (model SpectraMax 190, Molecular Devices Corp., Sunnyvale, CA) at 440 nm after ashing at 450°C overnight (Fenton and Fenton, 1979). The GE content of ingredients, diets, and feces was measured by an adiabatic bomb calorimeter (AC-300, Leco Corp.); benzoic acid was used as the standard. Ingredients, diets, and feces were analyzed for ash (method 942.05; AOAC, 2003) and ether extract content (method 920.39; AOAC, 2003).

The starch content of ingredients, diets, feces, and digesta was determined using a spectrophotometer (Jenway 6300, Jenway Ltd., Essex, UK) at 510 nm. The starch content was determined after converting starch to glucose by using an enzyme assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland; method 996.11; AOAC, 2003). The amylose content was measured using an enzyme assay kit (Megazyme International Ireland Ltd.). Separation and quantification of AA in ingredients, diets, and digesta samples were performed using a high-performance liquid chromatograph (Shimadzu, Columbia, MD) with a Fluorichrome detector with precolumn derivatization, using fluoraldehyde as the reagent (Sedgwick et al., 1991). For all AA except Cys and Met, the samples were hydrolyzed with 6 *M* HCl for 24 h at 110°C before injection. A β-amino-*n*-butyric acid and ethanol amine mixture was used as the internal standard. The Cys content was determined as cysteic acid and the Met content was determined as Met sulfone after oxidation with performic acid before hydrolyzing with 6 *M* HCl. The Trp content was not analyzed. The tannin content (Folin and Denis, 1912; method 9648; International Organization for Standardization, 1988; Jansman, 1993) and the trypsin inhibitor activity (method 14902; International Organization for Standardization, 2001) were analyzed by spectrophotometry (Nutrilab, Giessen, the Netherlands).

Calculations and Statistical Analyses

The ATTD of DM, OM, energy, starch, CP, ether extract, and ash and the AID of CP, AA, energy, and

Table 2. Ingredient composition of the experimental diets (as-fed basis)

	Protein concentrate			Starch concentrate		
Ingredient, %	Soy	Faba bean	Field pea	Faba bean	Field pea	Corn
Corn starch concentrate[1]	63.27	58.27	48.27	—	—	92.57
Faba bean starch concentrate	—	—	—	93.27	—	—
Field pea starch concentrate[2]	—	—	—	—	73.27	—
Field pea protein concentrate[3]	—	—	45.00	—	—	—
Faba bean protein concentrate	—	35.00	—	—	—	—
Soy protein concentrate[4]	30.00	—	—	—	20.00	—
Canola oil	2.00	2.00	2.00	2.00	2.00	2.00
Mono-/dicalcium phosphate	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.50	1.50	1.50	1.50	1.50	1.50
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Chromic oxide	0.38	0.38	0.38	0.38	0.38	0.38
KCl	—	—	—	—	—	0.35
$MgK(SO_4)_2$	—	—	—	—	—	0.35
Vitamin premix[5]	0.15	0.15	0.15	0.15	0.15	0.15
Mineral premix[6]	0.15	0.15	0.15	0.15	0.15	0.15
Choline chloride 60%	0.05	0.05	0.05	0.05	0.05	0.05

[1]Melojel (National Starch and Chemical Co., Bridgewater, NJ).

[2]Probond (Parrheim Foods, Saskatoon, Saskatchewan, Canada).

[3]Prestige (Parrheim Foods).

[4]Soycomil (Archer Daniels Midland Company, Decatur, IL).

[5]Provided the following per kilogram of diet: vitamin A, 22,500 IU; vitamin D, 2,250 IU; vitamin E, 60 mg; vitamin K, 3.09 mg; vitamin B_{12}, 0.066 mg; riboflavin, 13.12 mg; pantothenic acid, 46.88 mg; pyridoxine, 4.95 mg; niacin, 71.25 mg; biotin, 0.18 mg.

