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Non Ruminant Nutrition

Reduction of particle size of field peas (*Pisum sativum* L.) increases net energy and digestibility of starch when fed to growing pigs, but there is no difference in nutritional value between peas from the United States and peas from Canada

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Abstract

Two experiments were conducted to test the hypotheses that particle size of field peas and location where peas are grown do not affect apparent total tract digestibility of nutrients and gross energy, digestible energy (**DE**), metabolizable energy (**ME**), and net energy (**NE**), apparent ileal digestibility (**AID**) of starch, or standardized ileal digestibility (**SID**) of crude protein (**CP**) and amino acids (**AA**). In both experiments, 3 sources of field peas were used. One source was obtained from the United States and 2 sources were obtained from Canada (i.e., Canada 1 and Canada 2). The U.S. field peas were ground to 678, 457, or 265 µm, whereas the 2 sources of Canadian peas were ground to 411 and 415 µm, respectively. Therefore, 5 batches of field peas were used in both experiments. A basal diet contained corn and soybean meal as the only source of energy, starch, and AA, and 5 diets containing corn and soybean meal and 50% of each source of field peas were also formulated. The ratio between corn and soybean meal was 1.92:1 in all diets. In experiment 1, an N-free diet was also used to calculate basal endogenous losses of AA and CP, but in experiment 2, no N-free diet was used. In experiment 1, 7 barrows (initial body weight = 60.6 ± 2.1 kg) that had a T-cannula installed in the distal ileum were allotted to a 7 × 7 Latin square design with 7 diets and 7 periods. In experiment 2, 24 pigs (initial body weight = 30.8 ± 1.0 kg) were housed in 6 calorimeter chambers with 4 pigs per chamber. The 6 chambers were allotted to one of the 6 diets using a 6 × 6 Latin square design with 6 consecutive periods of 15 d. Results of experiment 1 demonstrated that the SID of CP and AA was not influenced by the origin of the peas or by the particle size, but the AID of starch increased (linear, $P < 0.001$) as particle size was reduced from 678 to 457 or 265 µm. Results of experiment 2 indicated that growing location did not affect concentrations of DE, ME, or NE of field peas, but concentrations of DE, ME, and NE increased (linear, $P < 0.05$) when particle size was reduced from 678 to 457 or 265 µm. In conclusion, field peas grown in Canada or the United States have the same nutritional value, but starch digestibility and NE increase if the particle size of field peas is reduced.

Lay Summary

The objective of this research was to test the hypothesis that the particle size of field peas and the location where field peas are grown may affect the apparent total tract digestibility of nutrients and gross energy, concentrations of net energy (**NE**), the apparent ileal digestibility of starch, and the standardized ileal digestibility (**SID**) of crude protein (**CP**) and amino acids (**AA**). Results demonstrated that values for SID of CP and AA were not different among field peas grown in the United States and peas grown in Canada, and the SID of AA was not influenced by the particle size of field peas. The growing location of field peas did not affect the NE of diets, but an increase in NE was observed when the particle size of field peas was reduced from 678 to 457 or 265 µm.

Key words: amino acids, energy digestibility, field peas, ileal digestibility, net energy, particle size

Abbreviations: AA, amino acids; AEE, acid hydrolyzed ether extract; AID, apparent ileal digestibility; ATTD, apparent total tract digestibility; CP, crude protein; DE, digestible energy; DM, dry matter; FHP, fasting heat production; GE, gross energy; ME, metabolizable energy; NE, net energy; RQ, respiratory quotient; SID, standardized ileal digestibility; TDF, total dietary fiber; THP, total heat production

Introduction

Field pea (*Pisum sativum* L.) is an annual grain legume crop and is mainly cultivated in areas that are too cold for the cultivation of soybeans (Siddique et al., 2013). Market opportunities for field peas have increased in recent years, and the cost of cultivation is less for peas than for soybeans (Jezierny et al., 2010). The concentration of starch in field peas is less, but crude protein (CP) and amino acids (AA) are greater than in cereal grains (Stein et al., 2016). Therefore, in addition to providing AA, field peas also provide energy to swine diets, which is important because energy is the most expensive component in diets (Patience et al., 2015). As a consequence, it is important to determine the energy value of field peas. Agronomic practices, growing location, and differences among varieties

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may impact the nutritional properties of field peas, including energy digestibility (Stein et al., 2004; Stein and Bohlke, 2007). In vitro energy digestibility of field peas increased by reducing the particle size (Montoya and Leterme, 2011), but there is no information about effects of reducing particle size on concentrations of digestible energy (**DE**), metabolizable energy (**ME**), or net energy (**NE**) in field peas fed to group-housed pigs. Likewise, the digestibility of energy in field peas grown in the United States has not been compared to the digestibility of energy of field peas grown in Canada. Therefore, the objective of this research was to test the null hypothesis that the particle size of field peas and location where field peas are grown do not affect the apparent total tract digestibility (**ATTD**) of nutrients and gross energy (**GE**), concentrations of DE, ME, and NE, the apparent ileal digestibility (**AID**) of starch, and the standardized ileal digestibility (**SID**) of CP and AA when fed to growing pigs.

Materials and Methods

Two experiments were conducted, and the protocols for both experiments were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois before animal work was initiated. Pigs used in both experiments were the offspring of Line 800 boars mated to Camborough females (Pig Improvement Company, Hendersonville, TN, USA).

Experimental diets, animals, and feeding

In both experiments, 3 sources of field peas were used. One source was obtained from the United States (U.S. field peas), and the other 2 sources (CDC Meadow Yellow and CDC Amarillo Yellow) were obtained from Canada (i.e., Canada 1 and Canada 2). The field peas from the United States were from a nonspecified variety and were obtained from a feed mill in North Dakota, USA. The U.S. peas were ground using a hammer mill to 3 different particle sizes with a mean particle size of 678, 457, or 265 µm, whereas the 2 Canadian sources were ground to 411 and 415 µm, respectively. Therefore, 5 batches of field peas were used (Table 1). A basal diet containing corn and soybean meal as the only source of energy, starch, and AA, and 5 diets containing corn, soybean meal, and 50% of each source of field peas were used in both experiments (Tables 2 and 3). The ratio between corn and soybean meal was 1.92:1 in all diets. In experiment 1, an N-free diet was also used to calculate basal endogenous losses of AA and CP. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates for growing pigs (NRC, 2012). All diets contained 0.40% titanium dioxide as an indigestible marker. A sample of the main ingredients and all diets was collected at the time of diet mixing and used for chemical analysis. All diets were fed in a meal form.

