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The effects of thermal treatment of field peas (*Pisum sativum* L.) on nutrient and energy digestibility by growing pigs[1]

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ABSTRACT: An experiment was conducted to measure the effect of thermal treatment on the digestibility of CP, AA, starch, NDF, ADF, and energy in field peas fed to growing pigs. Five pea-containing diets were formulated. The peas included in these diets were either not heat-treated (control) or extruded at 75, 115, or 155°C or pelleted at 75°C. A N-free diet was also included in the experiment to measure basal endogenous losses of CP and AA. The 6 diets were fed to 6 growing pigs (initial BW: 69.3 ± 2.9 kg) that were allotted to dietary treatments in a 6 × 6 Latin square design. A T-cannula was installed in the distal ileum of each pig, allowing for the collection of ileal digesta. Each experimental period lasted 9 d; fecal samples were collected on d 6 and 7, and ileal samples were collected on d 8 and 9 of each period. Apparent ileal digestibilities (AID) for CP, AA, starch, and energy and standardized ileal digestibility values (SID) for CP and AA were calculated. Apparent total tract digestibilities (ATTD) for NDF, ADF, starch, and energy were also calculated. As the extrusion temperature increased, the AID and SID for CP and all AA, except Pro, increased (quadratic, $P < 0.05$). In contrast, except for Arg and Pro, the peas that were pelleted at 75°C had AID and SID for CP and AA that were similar to those obtained for the control peas but less ($P < 0.05$) than the AID for the peas that were extruded at 75°C. The AID for starch and energy increased (linear, $P < 0.001$) as the extrusion temperature increased to 155°C (from 89.8 to 95.9% and from 71.5 to 79.0%, respectively), but the AID for starch and energy in the pelleted diet was not different from the AID in the control diet (90.1 vs. 89.8% and 69.1 vs. 71.5%, respectively). The ATTD for starch varied from 98.6 to 99.7% and did not differ among treatments. Likewise, no differences were observed for the ATTD of NDF and ADF. However, the ATTD for energy in the diets increased from 89.0 to 93.3% (linear and quadratic, $P < 0.05$) as field peas were extruded, and the ATTD for energy in the pelleted diet was also greater ($P < 0.05$) than that of the control diet (91.6 vs. 89.0%). In conclusion, extrusion of field peas increases the AID of CP, AA, starch, and energy and the ATTD of energy. Pelleting field peas at 75°C does not influence the AID of nutrients or energy but improves the ATTD of energy.

Key words: energy digestibility, extrusion, field pea, nutrient digestibility, pig, thermal treatment

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INTRODUCTION

Field peas grown in the United States can be included in corn-based diets fed to growing and finishing pigs in quantities sufficient to supply all supplemental AA without reducing pig performance or carcass quality (Petersen and Spencer, 2006; Stein et al., 2006). Values for the digestibility of AA and energy in US-grown field peas have been reported (Stein et al., 2004). However, data from studies with European-grown field peas have indicated that the digestibility of AA and energy may be improved if field peas are heat-treated before feeding (Canibe and Eggum, 1997; O'Doherty and Keady, 2000; Mariscal-Landín et al., 2002). Extrusion and enzyme supplementation has also been shown to improve AA digestibility in newly weaned pigs fed Canadian-grown field peas (Owusu-Asiedu et al., 2002). Improved protein utilization was reported in rats fed diets containing extruded field peas rather than raw peas (Wang and McIntosh, 1996; Alonso et al., 2001). Extrusion also improved in vitro digestibility of starch (Alonso et al., 2000; Masoero et al., 2005) and in vivo apparent ileal digestibility (**AID**) of starch in pigs fed European-grown field peas (Sun et al., 2006). However, there is no information on the effects of heat treatment of the varieties of field peas that are grown in the United States. Like-

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wise, there is no information on the effects of pelleting on energy and nutrient digestibility of field peas fed to growing pigs, and the effects of extrusion of field peas have not been compared with the effects of pelleting. From a practical standpoint, that is an important question, because many feed mills have pelleting equipment installed but no extruders.