[6]Provided the following per kilogram of diet: Fe, 127.5 mg as $FeSO_4$; Zn, 225 mg as $ZnSO_4$; Mn, 60 mg as $MnSO_4$; Cu, 150 mg as $CuSO_4$; I, 0.54 mg as $Ca(IO_3)_2$; and Se, 0.45 mg as Na_2SeO_3.

starch of diets were determined using the indicator method (Eq. 2; Stein et al., 2007). Each pig, while being fed the N-free diet, was used to calculate its own basal endogenous AA loss (Eq. 3; Stein et al., 2007). The SID for the dietary AA was calculated using AID and the basal endogenous AA loss (Eq. 7; Stein et al., 2007). The SID AA content in the ingredient was calculated by multiplying the AA content in the ingredient by the corresponding SID for that same AA. For ingredients that provided the sole source of a nutrient, the direct method was used. For diets that had 2 or 3 contributing ingredient sources for the same nutrient, the difference method was used (Adeola, 2001). Digestible energy was calculated using GE multiplied by its digestibility value. The NE content of the ingredients was calculated using a prediction equation (Eq. 4; Noblet et al., 1994), using analyzed nutrients and determined DE content of each ingredient.

The nutrient digestibility values and DE, NE, and SID AA content were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC), with animal as the experimental unit. The model included diet as a fixed effect and period and animal as random effects. Means were separated using the probability of difference ($P <$ 0.05). The model for analyses was

$$Y_{ijkl} = \mu + D_i + A_j + P_k + E_{ijkl},$$

where Y_{ijkl} is the response variable, μ is sample mean, D_i is diet, A_j is animal, P_k is period, and E_{ijkl} is the error.

RESULTS

Pigs remained healthy and readily consumed their feed during the experiment, except for a few occasions when some pigs did not consume the total feed allowance or did not void a sufficient amount of feces. Therefore, the experiment was extended by 1 period to 7 for 4 pigs. The mean BW of the pigs from periods 1 to 7 were 33.7 ± 2.6, 37.4 ± 4.2, 41.1 ± 4.3, 46.2 ± 5.3, 53.4 ± 5.1, 59.0 ± 6.2, and 63.9 ± 4.1 kg, respectively.

The analyzed GE content of the protein and starch concentrates averaged 4.57 and 3.90 Mcal/kg, respectively (Table 1). For protein concentrates, the CP content was 40% greater for soy and faba bean than for field pea; starch content in field pea was eightfold greater than in soy or faba bean protein. For starch concentrates, CP content was 2.4 times greater for faba bean than field pea and was least for corn; starch content in corn was approximately double that in faba bean and was 20% greater than in field pea. The AA content in protein and starch concentrates mimicked CP content. The analyzed nutrient content of the experimental diets is reported in Table 3.

Protein Concentrates

For protein concentrate diets, the ATTD of DM was greater ($P < 0.05$) for faba bean than soy, with field pea being intermediate and not different from either faba bean or soy (Table 4). The ATTD of OM, GE, and CP was not different among protein concentrate

Table 3. Analyzed nutrient content of the experimental diets (as-fed basis)

	Protein concentrate			Starch concentrate		
Item	Soy	Faba bean	Field pea	Faba bean	Field pea	Corn
Moisture, %	7.2	6.8	6.3	6.0	6.5	9.8
GE, Mcal/kg	3.99	4.04	4.17	4.09	3.98	3.71
CP, %	20.2	22.9	21.7	18.3	17.5	2.35
Ether extract, %	2.04	3.91	1.59	2.54	3.27	3.52
Ash, %	5.38	5.50	6.84	5.83	6.64	4.24
Indispensable AA, %						
Arg	1.27	2.05	1.76	1.31	1.47	0.01
His	0.54	0.62	0.62	0.49	0.56	0.01
Ile	0.90	1.09	1.01	0.75	0.94	0.02
Leu	1.46	1.85	1.70	1.29	1.55	0.05
Lys	1.18	1.13	1.17	1.16	1.11	0.01
Met	0.14	0.15	0.19	0.11	0.24	0.01
Phe	0.95	1.06	1.12	0.79	1.00	0.05
Thr	0.74	0.93	0.85	0.65	0.86	0.01
Val	0.97	1.21	1.09	0.90	1.05	0.01
Dispensable AA, %						
Ala	0.81	1.04	0.99	0.73	0.92	0.03
Asp	1.92	2.39	2.59	2.19	2.61	0.04
Cys	0.11	0.14	0.24	0.17	0.14	0.01
Glu	3.08	3.97	3.79	3.17	4.33	0.08
Gly	0.91	1.17	1.13	0.96	1.08	0.02
Ser	1.03	1.20	1.20	0.91	1.09	0.02
Tyr	0.55	0.68	0.60	0.43	0.43	0.01
All AA,[1] %	16.5	20.7	20.1	16.0	19.4	0.37

[1]Sum of AA analyzed for the diets.

diets. The DE content was greatest ($P < 0.05$) for field pea, intermediate for faba bean, and least for soy. The ATTD of ether extract was greatest ($P < 0.05$) for faba bean, intermediate for soy, and least for field pea. The ATTD of ash was greatest ($P < 0.05$) for field pea, intermediate for faba bean, and least for soy.