In experiment 1, 7 barrows with an average initial body weight of 60.6 ± 2.1 kg were allotted to a 7 × 7 Latin square design with 7 diets and 7 periods (Kim and Stein, 2009). A T-cannula had been surgically inserted in the distal ileum of pigs for collection of ileal digesta (Stein et al., 1998) when pigs had a body weight of approximately 21 kg, and they had been used in a previous experiment, before being fed a common diet for 7 d and then allotted to the diets in this experiment. Pigs were housed in individual pens (1.2 × 1.5 m) in an environmentally controlled room with the ambient temperature maintained between 20 and 24 °C. Pens had smooth sides, and fully slatted tribar floors, and a feeder and a nipple drinker were installed in each pen. Feed allowance was calculated as 3.0 times the maintenance requirement for ME (i.e., 197 kcal ME per kg body weight$^{0.60}$; NRC, 2012) and was adjusted according to the body weight of pigs at the beginning of each period. All pigs had free access to water.

In experiment 2, 24 pigs with an average initial body weight of 30.8 ± 1.0 kg were allotted to 6 diets in a 6 × 6 Latin square design with 6 calorimetry chambers and 6 consecutive periods. Four pigs (i.e., 2 gilts and 2 barrows) were housed in each chamber. The 6 diets were fed to pigs in each chamber in one period, and the same diet was provided only once to pigs in each chamber. Therefore, there were 6 replicate chambers per treatment. Each chamber was equipped with a feeder, a nipple waterer, a fully slatted floor, stainless steel screens for the collection of fecal materials, and urine pans, which allowed for the total, but separate, collection of feces and urine. The temperature in the chambers was maintained between 22 and 23 °C, and the relative humidity inside the chambers was 55%, controlled by temperature and humidity control units (Parameter Generation & Control, Parameter, Black Mountain, NC, USA). The air velocity was 1.13 m^3/min, which was controlled using an airflow meter (AccuValve; Accutrol, LLC, Danbury, CT, USA). Diets were fed for 13 d on an ad libitum basis, but in the morning of day 14, feeders were emptied, and pigs were deprived of feed during the following 36 h. Throughout the experiment, water was freely available.

Sample collection

In experiment 1, each period lasted 7 d, with the initial 5 d being the adaptation period to the diet and ileal digesta were collected on days 6 and 7 for 9 h each day (from 0700 to 1600 hours) following standard procedures (Stein et al., 1998). In short, a plastic bag was attached to the opened cannula barrel using a cable tie, and digesta flowing into the bag were collected. Bags were removed and replaced every time they were filled with ileal digesta or at least once every 30 min and immediately stored at −20 °C to prevent bacterial degradation of AA in the digesta (Lee et al., 2021). At the conclusion of the experiment, ileal digesta samples were thawed at room temperature, mixed, and a subsample was collected, lyophilized, and finely ground in preparation for chemical analysis.

In experiment 2, pigs were fed experimental diets for 13 d, with the initial 7 d being the adaptation period to the diet. From the morning (0700 hours) of day 8 to the morning of day 13, gas analyzers measured O_2 consumption and CO_2 and CH_4 production for the determination of total heat production (**THP**). Fecal and urine samples were also collected quantitatively from days 8 to 13. The initial 24 h of the fasting period was considered the time the animals digested and metabolized the remaining feed in the intestinal tract, whereas gas exchange was measured, and urine was collected, during the following 12 h, which was considered the actual period when animals mobilized endogenous nutrients to produce energy (de Lange et al., 2006). Fasting heat production (**FHP**) was calculated using urine N and measured O_2 consumption and CO_2 and CH_4 production during this period. Therefore, each period lasted 14.5 d.

All pigs were weighed prior to being moved into calorimetry chambers and also at the conclusion of each collection period. Chambers were opened for approximately 1 h daily

Table 1. Analyzed nutrient composition of ingredients[1]

Item, %	Field pea source:	United States			Canada 1	Canada 2	Corn	Soybean meal
	Particle size, µm:	678	457	265	411	415		
Gross energy, kcal/kg		3,846	3,893	3,883	3,841	3,850	3,808	4,106
Dry matter		89.54	89.21	89.33	89.77	89.72	90.52	91.00
Crude protein		19.80	19.63	18.79	19.84	20.03	8.69	44.82
Ash		2.75	2.80	2.84	2.61	2.59	1.20	6.38
Starch		38.62	40.44	40.59	41.86	39.23	63.39	2.22
Acid hydrolyzed ether extract		0.91	0.97	0.99	0.93	0.98	3.56	2.17
Insoluble dietary fiber		15.60	15.79	15.34	15.53	16.40	10.21	15.18
Soluble dietary fiber		1.82	2.33	1.27	1.78	1.91	0.78	0.77
Total dietary fiber		17.42	18.12	16.61	17.31	18.31	10.99	15.96
Sucrose		2.98	2.81	2.97	3.40	1.92	1.09	7.81
Maltose		2.26	2.13	2.18	1.90	2.24	0.06	0.12
Stachyose		2.76	2.61	2.68	3.14	2.73	0.06	5.84
Raffinose		0.77	0.72	0.71	0.67	0.64	0.15	1.14
Indispensable amino acids								
Arg		1.57	1.60	1.56	1.66	1.62	0.40	3.14
His		0.49	0.50	0.48	0.52	0.51	0.22	1.17
Ile		0.94	0.96	0.95	0.98	0.98	0.29	2.29
Leu		1.44	1.46	1.44	1.53	1.52	0.84	3.44
Lys		1.53	1.56	1.52	1.61	1.60	0.30	2.79
Met		0.21	0.21	0.20	0.21	0.21	0.17	0.62
Phe		1.02	1.04	1.02	1.06	1.05	0.37	2.34
Thr		0.72	0.73	0.71	0.75	0.76	0.26	1.66
Trp		0.16	0.16	0.16	0.18	0.17	0.05	0.58
Val		1.00	1.02	0.99	1.05	1.05	0.38	2.25
Total		9.09	9.22	9.02	9.54	9.46	3.29	20.30
Dispensable amino acids								
Ala		0.87	0.89	0.87	0.86	0.88	0.53	1.91
Asp		2.26	2.29	2.24	2.23	2.31	0.52	4.98
Cys		0.32	0.34	0.32	0.31	0.30	0.17	0.64
Glu		3.27	3.31	3.23	3.30	3.33	1.28	7.88
Gly		0.90	0.92	0.89	0.89	0.91	0.33	1.89
Pro		0.80	0.82	0.80	0.81	0.80	0.57	2.17
Ser		0.80	0.81	0.79	0.83	0.88	0.32	1.89
Tyr		0.58	0.60	0.59	0.61	0.60	0.21	1.49
Total		9.81	9.97	9.71	9.85	10.02	3.96	22.84
Total amino acids		19.13	19.41	18.97	19.97	19.80	7.24	43.14
Lys:crude protein[2]		7.61	7.83	7.96	7.94	7.83	3.37	6.03