The present experiment was conducted to test the hypothesis that thermal treatment of US-grown field peas in the form of pelleting or extrusion will improve the digestibility of starch, energy, ADF, NDF, CP, and AA by growing pigs.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The experiment was reviewed and approved by the Institutional Animal Care and Use Committee at South Dakota State University.

Six growing pigs (initial BW: 69.3 ± 3.0 kg), originating from the matings of Landrace × Yorkshire × Duroc sows to Hampshire × Duroc boars, had a T-cannula installed in the distal ileum according to procedures adapted from Stein et al. (1998). Pigs were housed individually in 1.2 × 1.8-m pens in an environmentally controlled building, and room temperature was maintained at 20°C.

Pigs were allotted to dietary treatments in a 6 × 6 Latin square design, with 6 periods and 6 animals. Each experimental period lasted 9 d, and each pig received each diet in only 1 period. Feed was provided at a daily level of 3 times the estimated energy requirement for maintenance (i.e., 106 kcal of ME/kg of $BW^{0.75}$; NRC, 1998) in 2 equal meals. Water was available at all times from nipple drinkers.

Diets and Feeding

Six diets were prepared (Tables 1 and 2). Four of the diets contained 85% field peas (as-fed basis) that were either not extruded (control) or extruded at 75, 115, or 155°C; these diets were fed in a meal form. A fifth diet also contained 85% field peas that had not been extruded, but this diet was pelleted at 75°C. The last diet was a N-free diet used to estimate basal endogenous losses of CP and AA. Solka floc, a synthetic source of fiber (Fiber Sales and Development Corp., Urbana, OH), was included in the N-free diet, and dextrose and soybean oil were included in all diets to enhance palatability. Chromic oxide (0.25%) was included in all diets as an inert marker. Vitamins and minerals were included at concentrations that met or exceeded the current requirement estimates for growing pigs (NRC, 1998). Field peas (variety Carneval) used in this experiment were grown and harvested in South Dakota. Carneval is a smooth, white-flowered variety of spring field peas.

Data Recording and Sample Collection

Pig BW were recorded at the beginning of each feeding period, and the daily feed allowance was adjusted at the beginning of each new feeding period according to the recorded BW. On d 6 and 7 of each period, freshly voided fecal samples were collected and stored at –20°C. On d 8 and 9, ileal digesta were collected over 10-h periods by opening the cannula and attaching a plastic bag to the cannula barrel. Digesta flowing into the bag were collected. Bags were removed when filled with digesta, or at least once every 30 min, and immediately stored at –20°C.

Sample Analysis

At the conclusion of the experiment, ileal digesta and fecal samples were thawed, and samples of ileal digesta or fecal samples pooled within pig and period, and a subsample was taken for chemical analysis. Ileal digesta samples were lyophilized, but fecal samples were dried in a forced-air oven. All samples were finely ground before chemical analysis. Samples of peas, diets, ileal digesta, and feces were analyzed for DM (procedure 4.1.06; AOAC, 2000). Crude protein was analyzed in peas, diets, and ileal digesta (Thiex et al., 2002). Gross energy was measured in diets, ileal digesta, and fecal samples using bomb calorimetry (Parr Instruments, Moline, IL). Starch was analyzed in all diets and in the ileal and fecal samples from pigs fed the 5 pea-containing diets using the method of Xiong et al. (1990). Diets and fecal samples from pigs fed pea-containing diets were also analyzed for ADF and NDF (procedure 4.6.03; AOAC, 2000). The AA concentrations in field peas, diets, and digesta samples were determined using an HPLC (Thermo Quest HPLC, Thermo Separation Products Inc., San Jose, CA), with ninhydrin for postcolumn derivatization and norleucine as the internal standard. All samples were hydrolyzed for 24 h at 110°C with 6 *N* HCl before AA analysis (procedure 4.1.11, alternative 3; AOAC, 2000). Methionine and Cys were determined as Met sulfone and cysteic acid, respectively, after cold performic acid oxidation overnight before analysis (procedure 4.1.11, alternative 1; AOAC, 2000). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (procedure 988.15; AOAC, 1995). The Cr concentration of the diets, digesta, and fecal samples was determined by the method of Fenton and Fenton (1979).