For protein concentrate diets, the AID of CP was greatest for faba bean and field pea and was 11% less ($P < 0.05$) for soy (Table 5). The AID of starch was similar among protein concentrate diets. The AID of AA, including Lys, Met, and Thr, was not different for faba bean and field pea, but it was, respectively, 6, 8, and 14% less ($P < 0.05$) for soy.

For protein concentrates, the ATTD of GE was greater ($P < 0.05$) for faba bean than soy protein concentrate and was intermediate for field pea (Table 6). The ATTD of CP and starch did not differ among protein concentrates. For protein concentrates, the ATTD of ether extract was greatest ($P < 0.05$) for faba bean, intermediate for soy, and least for field pea.

For protein concentrates, the AID of CP was 11% greater ($P < 0.05$) for field pea and faba bean than for soy (Table 7). The AID of starch did not differ among protein concentrates. The SID of Lys, Met, and Thr did not differ between faba bean and field pea. The SID of Lys and Thr was, respectively, 6 and 10% less ($P < 0.05$) for soy than faba bean and field pea. The SID of Met was 8% less ($P < 0.05$) for soy than faba bean, and was intermediate for field pea.

For protein concentrates, the DE content was 5% greater ($P < 0.05$) for faba bean than field pea or soy (Table 8). The calculated NE content was 5% greater

Table 4. Apparent total tract digestibility of nutrients and energy and DE content (as-fed basis) of the experimental diets

	Protein concentrate			Starch concentrate				
Item	Soy	Faba bean	Field pea	Faba bean	Field pea	Corn	Pooled SEM	*P*-value
DM, %	93.1^{bc}	94.0^{a}	93.8^{ab}	90.9^{d}	92.8^{c}	94.5^{a}	0.36	<0.001
OM, %	96.3^{bc}	96.8^{ab}	96.5^{bc}	93.4^{d}	95.8^{c}	97.3^{a}	0.28	<0.001
GE, %	95.2^{ab}	95.6^{a}	95.2^{a}	92.1^{c}	94.6^{b}	95.9^{a}	0.36	<0.001
DE, Mcal/kg	3.80^{c}	3.87^{b}	3.97^{a}	3.76^{d}	3.77^{d}	3.56^{e}	0.02	<0.001
CP, %	91.0^{ab}	93.8^{a}	92.4^{ab}	88.0^{b}	88.8^{b}	59.1^{c}	1.56	<0.001
Ether extract, %	87.3^{b}	92.0^{a}	79.2^{c}	88.1^{b}	92.0^{a}	89.1^{ab}	1.08	<0.001
Starch, %	100.0^{a}	100.0^{a}	100.0^{a}	99.8^{b}	100.0^{a}	100.0^{a}	0.04	0.038
Ash, %	45.0^{c}	53.0^{b}	62.1^{a}	56.6^{ab}	57.4^{ab}	44.2^{c}	2.61	<0.001

[a–e]Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 5. Apparent ileal digestibility of AA, CP, and starch of the experimental diets