[1]All values except dry matter are expressed on an 88% dry matter basis.
[2]Lys:CP ratio was calculated by expressing the concentration of Lys in each source of field peas as a percentage of the concentration of CP (Stein et al., 2009).

to feed pigs and to collect feces and urine. Heat production calculations did not include data recorded during this time or during the time it took for the chambers to reach the condition set by the temperature and humidity control unit. To avoid N loss in the urine, 50 mL of 6 *N* HCl was added to each urine pan daily. Feed spillage on the screens was collected daily during the collection period, and the weight of feed spilled was recorded to determine feed intake. Collected feces were dried immediately after collection in a 65 °C forced air drying oven (Thermo Fisher Scientific Inc.; model Heratherm OMH750, Waltham, MA, USA) and ground through a 1-mm screen using a hammer mill (model: MM4; Schutte Buffalo, NY, USA). Collected urine was weighed and mixed, and 10% was stored at −20 °C immediately after collection. At the conclusion of the experiment, urine samples were thawed and mixed within each chamber and period, and 2 subsamples were collected. One urine subsample was lyophilized, and the other subsample was stored at −20 °C until analyzed for N. Likewise, a subsample of the urine collected during the fasting period was stored at −20 °C until analyzed for N.

Table 2. Ingredient composition of experimental diets

Item, %	Basal	Field pea source:	United States			Canada 1	Canada 2	N-free
		Particle size, µm:	678	457	265	411	415	
Field peas	—		50.00	50.00	50.00	50.00	50.00	—
Soybean meal	33.20		16.10	16.10	16.10	16.10	16.10	—
Corn	63.80		30.84	30.84	30.84	30.84	30.84	—
Corn starch	—		—	—	—	—	—	68.15
Soybean oil	—		—	—	—	—	—	4.00
Solka floc[1]	—		—	—	—	—	—	4.00
Dicalcium phosphate	0.90		0.70	0.70	0.70	0.70	0.70	1.75
Ground limestone	0.80		0.98	0.98	0.98	0.98	0.98	0.30
Sucrose	—		—	—	—	—	—	20.00
Sodium chloride	0.40		0.40	0.40	0.40	0.40	0.40	0.40
DL-Met	—		0.08	0.08	0.08	0.08	0.08	—
Vitamin–mineral premix[2]	0.50		0.50	0.50	0.50	0.50	0.50	0.50
Titanium dioxide	0.40		0.40	0.40	0.40	0.40	0.40	0.40
Potassium carbonate	—		—	—	—	—	—	0.40
Magnesium oxide	—		—	—	—	—	—	0.10
Calculated composition								
Metabolizable energy, kcal/kg	3,260		3,258	3,258	3,258	3,258	3,258	—
Crude protein, %	17.99		17.63	17.63	17.63	17.63	17.63	—
Total Ca, %	0.66		0.66	0.66	0.66	0.66	0.66	—
Digestible P[3], %	0.31		0.31	0.31	0.31	0.31	0.31	—

[1]Fiber Sales and Development Corp., Urbana, OH.
[2]The vitamin–micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 10,622 IU; vitamin D_3 as cholecalciferol, 1,660 IU; vitamin E DL-alpha-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.40 mg; thiamin as thiamin mononitrate, 1.08 mg; riboflavin, 6.49 mg; pyridoxine as pyridoxine hydrochloride, 0.98 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.2 mg; niacin, 43.4 mg; folic acid, 1.56 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 123 mg as iron sulfate; I, 1.24 mg as ethylenediamine dihydriodide; Mn, 59.4 mg as manganese hydroxychloride; Se, 0.27 mg as sodium selenite and selenium yeast; and Zn, 124.7 mg as zinc hydroxychloride.
[3]Standardized total tract digestible P.

Chemical analyses

Diet and ingredient samples were analyzed for dry matter (**DM**; method 927.05; AOAC Int., 2019) and ash (method 942.05; AOAC Int., 2019). Gross energy was analyzed using an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL, USA). Benzoic acid was used for standard calibration. The concentration of N was analyzed by combustion (method 990.03; AOAC Int., 2019) using a LECO FP628 analyzer (LECO Corp., Saint Joseph, MI, USA) with subsequent calculation of CP as N × 6.25. All diets and ingredients were also sent to the Agricultural Experiment Station Chemical Laboratories at the University of Missouri (Columbia, MO, USA) and analyzed for AA (method 982.30 E [a, b, c]; AOAC Int., 2019), and total starch was analyzed using the glucoamylase procedure (method 979.10; AOAC Int., 2019). Diet and ingredient samples were also analyzed for acid hydrolyzed ether extract (**AEE**) using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System; Ankom Technology, Macedon, NY, USA) followed by crude fat extraction using petroleum ether (method 2003.06, AOAC Int., 2019) AnkomXT15 Extractor; Ankom Technology. Sugars, including maltose, sucrose, stachyose, and raffinose, were analyzed in diets and ingredients using high-performance liquid chromatography (Dionex App Notes 21 and 92). Insoluble dietary fiber and soluble dietary fiber were analyzed in diets and ingredients according to method 991.43 (AOAC Int., 2019) using the Ankom Dietary Fiber Analyzer (Ankom Technology). Total dietary fiber (**TDF**) was calculated as the sum of insoluble dietary fiber and soluble dietary fiber. The particle size of field peas was determined using 100 g of the ingredient placed on top of test sieves and placed in a vibratory sieve shaker for 15 min. The weight of the material in each of the test sieves was recorded for the calculation of mean particle size (ANSI/ASAE, 2008).