Calculations and Statistical Analysis

The AID for CP, AA, starch, and GE in each of the pea-containing diets was calculated as previously described (Stein et al., 2004). The apparent total tract digestibility (**ATTD**) for NDF, ADF, starch, and energy was calculated using the same equation. Likewise, basal endogenous losses of CP and AA and values for standardized ileal digestibility (**SID**) of CP and AA in all pea-con-

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Table 1. Ingredient composition (%) of the experimental diets, as-fed basis

	Diet					
Ingredient	Control	Extruded at 75°C	Extruded at 115°C	Extruded at 155°C	Pelleted at 75°C	N-free
Field peas	85.00	85.00	85.00	85.00	85.00	—
Dextrose	7.65	7.65	7.65	7.65	7.65	10.00
Soybean oil	4.00	4.00	4.00	4.00	4.00	5.00
Cornstarch	—	—	—	—	—	75.75
Solka floc[1]	—	—	—	—	—	5.00
Chromic oxide	0.25	0.25	0.25	0.25	0.25	0.25
Dicalcium phosphate	1.65	1.65	1.65	1.65	1.65	3.25
Limestone	0.70	0.70	0.70	0.70	0.70	—
Salt	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[2]	0.10	0.10	0.10	0.10	0.10	0.10
Micromineral premix[3]	0.25	0.25	0.25	0.25	0.25	0.25

[1]Fiber Sales and Development Corp., Urbana, OH.

[2]Provided the following vitamins per kilogram of complete diet: vitamin A, 5,000 IU as vitamin A acetate; vitamin D_3, 500 IU as D-activated animal sterol; vitamin E, 44 IU as α tocopherol acetate; vitamin K_3, 2.2 mg as menadione dimethylepyrimidinol bisulphite; thiamin, 1.5 mg as thiamine mononitrate; riboflavin, 5 mg; pyridoxin, 2.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.025 mg; D-pantothenic acid, 13.2 mg as Ca pantothenate; niacin, 25 mg; folic acid, 1.5 mg; and biotin, 0.2 mg.

[3]Provided the following minerals per kilogram of complete diet: Cu, 25 mg as $CuSO_4$; Fe, 120 mg as $FeSO_4$; I, 0.3 mg as KIO_3; Mn, 25 mg as $MnSO_4$; Se, 0.3 mg as Na_2SeO_3; and Zn, 125 mg as ZnO.

taining diets were calculated according to Stein et al. (2004).

Data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC; Littell et al., 1996). Linear and quadratic effects of extrusion temperature on the digestibility of energy, starch, ADF, NDF, CP, and AA were analyzed using a contrast statement. The control diet and the 3 diets containing extruded peas were in-

Table 2. Analyzed composition of the experimental diets, as-fed basis

	Diet					
Item	Control	Extruded at 75°C	Extruded at 115°C	Extruded at 155°C	Pelleted at 75°C	N-free[1]
CP, %	17.72	18.05	19.17	18.50	17.76	—
Ca,[2] %	0.70	0.70	0.70	0.70	0.70	0.70
P,[2] %	0.60	0.60	0.60	0.60	0.60	0.60
Starch, %	43.56	43.52	43.53	42.76	43.63	75.45
NDF, %	9.02	7.97	8.46	8.25	8.91	2.74
ADF, %	6.62	5.43	5.93	6.06	5.80	0.81
GE, Mcal/kg	3.987	3.969	3.996	3.996	4.059	4.030
Indispensable AA, %						
Arg	1.35	1.53	1.45	1.55	1.50	—
His	0.38	0.42	0.41	0.41	0.41	—
Ile	0.77	0.80	0.75	0.81	0.79	—
Leu	1.35	1.42	1.36	1.45	1.41	—
Lys	1.33	1.43	1.34	1.42	1.31	—
Met	0.21	0.24	0.20	0.23	0.20	—
Phe	0.92	0.96	0.92	0.97	0.93	—
Thr	0.63	0.70	0.67	0.71	0.67	—
Trp	0.13	0.15	0.15	0.14	0.12	—
Val	0.85	0.88	0.83	0.88	0.88	—
Dispensable AA, %						
Ala	0.74	0.84	0.80	0.85	0.82	—
Asp	1.99	2.17	2.08	2.19	2.10	—
Cys	0.29	0.30	0.31	0.31	0.30	—
Glu	2.93	3.28	3.12	3.33	3.13	—
Gly	0.81	0.82	0.79	0.83	0.79	—
Pro	0.78	0.79	0.74	0.79	0.77	—
Ser	0.78	0.79	0.73	0.78	0.72	—
Tyr	0.48	0.51	0.51	0.55	0.53	—