	Protein concentrate			Starch concentrate				
Item, %	Soy	Faba bean	Field pea	Faba bean	Field pea	Corn	Pooled SEM	*P*-value
CP	73.5[b]	82.2[a]	82.5[a]	78.5[ab]	73.0[b]	24.5[c]	2.99	<0.001
Starch	99.3[a]	99.4[a]	99.2[ab]	98.6[bc]	98.2[c]	98.9[ab]	0.25	0.012
Indispensable AA								
Arg	86.7[b]	94.4[a]	93.4[a]	91.8[a]	91.3[a]	—	1.56	0.003
His	86.6[b]	92.9[a]	92.7[a]	92.7[a]	90.8[a]	—	1.12	<0.001
Ile	83.9[b]	89.6[a]	87.8[a]	88.2[a]	86.4[ab]	—	1.29	0.027
Leu	82.8[c]	90.9[a]	88.1[ab]	89.3[ab]	85.8[bc]	—	1.29	0.001
Lys	84.4[c]	90.9[a]	88.3[ab]	91.2[a]	85.6[bc]	—	1.12	0.001
Met	78.6[c]	86.8[ab]	84.1[ab]	82.9[bc]	88.0[a]	—	1.56	0.002
Phe	85.0	89.4	88.4	88.0	86.6	—	1.21	0.064
Thr	71.6[c]	84.8[a]	81.2[ab]	82.5[ab]	79.0[b]	—	1.91	0.001
Val	79.9[c]	87.7[a]	84.8[ab]	86.5[ab]	83.5[bc]	—	1.51	0.005
Dispensable AA								
Ala	74.0[b]	87.2[a]	83.6[a]	83.4[a]	80.5[ab]	—	2.68	0.021
Asp	69.9[c]	89.7[a]	87.4[ab]	89.1[ab]	85.5[b]	—	1.45	<0.001
Cys	57.1	60.0	74.1	71.0	62.1	—	6.21	0.102
Glu	79.7[b]	93.2[a]	91.0[a]	89.8[a]	89.3[a]	—	1.73	<0.001
Gly	53.1[b]	80.5[a]	79.8[a]	76.3[a]	74.0[a]	—	4.07	<0.001
Ser	79.4[c]	87.3[a]	85.4[ab]	85.6[ab]	83.0[bc]	—	1.62	0.007
Tyr	83.8[b]	89.2[a]	87.4[ab]	83.7[b]	79.4[c]	—	1.64	0.002

[a–c]Within a row, means without a common superscript letter differ ($P < 0.05$).

($P < 0.05$) for faba bean than for field pea and soy, which did not differ from each other. The SID Lys content of soy was similar to that of faba bean and was greater ($P < 0.05$) than that of field pea.

Starch Concentrates

For starch concentrate diets, the ATTD of DM, OM, and GE was greatest ($P < 0.05$) for corn, followed by field pea, and was least for faba bean (Table 4). The DE content did not differ between field pea and faba bean, but it was less ($P < 0.05$) for corn. The ATTD of CP was 33% less ($P < 0.05$) for corn than faba bean or field pea, which did not differ. The ATTD of ether extract was greater ($P < 0.05$) for field pea than faba bean; corn starch was intermediate and was not different from faba bean or field pea. The ATTD of starch was 100% for field pea and corn, but was 0.2% less ($P < 0.05$) for the faba bean starch diet. The ATTD of ash did not differ between field pea and faba bean, but it was less ($P < 0.05$) for corn.

For starch concentrate diets, the AID of CP was 66% less ($P < 0.05$) for corn than faba bean and field pea (Table 5). The AID of starch was less ($P < 0.05$) for field pea than corn and was intermediate for faba bean. The AID of Lys was 6% greater ($P < 0.05$) for faba bean than field pea. In contrast, the AID of Met was 6% greater ($P < 0.05$) for field pea than faba bean. The AID of Thr was not different between pulse starch diets.

For starch concentrates, the ATTD of GE did not differ between corn and field pea, but it was less ($P < 0.05$) for faba bean (Table 6). The ATTD of CP was 33% less ($P < 0.05$) for corn starch than faba bean or field pea. The ATTD of ether extract did not differ between field pea and corn, but it was less ($P < 0.05$) for faba bean. The ATTD of starch was 100% for field pea and corn, but it was 0.2% less ($P < 0.05$) for faba bean.

For starch concentrates, the AID of CP was greater ($P < 0.05$) for faba bean than field pea (Table 7). The AID of starch was 1.0% greater ($P < 0.05$) for corn than field pea but was not different between corn and

Table 6. Apparent total tract digestibility of nutrients and energy of the experimental ingredients