In experiment 1, ileal digesta samples were also analyzed for DM, CP, AA, and starch as described for diets and ingredients. Diets and all ileal digesta samples were analyzed for Ti following the procedure by Myers et al. (2004).

In experiment 2, the lyophilized urine samples and dried fecal samples were analyzed for GE as described for diets and ingredients, and urine samples that were not lyophilized were analyzed for N using the Kjeldahl method (method 984.13; AOAC Int., 2019) on a Kjeltec 8400 (FOSS Inc., Eden Prairie, MN, USA). Fecal samples were also analyzed for TDF, DM, and ash as described for ingredients and diets.

Calculations

In experiment 1, AID of CP, AA, and starch was calculated using analyzed CP, AA, starch, and Ti in diets and ileal digesta (Stein et al., 2007). The basal endogenous losses of CP and AA were calculated from pigs fed the N-free diet, and the SID of CP and AA was calculated by correcting AID values for basal endogenous losses of CP and AA (Stein et al., 2007). For all diets, the contributions of AA and starch from corn and

Table 3. Analyzed nutrient composition of experimental diets containing corn and soybean meal or corn, soybean meal, and 50% field peas, as fed basis

Item, %	Basal	Field pea source:	United States			Canada 1	Canada 2
		Particle size, µm:	678	457	265	411	415
Gross energy, kcal/kg	3,790		3,738	3,780	3,742	3,775	3,765
Dry matter, %	90.33		90.96	91.20	91.23	90.72	90.61
Crude protein, %	17.24		16.47	16.69	17.20	16.14	16.42
AEE[1], %	1.53		1.29	1.78	1.51	1.50	1.50
Ash, %	5.31		5.20	5.53	5.90	5.12	5.09
Insoluble dietary fiber	10.90		14.40	15.70	14.90	14.40	14.50
Soluble dietary fiber	4.40		4.00	0.90	0.20	1.30	6.60
Total dietary fiber	15.30		18.40	16.60	15.10	15.70	21.10
Organic matter[2], %	85.03		85.76	85.67	85.33	85.60	85.52
Starch	42.50		39.00	40.00	40.50	39.20	38.50
Sucrose	3.68		3.11	3.14	3.09	4.34	2.89
Maltose	0.16		1.35	1.35	1.44	0.95	1.40
Stachyose	2.11		2.39	2.61	2.36	2.57	2.43
Raffinose	0.49		0.58	0.68	0.63	0.53	0.55
Indispensable amino acids							
Arg	1.26		1.40	1.50	1.43	1.45	1.43
His	0.51		0.51	0.53	0.50	0.51	0.50
Ile	0.93		0.94	0.98	0.94	0.95	0.93
Leu	1.70		1.59	1.63	1.57	1.60	1.58
Lys	1.10		1.31	1.39	1.33	1.33	1.33
Met	0.30		0.31	0.34	0.34	0.33	0.31
Phe	1.02		1.02	1.06	1.02	1.03	1.01
Thr	0.71		0.72	0.75	0.72	0.73	0.72
Trp	0.23		0.18	0.20	0.18	0.21	0.19
Val	0.99		1.00	1.04	0.99	1.02	1.00
Total	8.75		8.98	9.42	9.02	9.16	9.00
Dispensable amino acids							
Ala	0.98		0.94	0.97	0.93	0.94	0.93
Asp	1.97		2.12	2.22	2.12	2.12	2.12
Cys	0.30		0.31	0.32	0.29	0.31	0.29
Glu	3.47		3.41	3.55	3.38	3.46	3.34
Gly	0.81		0.87	0.90	0.86	0.86	0.86
Pro	1.11		0.98	0.99	0.95	0.97	0.94
Ser	0.81		0.82	0.84	0.81	0.81	0.81
Tyr	0.65		0.60	0.66	0.65	0.64	0.63
Total	10.10		10.05	10.45	9.99	10.11	9.92
Total amino acids	18.85		19.03	19.87	19.01	19.27	18.92

[1]AEE, acid hydrolyzed ether extract.
[2]Organic matter was calculated as dry matter—ash.

soybean meal were subtracted from the AID or SID values for the diets, and the AID and SID of AA and CP and the AID of starch in field peas were calculated by difference (Kong and Adeola, 2014). Contributions of DL-Met to total and digestible Met in the 5 diets containing corn, soybean meal, and field peas were also considered when the AID and SID of Met in field peas were calculated by difference.

In experiment 2, the ATTD of DM, GE, and TDF was calculated for each diet (Adeola, 2001), and the DE and ME in the 6 diets were calculated (NRC, 2012). Data for O_2, CO_2, and CH_4 were averaged within each collection period and for the last 12 h of the fasting period. The THP from pigs during the collection period was calculated using the following equation (Brouwer, 1965):

$$THP_{kcal} = [(3.866 \times O_2 + 1.200 \times CO_2 - 0.518 \times CH_4 - 1.431 \times \text{urine N})],$$

where O_2, CO_2, and CH_4 are expressed in liters, and urine N is expressed in grams. The FHP from pigs during fasting was calculated as described for THP. Heat increment was calculated by subtracting FHP from THP, and the concentration of NE was then calculated (NRC, 2012):

$$NE_{kcal/kg} = \frac{ME(THP - FHP)}{\text{feed intake}},$$

Table 4. Apparent ileal digestibility (AID) of crude protein, starch, and amino acids (AA) in field peas[1,2], experiment 1