[1]The N-free diet was not analyzed for CP and AA.

[2]The values for Ca and P were calculated (NRC, 1998) rather than analyzed.

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Table 3. Apparent ileal digestibility (%) of CP and AA in heat-treated field peas[1]

	Diet						P-value[2]	
Item	Control	Extruded at 75°C	Extruded at 115°C	Extruded at 155°C	Pelleted at 75°C	SEM	Linear	Quadratic
CP[3]	73.0	80.3	85.5	84.0	74.4	1.3	0.001	0.004
Indispensable AA								
Arg[3,4]	89.1	93.3	95.0	95.3	90.6	0.5	0.001	0.001
His[3]	83.1	88.6	90.8	89.6	83.8	0.7	0.001	0.001
Ile[3]	74.9	84.7	87.5	88.0	77.9	1.1	0.001	0.001
Leu[3]	79.4	86.9	89.7	89.7	81.2	0.8	0.001	0.001
Lys[3]	87.8	92.5	94.1	93.5	88.6	0.6	0.001	0.001
Met[3]	78.4	88.6	86.6	87.2	76.6	1.2	0.001	0.001
Phe[3]	79.5	87.5	90.8	91.1	81.6	0.8	0.001	0.001
Thr[3]	72.9	82.1	84.5	84.2	72.7	1.2	0.001	0.001
Trp[3]	71.9	80.4	84.5	85.2	72.9	1.6	0.001	0.001
Val[3]	72.8	83.4	86.2	86.1	75.9	1.2	0.001	0.001
Mean[3]	79.0	86.8	89.0	89.0	79.2	0.9	0.001	0.001
Dispensable AA								
Ala[3]	71.4	81.5	84.1	83.6	73.4	1.2	0.001	0.001
Asp[3]	78.7	85.9	88.4	86.4	80.1	0.9	0.001	0.001
Cys[3]	63.1	75.1	80.9	79.3	62.7	1.1	0.001	0.001
Glu[3]	84.0	89.1	91.7	91.2	84.8	0.8	0.001	0.001
Gly[3]	65.5	77.4	79.6	79.9	67.9	2.0	0.001	0.006
Pro	53.9	73.3	74.9	80.3	64.4	5.1	0.001	0.015
Ser[3]	75.4	84.4	87.0	87.1	75.2	1.0	0.001	0.001
Tyr[3]	77.1	84.2	87.7	88.6	78.7	1.0	0.001	0.004
Mean[3]	69.3	79.8	84.3	84.6	73.4	1.7	0.001	0.007
Mean, all AA[3]	77.5	85.7	88.4	88.3	79.7	1.0	0.001	0.001

[1]Values are means of 6 observations per treatment.
[2]Linear and quadratic effects of extrusion temperature.
[3]Pelleted differed from extruded at 75°C ($P < 0.05$).
[4]Pelleted differed from control ($P < 0.05$).

cluded in these analyses. Values for the pelleted diet were contrasted against values for the control diet and for the diet containing peas that were extruded at 75°C. The pig was the experimental unit for all analyses, and an α value of 0.05 was used to assess significance among means.