	Protein concentrate			Starch concentrate				
Item, %	Soy	Faba bean	Field pea	Faba bean	Field pea	Corn	Pooled SEM	*P*-value
DM	89.5[c]	93.1[ab]	92.8[b]	90.6[c]	93.4[ab]	94.3[a]	0.67	<0.001
OM	93.9[c]	96.1[ab]	95.5[b]	93.1[c]	96.1[ab]	97.2[a]	0.47	<0.001
GE	93.7[bc]	95.6[a]	94.9[ab]	92.3[c]	95.1[a]	96.2[a]	0.63	<0.001
CP	91.0[ab]	93.8[a]	92.4[a]	88.0[b]	88.2[b]	59.1[c]	1.59	<0.001
Ether extract	83.2[c]	96.7[a]	67.9[d]	87.6[c]	94.3[ab]	88.6[bc]	2.27	<0.001
Starch	99.9[ab]	99.9[a]	99.9[a]	99.8[b]	100.0[a]	100.0[a]	0.05	0.033
Ash	48.4[d]	65.8[b]	80.1[a]	54.6[cd]	58.9[bc]	42.1[d]	4.45	<0.001

[a–d]Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 7. The apparent ileal digestibility (AID) of protein and starch and standardized ileal digestibility (SID) of AA of the experimental ingredients

	Protein concentrate			Starch concentrate			
Item, %	Soy	Faba bean	Field pea	Faba bean	Field pea	Pooled SEM	*P*-value
AID							
CP	73.6[bc]	82.2[a]	82.4[a]	78.4[ab]	72.4[c]	2.02	0.001
Starch[1]	99.1[a]	99.3[a]	99.0[a]	98.6[ab]	97.9[b]	0.27	0.022
SID							
Indispensable AA							
Arg	95.7	100.2	100.3	100.9	99.4	1.64	0.056
His	90.6[b]	96.4[a]	96.3[a]	97.2[a]	94.9[a]	1.13	0.001
Ile	87.7[b]	92.9[a]	91.3[a]	93.0[a]	90.5[ab]	1.39	0.032
Leu	87.3[c]	94.5[a]	92.0[ab]	94.5[a]	90.3[bc]	1.38	0.001
Lys	88.7[d]	95.5[ab]	92.6[bc]	95.6[a]	90.3[cd]	1.27	<0.001
Met	84.8[b]	92.7[a]	88.8[ab]	90.7[a]	91.7[a]	1.66	0.016
Phe	88.9	93.2	92.0	93.1	90.8	1.31	0.069
Thr	81.2[c]	92.4[ab]	89.6[ab]	93.6[a]	87.6[b]	2.40	<0.001
Val	85.6[b]	92.2[a]	90.0[a]	92.9[a]	89.1[a]	1.70	0.008
Dispensable AA							
Ala	88.4	98.5	95.6	99.7	93.9	3.60	0.077
Asp	77.0[c]	94.6[a]	92.0[ab]	94.5[a]	89.6[b]	1.76	<0.001
Cys	70.6	71.5	81.0	80.5	74.2	6.75	0.549
Glu	84.0[b]	96.7[a]	94.7[a]	94.1[a]	92.2[a]	1.65	0.001
Gly	81.6	97.4	98.4	97.4	99.0	4.79	0.063
Ser	86.7[b]	93.9[a]	92.0[ab]	94.3[a]	90.4[ab]	1.90	0.011
Tyr	89.4[bc]	94.2[a]	92.8[ab]	91.0[abc]	87.3[c]	1.86	0.042

[a–d]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]The AID of starch for corn starch was 98.9.

faba bean. The SID of Lys and Thr was, respectively, 5 and 6% greater ($P < 0.05$) for faba bean than field pea, but was not different for Met.

For starch concentrates, the DE content did not differ between faba bean and field pea, but it was less ($P < 0.05$) for corn (Table 8). The calculated NE content

Table 8. Standardized ileal digestible (SID) AA content and DE and NE content of the experimental ingredients (as-fed basis)[1]