Item	Origin of peas:	United States			Canada 1	Canada 2	SEM	*P*-value	Linear effects of particle size[3]
	Particle size, µm:	678	457	265	411	415			
Crude protein		58.99	63.62	65.51	62.40	57.72	3.74	0.446	0.177
Starch		75.24[b]	80.03[ab]	88.49[a]	78.45[b]	76.71[b]	2.44	0.003	<0.001
Indispensable AA									
Arg		81.24	85.67	85.55	82.91	83.55	1.65	0.172	0.041
His		74.51	79.59	75.80	76.82	75.75	2.68	0.632	0.704
Ile		68.31	72.40	69.92	70.96	69.36	3.00	0.847	0.675
Leu		68.76	72.47	69.79	70.79	69.84	3.04	0.908	0.797
Lys		78.42	82.08	79.49	81.14	78.21	2.06	0.538	0.694
Met		66.28	72.77	69.59	69.53	64.61	3.45	0.386	0.452
Phe		69.25	73.52	71.22	71.47	70.58	2.94	0.852	0.610
Thr		61.58	68.17	63.96	65.50	61.48	3.61	0.570	0.611
Trp		56.06	67.06	59.29	66.08	60.84	4.21	0.276	0.568
Val		66.24	70.90	67.00	69.76	67.25	3.13	0.749	0.853
Total		72.09	76.63	74.09	74.73	73.12	2.59	0.724	0.560
Dispensable AA									
Ala		65.41	68.08	63.23	67.06	64.26	3.67	0.818	0.637
Asp		68.68	73.90	69.85	71.38	69.27	3.01	0.677	0.765
Cys		52.64	59.63	48.77	56.06	46.89	4.97	0.322	0.563
Glu		70.19	75.45	69.09	72.39	67.83	4.20	0.596	0.830
Gly		52.36	58.18	53.09	59.02	51.79	5.52	0.648	0.906
Pro		60.32	63.87	58.57	62.12	62.52	4.54	0.873	0.745
Ser		65.93	70.53	67.57	67.69	64.10	3.26	0.629	0.697
Tyr		67.68	75.61	74.08	72.63	71.32	3.01	0.381	0.130
Total		66.21	71.58	66.53	69.27	65.31	3.70	0.659	0.946
Total AA		69.22	74.15	70.41	72.07	69.32	3.10	0.702	0.768

[1]Each least squares mean is the mean of 7 observations per treatment.
[2]Values for the AID of crude protein and AA in field peas were calculated by difference (Kong and Adeola, 2014).
[3]*P*-value for the linear effects of reducing particle size of the U.S. peas.

where ME is in kcal/kg, THP and FHP are in kcal, and feed intake is in kg during the collection period. The respiratory quotient (**RQ**) was calculated as the ratio between CO_2 production and O_2 consumption.

The contribution of DE, ME, and NE from corn and soybean meal to the DE, ME, and NE in the 5 diets containing field peas were subtracted from the DE, ME, and NE in these diets, and the DE, ME, and NE in field peas were calculated by difference (Kong and Adeola, 2014). The difference procedure was also used to calculate the ATTD of GE and TDF in field peas.

Statistical analyses

Model assumptions on the residuals for both experiments were confirmed using the MIXED procedure and the Brown-Forsythe test of the GLM procedure of SAS (SAS Inst. Inc., Cary, NC, USA). The MIXED procedure in SAS was used to generate studentized residuals and outliers were defined as means having residuals greater than 3 or less than −3. However, no outliers were detected in any of the experiments. Data were analyzed with the MIXED procedure of SAS. In experiment 1, the statistical model included the diet as the main effect, and period and animal as random effects. Contrast coefficients were also used to determine the linear effects of reducing particle size of the U.S. peas on the ileal digestibility of CP, AA, and starch. The pig was the experimental unit for all analyses. In experiment 2, the model included diet as the main effect and chamber and period as random effects. Contrast coefficients were also used to determine the linear effects of particle size on the digestibility of energy and nutrients and concentrations of DE, ME, and NE in diets and ingredients. The chamber was the experimental unit. Least-square means were calculated and separated for both experiments and if the model was significant using the PDIFF option with the Tukey's adjustment. Results were considered significant at $P \leq 0.05$.

Results

For both experiments, all pigs consumed their diets throughout the experiment without apparent problems. Analyzed concentrations of energy and nutrients in diets were in accordance with calculated values.

Experiment 1

The AID and SID of CP were not affected by the source of peas or by particle size (Tables 4 and 5). The AID and SID of Arg increased (linear, $P < 0.05$) as particle size was reduced, but for all other AA, neither particle size nor source impacted AID or SID values. The AID of starch increased (linear, $P < 0.001$)

Table 5. Standardized ileal digestibility (SID) of crude protein and amino acids (AA) in field peas[1,2,3], experiment 1

Item	Origin of peas:	United States			Canada 1	Canada 2	SEM	*P*-value	Linear effects of particle size[4]
	Particle size, µm:	678	457	265	411	415			
Crude protein		64.73	69.28	70.85	68.34	63.46	3.74	0.482	0.204
Indispensable AA									
Arg		83.43	87.60	87.65	84.96	85.65	1.65	0.199	0.045
His		76.75	81.68	78.14	79.06	78.06	2.68	0.666	0.682
Ile		70.83	74.74	72.46	73.43	71.92	3.00	0.868	0.673
Leu		71.07	74.69	72.17	73.06	72.16	3.04	0.917	0.783
Lys		80.10	83.59	81.12	82.78	79.84	2.06	0.565	0.706
Met		69.50	75.35	72.17	72.28	67.81	3.45	0.482	0.543
Phe		71.42	75.56	73.41	73.61	72.79	2.94	0.868	0.608
Thr		66.79	73.02	69.19	70.57	66.67	3.61	0.616	0.608
Trp		60.89	71.04	64.15	69.60	65.13	4.21	0.383	0.565
Val		68.90	73.39	69.73	72.32	69.90	3.13	0.777	0.841
Total		74.56	78.90	76.56	77.11	75.58	2.59	0.756	0.562
Dispensable AA									
Ala		69.55	72.01	67.48	71.20	68.47	3.67	0.847	0.654
Asp		70.88	75.94	72.07	73.60	71.47	3.01	0.702	0.764
Cys		56.93	63.71	53.66	60.34	51.74	4.97	0.387	0.624
Glu		72.16	77.29	71.10	74.30	69.87	4.20	0.621	0.837
Gly		61.35	66.67	62.32	68.24	60.96	5.52	0.675	0.876
Pro		87.65	90.81	87.77	89.78	91.81	4.54	0.912	0.982
Ser		69.81	74.26	71.57	71.67	68.06	3.26	0.652	0.677
Tyr		70.75	78.18	76.71	75.33	74.09	3.01	0.448	0.157
Total		69.49	74.62	69.85	72.50	68.64	3.70	0.694	0.940
Total AA		72.09	76.81	73.29	74.87	72.21	3.10	0.736	0.766