RESULTS

The AID of CP and all AA increased (linear and quadratic, $P < 0.05$) as the extrusion temperature of field peas increased (Table 3). The AID of the indispensable AA for the diets containing peas that were extruded at 115 or 155°C were 6 to 14 percentage units greater than the values obtained for the control diet, and the average increase in AID was approximately 10 percentage units for the indispensable AA and 15 percentage units for the dispensable AA. The quadratic response to extrusion indicates that the optimum extrusion temperature was from 75 to 115°C, with no further improvement with extrusion at 155°C. The pelleted diet had an AID for Arg that was greater ($P < 0.05$) than the control diet, but for CP and all other AA, no difference between the control diet and the pelleted diet was observed. However, the AID for CP and all AA except Pro were lower ($P < 0.05$) for the pelleted diet than for the diet containing peas extruded at 75°C.

The SID for CP and all AA except Pro (Table 4) were also improved by extrusion (linear and quadratic, $P < 0.05$). The magnitude of the increase obtained by extrusion was similar to the increase that was obtained for AID. As was the case for AID values, the optimum extrusion temperature was between 75 to 115°C. There were no differences in SID between the pelleted diet and the control diet, but the SID for CP and all AA except Pro were lower ($P < 0.05$) for the pelleted diet than for the diet containing peas that were extruded at 75°C.

The AID for starch and energy increased (linear, $P < 0.05$) as the extrusion temperature increased from 0 to 155°C (Table 5). However, there was a tendency for a quadratic response in the AID for energy ($P = 0.09$), which indicated that the greatest AID for energy may have been obtained at an extrusion temperature of 115°C. The AID for starch and energy in the pelleted diet were not different from the values obtained for the control diet, but they were lower ($P < 0.05$) than the values obtained for the diet containing field peas extruded at 75°C.

The ATTD for starch varied between 98.6 and 99.7% and was not affected by treatments, but the ATTD for energy increased (linear and quadratic, $P < 0.05$) as field peas were extruded (from 89.0 to 93.3%). The greatest ATTD for energy was obtained for the diet extruded at

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Table 4. Standardized ileal digestibility (%) of CP and AA in heat-treated field peas[1]

	Diet						*P*-value[2]	
Item	Control	Extruded at 75°C	Extruded at 115°C	Extruded at 155°C	Pelleted at 75°C	SEM	Linear	Quadratic
CP[3]	81.4	88.8	93.5	92.2	83.0	1.7	0.001	0.03
Indispensable AA								
Arg[3]	92.3	96.1	97.9	98.0	93.4	0.5	0.001	0.001
His[3]	87.3	92.4	94.7	93.5	87.7	0.7	0.001	0.001
Ile[3]	81.4	90.1	93.2	93.3	83.4	1.1	0.001	0.001
Leu[3]	84.1	91.0	94.0	93.7	85.3	0.8	0.001	0.001
Lys[3]	91.1	95.3	97.1	96.4	91.7	0.6	0.001	0.001
Met[3]	84.0	92.9	92.6	92.4	82.5	1.2	0.001	0.001
Phe[3]	83.8	91.2	94.6	94.7	85.4	0.8	0.001	0.001
Thr[3]	81.4	89.6	92.4	91.7	80.6	1.2	0.001	0.001
Trp[3]	80.6	87.9	92.0	92.2	82.05	1.7	0.001	0.001
Val[3]	79.5	89.1	92.3	91.8	81.6	1.2	0.001	0.001
Mean[3]	84.5	91.6	94.1	93.8	84.4	0.8	0.001	0.001
Dispensable AA								
Ala[3]	80.5	89.4	92.5	91.4	81.6	1.3	0.001	0.001
Asp[3]	83.5	90.2	92.9	90.7	84.6	0.9	0.001	0.001
Cys[3]	72.5	84.4	89.7	87.9	71.6	1.1	0.001	0.001
Glu[3]	88.2	92.7	95.5	94.8	88.6	0.8	0.001	0.001
Gly[3]	82.7	92.3	95.2	94.7	83.4	2.1	0.001	0.015
Pro	101.4	127.3	132.3	134.4	119.5	8.7	0.014	0.18
Ser[3]	81.9	90.1	93.1	92.8	81.4	1.0	0.001	0.001
Tyr[3]	83.8	90.6	94.0	94.5	84.9	1.1	0.001	0.004
Mean[3]	84.3	93.0	98.1	97.7	87.0	1.7	0.001	0.011
Mean, all AA[3]	85.7	92.9	95.9	95.4	87.2	0.9	0.001	0.001