	Protein concentrate			Starch concentrate[2]			
Item, %	Soy	Faba bean	Field pea	Faba bean	Field pea	Pooled SEM	*P*-value
DE, Mcal/kg	4.26[b]	4.47[a]	4.23[b]	3.72[cd]	3.77[c]	0.03	<0.001
NE, Mcal/kg	2.92[b]	3.08[a]	2.94[b]	2.61[d]	2.68[c]	0.02	<0.001
Indispensable AA							
Arg	4.86[b]	5.41[a]	3.87[c]	1.44[d]	0.55[e]	0.06	<0.001
His	1.58[a]	1.51[b]	1.07[c]	0.45[d]	0.16[e]	0.02	<0.001
Ile	2.72[a]	2.36[b]	1.80[c]	0.67[d]	0.27[e]	0.04	<0.001
Leu	4.67[a]	4.45[b]	3.12[c]	1.25[d]	0.44[e]	0.06	<0.001
Lys	3.86[a]	3.95[a]	3.27[b]	1.16[c]	0.49[d]	0.04	<0.001
Met	0.79[a]	0.41[b]	0.37[c]	0.12[d]	0.06[e]	0.01	<0.001
Phe	3.09[a]	2.52[b]	2.12[c]	0.70[d]	0.30[e]	0.03	<0.001
Thr	2.11[a]	2.01[b]	1.46[c]	0.59[d]	0.24[e]	0.05	<0.001
Val	2.81[a]	2.57[b]	1.98[c]	0.78[d]	0.30[e]	0.04	<0.001
Dispensable AA							
Ala	2.60[a]	2.44[a]	1.86[b]	0.76[c]	0.30[d]	0.09	<0.001
Asp	5.37[b]	5.93[a]	4.52[c]	1.83[d]	0.74[e]	0.11	<0.001
Cys	0.60[a]	0.50[ab]	0.47[b]	0.19[c]	0.10[c]	0.04	<0.001
Glu	10.1[a]	9.79[a]	6.90[b]	2.74[c]	1.29[d]	0.18	<0.001
Gly	2.29[a]	2.41[a]	1.85[b]	0.79[c]	0.36[d]	0.12	<0.001
Ser	2.61[b]	2.79[a]	1.74[c]	0.71[d]	0.29[e]	0.04	<0.001
Tyr	2.13[a]	1.97[b]	1.42[c]	0.48[d]	0.18[e]	0.03	<0.001

[a–e]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]SID AA content was standardized to 92.4% of DM.

[2]The DE and NE content of corn starch was 3.68 and 2.63 Mcal/kg, respectively.

did not differ between corn and faba bean, but it was 2% less ($P < 0.05$) than for field pea.

Protein vs. Starch Concentrates

For diets, the diet DE content was less ($P < 0.05$) for starch than protein concentrate diets (Table 4). The ATTD of CP was greater ($P < 0.05$) in faba bean protein concentrate than faba bean and field pea starch concentrate diets.

For ingredients, the ATTD of CP for faba bean and field pea starch concentrates was less ($P < 0.05$) than for faba bean and field pea protein concentrates (Table 6). Protein concentrates had greater ($P < 0.05$) DE and NE content than starch concentrates (Table 8).

DISCUSSION

Enrichment of Protein and Starch Fractions

The efficiency of the air-classification process can be expressed as the protein enrichment factor: the CP content of the fine-protein fraction divided by the CP content of the feedstock (Bergthaller et al., 2001). For air-classified faba bean protein in the present study, the factor was 2.2; this was much greater than the 1.4 (Vose et al., 1976) and 1.9 (Colonna et al., 1980) reported previously for dehulled faba bean. The field pea protein and soy protein concentrates used in the present study were commercial products prepared by air classification and wet fractionation, respectively; information was not available on the nutrient content of their feedstocks. Soy protein concentrate is typically produced by wet fractionation. In comparison with wet fractionation, air classification does not require the use of aqueous solutions to separate fractions. Consequently, drying and disposal of the waste effluent is not required. Dry fractionation may cause fewer changes in the functional properties and chemical structure of the flour components compared with wet fractionation (Cloutt et al., 1987). Faba bean is more easily fractionated than field pea (Colonna et al., 1980) because faba bean has more uniform large starch granules (15 to 30 μm) compared with the mixed population of small-diameter (0 to 5 μm) and medium-diameter (10 to 20 μm) granules found in field pea. Thus, dry milling followed by air classification was a fast, simple, and economic process to produce unmodified faba bean and field pea protein and starch fractions of acceptable purity for feed application.