[1]Each least squares mean is the mean of 7 observations per treatment.
[2]Values for SID were calculated by correcting values for apparent ileal digestibility for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of dry matter intake) as crude protein, 10.54; Arg, 0.39; His, 0.13; Ile, 0.28; Leu, 0.40; Lys, 0.29; Met, 0.07; Phe, 0.26; Thr, 0.44; Trp, 0.08; Val, 0.31; Ala, 0.43; Asp, 0.58; Cys, 0.16; Glu, 0.76; Gly, 0.97; Pro, 2.68; Ser, 0.37; Tyr, 0.20; and total AA, 6.10.
[3]Values for the AID of crude protein and AA in field peas were calculated by difference (Kong and Adeola, 2014).
[4]*P*-value for the linear effects of reducing particle size of the U.S. peas.

as the particle size of the U.S. peas was reduced from 678 to 265 µm, but there were no differences among the U.S. source ground to 457 µm and the 2 Canadian sources.

Experiment 2

Pig weights at the end of the 6 periods were 41.2, 54.5, 67.1, 80.7, 93.7, and 107.2 kg indicating an average gain of 849 g/d over the 90-d experimental period. Feed intake and daily GE intake of pigs were not different among diets containing field peas from the United States or peas from Canada (Table 6). Intake of TDF was greater ($P < 0.05$) by pigs fed diets containing the Canada 2 peas than by pigs fed the other diets, except for pigs fed the diet containing field peas from the U.S. ground to 678 µm. Fecal weight, fecal GE output, and the ATTD of DM, and GE were not different among pigs fed the basal diet and pigs fed diets containing peas from Canada or field peas from the U.S. ground to 457 µm. However, the ATTD of TDF was greater ($P < 0.05$) in the diet containing the Canada 2 source compared with the other diets. As the particle size of the U.S. field peas was reduced, the weight of feces and excretion of GE in feces were reduced (linear, $P < 0.01$), which resulted in increases (linear, $P < 0.05$) in the ATTD of DM and GE. Intake and fecal excretion of TDF were reduced (linear, $P < 0.05$) by reducing the particle size of the U.S. peas, but the ATTD of TDF was not affected by particle size. Weight of urine and urine excretion of GE were not influenced by experimental diets.

Daily THP was not affected by the origin of peas, but daily THP by pigs was reduced (linear, $P < 0.05$) as the particle size of the U.S. peas was reduced from 648 to 265 µm (Table 7). Daily FHP was not affected by dietary treatments. The RQ was not affected by diets or by the particle size of the U.S. field peas in the fed state nor in the fasted state. On an as-is and a DM basis, DE, ME, and NE were not different among the basal diet and diets containing the U.S. peas ground to 457 µm or diets containing the Canada 1 or the Canada 2 peas. However, DE, ME, and NE in diets containing the U.S. field peas increased (linear, $P < 0.05$) as the particle size was reduced, but no differences were observed in the ME:DE, NE:DE, or NE:ME ratios among diets.

The ATTD of GE was not different among the U.S. peas ground to 457 µm and the 2 sources of peas from Canada, but the ATTD of GE increased (linear, $P = 0.017$) as the particle size of the U.S. peas was reduced from 678 to 265 µm (Table 8). No differences in the ATTD of TDF were observed among treatments, but the ATTD of GE was greater ($P < 0.05$) in the 2 Canadian sources of peas than in the U.S. peas ground to 678 µm. On as-is or DM basis, DE, ME, and NE

Table 6. Intake, output, and the apparent total tract digestibility (ATTD) of energy, dry matter, and total dietary fiber (TDF) from pigs fed corn–soybean meal diet or diets containing corn, soybean meal, and 50% field peas[1], experiment 2 (as fed basis; per one pig)

Item	Basal	Field pea source:	United States			Canada 1	Canada 2	SEM	*P*-value	Linear effects of particle size[2]
		Particle size, µm:	678	457	265	411	415			U.S. sources
Intake										
Feed intake, kg/d	2.66		2.70	2.63	2.49	2.72	2.65	0.19	0.531	0.102
Gross energy, Mcal/d	10.08		10.10	9.92	9.33	10.20	9.97	0.73	0.457	0.109
TDF, g/d	406.93^{c}		497.06^{ab}	438.44^{bc}	376.41^{c}	426.36^{c}	558.59^{a}	33.29	<0.001	<0.001
Fecal excretion										
Dry feces output, kg/d	0.26^{ab}		0.32^{a}	0.28^{ab}	0.25^{b}	0.26^{ab}	0.26^{ab}	0.02	0.036	0.003
Gross energy, kcal/d	1,111^{ab}		1,357^{a}	1,180^{ab}	1,015^{b}	1,124^{ab}	1,097^{ab}	83.33	0.018	0.001
TDF, g/d	95.54		118.38	101.83	92.25	98.64	94.46	8.41	0.120	0.012
Urine excretion										
Urine output, kg/d	5.50		6.30	5.32	6.37	5.91	5.94	1.03	0.951	0.946
Gross energy, kcal/d	292		256	221	260	244	303	44.10	0.287	0.908
ATTD, %										
Dry matter	90.08^{ab}		88.37^{b}	89.54^{ab}	89.93^{ab}	90.43^{a}	90.08^{ab}	0.49	0.045	0.020
Gross energy	88.86^{ab}		86.55^{b}	88.13^{ab}	88.96^{a}	88.99^{a}	88.80^{ab}	0.59	0.023	0.004
TDF	76.38^{b}		76.25^{b}	76.61^{b}	75.22^{b}	76.99^{b}	82.92^{a}	1.23	0.002	0.543

Within a row, means without a common superscript letter are different ($P < 0.05$).
[1]Each least squares mean is the mean of 6 observations per treatment.
[2]*P*-value for the linear effects of reducing particle size of the U.S. peas.