[1]Values are means of 6 observations per treatment. Standardized ileal digestibility values were calculated by correcting apparent ileal digestibility values for basal endogenous losses of CP and AA. Basal endogenous losses (g/kg of DMI) were as follows: CP, 16.95; Arg, 0.43; His, 0.16; Ile, 0.43; Leu, 0.59; Lys, 0.41; Met, 0.12; Phe, 0.35; Thr, 0.53; Trp, 0.12; Val, 0.50; Ala, 0.67; Asp, 0.94; Cys, 0.27; Glu, 1.18; Gly, 1.23; Pro, 4.26; Ser, 0.44; and Tyr, 0.33.
[2]Linear and quadratic effects of extrusion temperature.
[3]Pelleted differed from extruded at 75°C ($P < 0.05$).

115°C, indicating that the optimum extrusion temperature was between 75 and 115°C. The ATTD for energy in the pelleted diet (91.6%) was greater ($P < 0.05$) than in the control diet but not different from the diet containing peas that were extruded at 75°C (91.8%). There were no effects of extrusion or pelleting on the ATTD for ADF and NDF.

DISCUSSION

AA Digestibility

The AID and SID for CP and AA that were calculated for the control field peas agree with values reported recently from a different experiment using the same

Table 5. Apparent digestibility (%) of starch, NDF, ADF, and energy in experimental diets[1]

	Diet						*P*-value[2]	
Item	Control	Extruded at 75°C	Extruded at 115°C	Extruded at 155°C	Pelleted at 75°C	SEM	Linear	Quadratic
Ileal digestibility								
Starch[3]	89.8	92.1	94.7	95.9	90.1	0.8	0.001	0.502
Energy[3]	71.5	76.4	79.3	79.0	69.1	1.4	0.001	0.091
Total tract digestibility								
Starch	99.2	99.6	99.7	98.6	99.7	0.5	0.502	0.200
NDF	81.3	85.2	86.3	73.2	86.8	6.8	0.478	0.296
ADF	79.5	83.2	84.8	71.9	86.9	7.7	0.623	0.384
Energy[4]	89.0	91.8	93.3	91.7	91.6	0.8	0.020	0.010

[1]Values are means of 6 observations per treatment.
[2]Linear and quadratic effects of extrusion temperature.
[3]Pelleted differed from extruded at 75°C ($P < 0.05$).
[4]Pelleted differed from control ($P < 0.05$).

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variety of field peas (Stein et al., 2004) and with other published digestibility values for field peas (Patience et al., 1995; NRC, 1998; Owusu-Asiedu et al., 2002). The values for AID also agree with values reported for Canadian (Friesen et al., 2006) and European (Canibe and Eggum, 1997) field peas, but they are 5 to 10 percentage units greater than values reported for Australian field peas (van Barneveld and Batterham, 1994; Mariscal-Landín et al., 2002). However, pea variety has been shown to influence AID values for AA (Fan and Sauer, 1999; Grosjean et al., 2000; Friesen et al., 2006).

Extrusion of field peas improved both AID and SID for CP and all AA, which demonstrates that extrusion made more AA available for absorption in the small intestine. The quadratic response to extrusion indicates that an extrusion temperature close to 115°C gives the best results. Owusu-Asiedu et al. (2002) extruded field peas at 135°C and fed these peas to weanling pigs. The magnitude of the response to extrusion on AID and SID obtained in the present experiment was similar to the response reported by Owusu-Asiedu et al. (2002). Micronization of field peas at 110 to 115°C also improved the AID of most AA in a barley-based diet containing 45% field peas (Nyachoti et al., 2006). In contrast, van Barneveld and Batterham (1994) reported no effect of heat treatment on the AID for most AA in field peas that were autoclaved at 110, 135, 150, or 165°C. This observation indicates that the form in which heat is applied plays a role on the effectiveness of heat treatment in improving AA digestibility. This may also explain why pelleting at 75°C failed to improve AID and SID as compared with the nonheated field peas. Previously, no effect of pelleting at 80°C of grain-soybean meal-based diets on ileal N digestibility was reported (Vande Ginste and de Schrijver, 1998). Thus, it seems that pelleting at 75 to 80°C is ineffective in improving AID and SID for CP and AA.