Energy Digestibility

For faba bean, the ATTD of energy of the protein concentrate was greater than for soy and the ATTD of the starch concentrate was less than for corn. The greater ATTD of energy in the protein concentrates could be due to the greater fat and reduced fiber content of faba bean and field pea protein concentrates compared with the soy protein concentrate. The greater fiber content (8.6%) of faba bean starch concentrate indicates that the hulls mostly separated with the coarse starch fraction (Sosulski and Youngs, 1979) and contributed to reducing its GE digestibility. The starch of nondehulled field pea contained 8.4% crude fiber and that of nondehulled faba bean contained 10 to 11% crude fiber (Vose et al., 1976). This greater fiber content was not observed using dehulled seeds for air classification (Colonna et al., 1980). Dehulling before air classification reduces the fiber content for feed applications and the tan coloration of starch enhances its appearance. The DE content was not different for faba bean and field pea starch concentrates and was similar for faba bean and corn starch. The NE content of corn starch and faba bean starch was not different but was less than that of field pea starch. The small particle size of the feedstuffs tested may provide an explanation for the greater nutrient digestibility values reported in the present study. The recommended particle size for swine rations is 600 μm (Wondra et al., 1995). To separate protein from starch granules and attain a greater efficiency of air classification, most of the pulse flour (>95%) should be milled at <100 μm. With a decreased particle size, the ratio of surface area to volume increases, leading to more binding sites for the hydrolyzing enzymes in the digestive tract, thereby increasing nutrient digestibility (Crevieu et al., 1997). The high energy digestibility of faba bean and field pea fractions in the present study endorses the inclusion of these pulse concentrates in diet formulations for young pigs with high nutrient demands. The small particle size of air-classified pulse fractions would nonetheless dictate pelleting to prevent separation of fines in feeds. Pelleting is already the standard in presentation form for commercial nursery diets for weaned pigs.

CP and AA Digestibility

The ATTD of CP was similar among protein concentrates and among starch concentrates, except for corn starch. In contrast, the ATTD for CP was greater for soy protein concentrate than for air-classified field pea protein concentrate diets fed to weaned pigs (Valencia et al., 2008). The authors attributed the difference to a greater content of antinutritional factors (**ANF**) in field pea compared with soy protein concentrate. However, the SID of AA for soy protein concentrate in the study by Van Kempen et al. (2002) was similar to our values, further validating our results. Previously, the AID and SID of AA were reported to be greater for soy protein concentrate than for soybean meal (Fastinger and Mahan, 2003). The difference was attributed to a reduced particle size for the concentrate, similar to our explanation for the greater AID and SID of AA in faba bean and field pea protein concentrates. The major family of storage proteins of faba bean and field pea is the family of globulin proteins [i.e., legumin and vicilin; Boulter (1983)]. These proteins closely resemble each other (Argos et al., 1985) in faba bean and field pea (Jackson et al., 1969). Legumin contains more Trp, Cys, and Met than vicilin in these pulses but has less Lys and Ile (Boulter et al., 1973). The storage protein comparable with legumin in soybean is glycinin, and that comparable with vicilin is conglycinin (Boulter, 1983). When the analyzed total nutrient content of the ingredients was used, the ratio of Lys (the first-limiting AA to swine) to CP could be calculated for the present study. The ratio was greatest for field pea (0.08), intermediate for faba bean (0.07), and least for soy protein concentrate (0.06). This ratio indicates that the protein quality of the field pea and faba bean protein concentrates was superior to that of soy protein concentrate. Similarly, the AA composition of globulins indicates that the Lys content for soybean glycinin (3.8%) was less than that of faba bean (4.4%) and field pea (4.8%) legumins (Derbyshire et al., 1976). The greater Lys-to-CP ratio in our pulse protein concentrates would therefore support the formulation of starter pig diets with a low CP content to minimize the incidence of both postweaning diarrhea and N excretion in urine. Considering the greater AID of CP and AA and SID of AA of air-classified faba bean and field pea protein concentrate, an advantage for nutrient management exists in including these instead of soy protein concentrate in diets for weaned pigs.