Table 7. Effect of diet composition and source of field peas on energy balance of pigs fed a corn–soybean meal diet or diets containing corn, soybean meal, and 50% field peas[1,2], experiment 2 (per one pig)

Item	Basal	Field pea source:	United States			Canada 1	Canada 2	SEM	*P*-value	Linear effects of particle size[3]
		Particle size, µm:	678	457	265	411	415			U.S. sources
Heat production, kcal/d										
Total heat production	4,402		4,517	4,310	4,135	4,467	4,300	413.84	0.107	0.010
Fasting heat production	2,458		2,431	2,520	2,432	2,462	2,526	254.32	0.991	0.998
Respiratory quotient										
Fasted state	0.66		0.73	0.70	0.79	0.78	0.67	0.07	0.696	0.574
Fed state	1.03		1.00	1.02	1.02	1.02	0.99	0.04	0.751	0.486
Energy values, kcal/kg as-is										
DE	3,367^{a}		3,235^{b}	3,331^{a}	3,329^{a}	3,359^{a}	3,344^{a}	22.18	0.002	0.003
ME	3,258^{a}		3,141^{b}	3,250^{a}	3,225^{ab}	3,269^{a}	3,234^{a}	24.79	0.004	0.010
NE	2,530		2,364	2,576	2,556	2,535	2,562	63.95	0.113	0.022
Energy values, kcal/kg DM										
DE	3,728^{a}		3,556^{b}	3,652^{a}	3,649^{ab}	3,703^{a}	3,690^{a}	24.44	<0.001	0.006
ME	3,607^{a}		3,453^{b}	3,564^{a}	3,535^{ab}	3,603^{a}	3,569^{a}	27.31	0.001	0.021
NE	2,800		2,599	2,825	2,802	2,795	2,827	70.37	0.108	0.027
Energy utilization, %										
ME:DE	96.67		97.09	97.57	96.87	97.31	96.73	0.38	0.282	0.599
NE:DE	75.14		73.10	77.34	76.79	75.46	76.64	1.95	0.558	0.141
NE:ME	77.61		75.28	79.26	79.26	77.55	79.23	1.87	0.547	0.119

Within a row, means without a common superscript letter are different ($P < 0.05$).
[1]Each least squares mean is the mean of 6 observations per treatment.
[2]DM, dry matter; DE, digestible energy; ME, metabolizable energy; NE, net energy.
[3]*P*-value for the linear effects of reducing particle size of the U.S. field peas.

Table 8. Effect of origin and particle size of field peas on apparent total tract digestibility (ATTD) of energy, crude protein, and fiber and energy measurements in growing pigs[1,2], experiment 2

Item	Origin of peas:	United States			Canada 1	Canada 2	SEM	*P*-value	Linear effects of particle size[3]
	Particle size, µm:	678	457	265	411	415			
ATTD, %									
Gross energy		82.04[b]	86.23[ab]	86.23[ab]	88.29[a]	87.35[a]	1.12	0.011	0.017
Total dietary fiber		73.05	75.12	75.94	80.43	80.88	2.03	0.050	0.325
Energy utilization, %									
ME:DE		94.35	95.47	94.09	95.00	93.87	0.68	0.230	0.733
NE:DE		71.08	79.47	78.40	75.77	78.18	3.62	0.394	0.125
NE:ME		75.27	83.20	83.24	79.76	83.22	3.66	0.402	0.113
Energy values, kcal/kg as-is									
DE		3,211[b]	3,403[a]	3,399[a]	3,460[a]	3,428[a]	43.77	0.008	0.007
ME		3,030[b]	3,249[a]	3,198[ab]	3,287[a]	3,217[ab]	46.65	0.007	0.014
NE		2,280	2,704	2,664	2,622	2,676	119.19	0.064	0.020
Energy values, kcal/kg DM									
DE		3,586[b]	3,814[a]	3,805[a]	3,853[a]	3,821[a]	48.85	0.009	0.006
ME		3,384[b]	3,642[a]	3,580[a]	3,660[a]	3,586[a]	52.10	0.007	0.011
NE		2,547	3,031	2,983	2,921	2,982	133.28	0.061	0.019

Within a row, means without a common superscript letter are different ($P < 0.05$).
[1]Each least squares mean is the mean of 6 observations per treatment.
[2]DE, digestible energy; ME, metabolizable energy; NE, net energy.
[3]*P*-value for the linear effects of reducing particle size of the U.S. peas.

in field peas were not different among the U.S. peas ground to 457 µm or the Canada 1 and the Canada 2 peas, but linear ($P < 0.05$) increases in DE, ME, and NE were observed as the particle size of field peas from the United States was reduced.

Discussion

Field peas are a cool-season pulse crop cultivated mainly for human consumption, but they can also be used in pig diets as a source of AA and energy (Stein et al., 2006). The majority of the North American research on field peas as a feed ingredient for pigs is conducted in Canada, but it is not known if the nutritional value of Canadian field peas also is representative of field peas grown in the United States. Therefore, the current research aimed at determining if the nutritional value of field peas grown in the United States is different from that of peas grown in Canada. Because the main growing area for field peas in the United States is in the upper Midwest, with North Dakota being the biggest producer in the United States, big differences in growing conditions are not expected between peas grown in the United States and Canada although day length and summer temperatures are a little bit different between the 2 locations. However, to the best of our knowledge, the DE, ME, and NE of field peas grown in Canada and the United States have not been previously compared. Likewise, we are not aware of data for the impact of particle size of field peas on NE, which is the reason we determined NE in the U.S. field peas ground to 3 different particle sizes. Due to limitations in the number of calorimetry chambers available, it was not possible to also determine the impact of particle size on the Canadian varieties, but it is expected that results obtained for the U.S. field peas are also representative of the Canadian peas.

The chemical composition of the peas used in the current experiment was in agreement with previous data (NRC, 2012). Peas have a lower concentration of starch compared with cereal grains, whereas the concentration of AA in field peas is greater than in cereal grains, but less than in soybean meal (NRC, 2012; Rojas and Stein, 2015; Song et al., 2022). Therefore, field peas will replace both cereal grain and a portion of the soybean meal when included in diets for pigs.

The SID of AA in field peas obtained in experiment 1 is within the range of values reported in previous experiments (Stein et al., 2004; Friesen et al., 2006; Hugman et al., 2021). The observation that a reduction of particle size did not affect the SID of AA and CP indicates that protein-digesting enzymes are as efficient at hydrolyzing the peptide bonds in peas ground to 678 µm as in peas ground to a smaller particle size. This observation is in agreement with results of our previous experiment, which indicated that a reduction of particle size in field peas does not change the SID of AA (Ibagon et al., 2024). A reduction in the particle size of corn does also not influence the SID of AA (Rojas and Stein, 2015), whereas a reduction in the particle size of lupins results in increased AA digestibility (Kim et al., 2009). Nevertheless, the hypothesis that a reduction in the particle size of field peas did not influence the AID or SID of AA was confirmed.

Values for AID of starch that were observed in experiment 1 for field peas ground to 265 µm are in agreement with values reported by Stein and Bohlke (2007), but less than values reported by Woyengo and Zijlstra (2021). Starch in field peas and cereal grains contain amylose and amylopectin, but the digestibility of amylopectin is greater than the digestibility of amylose due to greater access to glycosidic bonds by digestive enzymes in the small intestine (Miles et al., 1985; Regmi et al., 2011). The content of amylose as a percentage of starch in field peas may range from 31% to 72%, whereas amylopectin comprises the remaining starch (Guillon and Champ, 2002). Amylopectin forms a crystalline system in the starch, whereas amylose forms a linear dispersed system (Bach Knudsen, 1997; Cummings and Stephen, 2007; NRC, 2012), which

makes the gelatinized amylopectin more digestible than amylose (Yin et al., 2010).

Grinding reduces resistant starch due to the release of encapsulated starch in the fiber matrix by the rupture of the seed cell matrix during grinding (Sun et al., 2006; Rodriguez et al., 2020). Likewise, decreasing the particle size may change the anatomy of the starch granules, which may increase access of α-amylase to the starch granules, and therefore, increase the digestion of starch (Kim et al., 2002, 2009; Rojas and Stein., 2015). An increase in the digestibility of starch after reduction of the particle size has been reported for lupins, corn, field peas, and wheat (Kim et al., 2002, 2005; Rojas and Stein, 2015; Ibagon et al., 2024). Therefore, the increase in AID of starch that was observed as particle size was reduced from 678 to 457 or 265 µm of field peas used in the current experiment is in agreement with observations from other ingredients, and as a consequence, the hypothesis that a reduction of the particle size of field peas will not affect the AID of starch was rejected. The observation that when ground to the same particle size, no differences in AID of starch or SID of AA were observed between field peas grown in Canada and peas grown in the United States indicates that growing location does not impact nutrient digestibility. The implication of this observation is that data for starch and AA digestibility obtained from research with Canadian peas can also be applied to peas grown in the United States, and the hypothesis that growing location does not affect starch and AA digestibility of field peas was accepted.

The values for ATTD of GE in field peas observed in experiment 2 are in agreement with reported values (Woyengo and Zijlstra, 2021; Adekoya and Adeola, 2023). The observation that a reduction of particle size from 678 to 265 µm increased the ATTD of GE is likely a result of the fact that much of the energy in field peas is from the glucose that is absorbed after digestion of starch. Therefore, the increased AID of starch, resulting from the reduction in particle size is likely the reason for the increased ATTD of GE, and the greater DE, ME, and NE that was observed as the particle size of the U.S. peas was reduced. Improvements in the ATTD of GE and subsequent improvements in DE and ME of corn, as particle size was reduced have been reported (Rojas and Stein, 2015), and results of experiment 2 are also in agreement with in vitro data (Montoya and Leterme, 2011). The observation that DE, ME, and NE of field peas grown in the United States and Canada did not differ when ground to the same particle size is likely a result of the fact that location does not impact nutrient digestibility. It is, therefore, concluded that if field peas grown in different locations are ground to the same target particle size, neither the digestibility of nutrients nor DE, ME, or NE will be different.

The values for THP and FHP observed in the current experiment were greater than some reported values (Noblet et al., 1994; Kim et al., 2018), but in agreement with other values from group-housed pigs (Lee et al., 2024). Contributions from heat increment, physical activity, and maintenance energy are considered when THP is calculated (van Milgen and Noblet, 2003; NRC, 2012). Values for THP and FHP in the current experiment and in the experiment by Lee et al. (2024) were obtained using group-house pigs with feed provided on an ad libitum basis. It is likely that the greater heat production observed in group-housed pigs allowed ad libitum access to feed compared with individually housed pigs fed restricted is a result of increased physical and metabolic activity (Lee et al., 2024).

The DE and ME of the corn–soybean meal diet that were calculated in this experiment were in agreement with values calculated from book values for corn and soybean meal (NRC, 2012). However, the observation that values of DE, ME, and NE in the diets containing 50% field peas ground to 400 or 265 µm were not different from the DE, ME, and NE in the corn–soybean meal diet demonstrates that field peas may be included in corn–soybean meal diets for pigs without changing the energy concentrations of the diets. The ME:DE was 97 on average for all diets, which is within the range of reported values for complete diets (NRC, 2012; Kim and Nyachoti, 2017). The NE:ME for all diets were greater than the 75% that has been reported as an average for conventional diets (Noblet et al., 1994). However, the increased FHP by pigs may have resulted in increased calculated NE in diets and, therefore, increased NE:ME. The observation that NE:DE and ME:DE were not affected by the particle size of the peas is in agreement with recent data indicating that the NE:ME is not affected by the particle size of corn (Lee et al., 2024). The implication of this observation is that prediction equations for NE that are based on DE or ME may be used to predict the increases in NE that are caused by reducing the particle size of field peas. This conclusion is in agreement with data indicating that changes in NE caused by differences in the particle size of corn can be predicted from the changes that are measured in ME values (Lee et al., 2024).

Conclusions

Results indicate that growing location does not affect ileal digestibility of starch and AA or DE, ME, or NE of field peas. The SID of AA was not affected by reducing the particle size of field peas, but the reduction of particle size resulted in increased digestibility of starch. Likewise, the ATTD of GE and DE, ME, and NE were increased by reducing the particle size of field peas from 678 to 457 or 265 µm.

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Conflict of interest statement

The authors declare no real or perceived conflicts of interest.

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