Starch Digestibility

The ATTD and the AID of starch was 100%, except for faba bean starch (99.8%). Many factors contribute to the rate and extent of starch digestion. The starch polymers are subunits of amylose and amylopectin (Buleon et al., 1998). In the present study, faba bean and field pea protein concentrate contained 0.44 and 3.42% amylose and 0.86 and 7.28% amylopectin, respectively. Faba bean and field pea starch concentrates contained 14.5 and 19.7% amylose and 31.6 and 49.2% amylopectin, respectively. The amylase-to-amylopectin ratio is one of many factors that affect the rate of digestion of starches (Hoover and Zhou, 2003). A high amylose content is associated with a more resistant starch formation (Sievert and Pomeranz, 1989). According to x-ray diffraction crystallography, pulse starches belong to type C, a combination of type A and type B granules (Zobel, 1988). Type C starch is digested slower by porcine pancreatic α-amylase than is native corn starch, which belongs to type A (Hizukuri, 1985) and has a greater rate of digestion (Hoover and Sosulski, 1985). The type C starch present and the milling of faba bean with hulls may explain the 0.2% decreased digestibility of faba bean starch compared with corn starch. The AID of starch in raw faba bean was not improved by dehulling (Van der Poel et al., 1992a). Fine milling disrupts the 3-dimensional structure of faba bean and field pea starch (Colonna et al. 1980), thereby increasing protein and AA digestibility. Fine milling could also have reduced the content of native resistant starch that otherwise would have bypassed the small intestine intact and undergone microbial fermentation in the hindgut.

ANF and Antigenic Proteins

Legume seeds contain a variety of ANF that reduce the digestibility of protein and carbohydrates in pigs, such as condensed tannins, lectins, and trypsin inhibitors (Van der Poel et al., 1992b). Trypsin inhibitors and lectins are the primary ANF in field pea (Lallès, 1993). In colored-flowering varieties of faba bean, tannins are more relevant (Jansman et al., 1995) and are present mainly in the seed coat (Marquardt et al., 1977). Therefore, tannins would have been concentrated in our nondehulled faba bean starch fraction. However, the faba bean variety used in this study (Snowbird) was a white-flowering variety with a reduced content of tannin (<1%). The ATTD of OM for the field pea protein concentrate diet improves with age (Valencia et al., 2008); thus, increased maturity of the gastrointestinal tract reduces negative effects associated with ANF in field pea. In our study, protein concentrates were fed to grower pigs with more mature digestive tracts. Negative effects of ANF were not observed in our study, as was evident by the generally greater nutrient digestibility compared with soy protein concentrate and corn starch. Tannins and trypsin inhibitors may have concentrated in the protein fractions in our study (Table 1), but these did not reduce nutrient digestibility of the faba bean and field pea fractions. Lectins may also concentrate in the fine-particle protein fraction of air-classified pulse flour (Van der Poel et al., 1990) and thereby reduce nutrient digestibility (Le Guen et al., 1995). In aquaculture, air-classified faba bean and field pea protein concentrates were reported to have greater nutrient digestibility than raw field pea or faba bean (Booth et al., 2001), indicating that the ANF content was small in the protein fraction, similar to our observations.

Soybean products can cause immunological reactions in weaned pigs, leading to hypersensitivity reactions (Lenehan et al., 2007). Approximately 35 antigenic proteins have been identified in soybean (Pedersen, 1989); soy vacuolar protein, glycinin, and β-conglycinin are recognized as the most allergenic proteins (van de Lagemaat et al., 2007). The hypersensitivity is most evident with soybean meal compared with further processed soy protein concentrate or isolate (Li et al., 1991), and the response varies according to the production method used (Wang et al., 2004). In soybean meal, residual antigenic activity may exist even after conventional crushing and solvent-extraction processing (Li et al., 1991). In pigs weaned at 28 d, faba bean and field pea can cause systemic immune responses, and these responses are much stronger with vicilin proteins than with legumin proteins (Salgado et al., 2002). In contrast, we previously reported that weaned pigs could be fed up to 40% faba bean of the same variety (Snowbird) used in the present study, replacing soybean meal in diets for pigs beginning 2 wk postweaning, indicating that the content of ANF or antipoetic factors present in zero-tannin faba bean did not have negative effects on growth performance (Omogbenigun et al., 2006).

In summary, the results of this study indicate that the air-classified faba bean and field pea protein concentrate have greater ATTD and AID of energy, protein, starch, DM, and OM and greater SID Lys than soy protein concentrate. The starch in the starch concentrates of these pulses was also highly digestible. Therefore, these concentrates are promising increased-quality proteins and starches for weaned and grower pigs because of the greater nutrient digestibility and similar digestible nutrient profile as international feedstuff standards. High-quality feedstuffs can thus be produced as value-added products from pulse seeds grown in temperate climate zones.

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