The reason for the improved AA digestibility of extruded field peas was not investigated in this experiment. However, it has been reported that inactivation of antinutritional factors may contribute to the improved AID and SID in extruded field peas (O'Doherty and Keady, 2000; Mariscal-Landín et al., 2002). Antinutritional factors that may be present in field peas include protease inhibitors, lectins, tannins, and α galactosides (Alonso et al., 1998), but the concentration of antinutritional factors may vary among varieties (Grosjean et al., 2000). Protease inhibitors contain large quantities of Cys and also induce increased secretion of pancreatic enzymes that are rich in Cys. As a result, both exogenous and endogenous supply of Cys will increase if antinutritional factors are included in diets fed to pigs, which in turn will result in low calculated AID and SID values for Cys (Mariscal-Landín et al., 2002). The fact that the greatest improvement in AID and SID upon extrusion of field peas in the present experiment was obtained for Cys indicates that inactivation of protease inhibitors may have contributed to the improved AA digestibility. It is recognized that heat processing is an effective method of inactivating trypsin inhibitors in soybeans (Hancock et al., 1990; Yin et al., 1993; Qin et al., 1996). Heat treatment may also induce conformational changes in the pea proteins, which may make them more accessible to digestive enzymes and thus increase AA digestibility (Canibe and Eggum, 1997; Owusu-Asiedu et al., 2002).

Carbohydrate Digestibility

The improvement in ileal starch digestibility that was observed as a result of extrusion indicates that extrusion of field peas improves the access of digestive enzymes to the starch molecule. It has been hypothesized that extrusion increases starch gelatinization (Mariscal-Landín et al., 2002; Sun et al., 2006). Previously, extrusion has been shown to increase ileal starch digestibility in field peas (Sun et al., 2006) and in a wheat-field pea-based diet (Bengala Freire et al., 1991). Toasting of water-soaked field peas at 130°C has also been shown to increase the AID for starch (Canibe and Bach Knudsen, 1997). These observations indicate that starch in raw field peas is not completely digested in the small intestine, but extrusion will improve the digestibility.

The ATTD for starch was close to 100% for all treatments. This observation is in close agreement with previous reports (Bengala Freire et al., 1991; Canibe and Bach Knudsen, 1997; Sun et al., 2006) and indicates that the microbes in the hindgut are effective in fermenting pea starch entering the cecum and the colon.

The ATTD for ADF and NDF was not influenced by pelleting or extrusion. This observation agrees with data showing no effect of toasting on the ATTD of nonstarch polysaccharides (Canibe et al., 1997). Likewise, no effects of extrusion on the digestibility of α-galactosides or on total nonstarch polysaccharides were observed (Bengala Freire et al., 1991; Sun et al., 2006). Therefore, it is concluded that heat treatment does not improve the digestibility of the nonstarch polysaccharides in field peas fed to pigs.

Energy Digestibility

The improved AID of energy in pigs fed diets containing field peas that were extruded is most likely a result of the improved AID of starch and AA, because more glucose and AA were absorbed in the small intestine. Pelleting did not improve the digestibility of energy in the small intestine, which is likely because there was no effect of pelleting on the AID of AA or starch. However, the ATTD was improved for pigs fed diets that were extruded or pelleted. The quadratic response of extrusion temperature to the ATTD for energy indicates that an extrusion temperature around 115°C will give the greatest energy digestibility. However, because of the relatively wide ranges in temperatures that were used in this experiment, it is possible that the optimum temperature is above or below 115°C. Previously, an

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increase in the ATTD of energy for a barley-based diet containing 40% field peas that were extruded at 130°C was reported by O'Doherty and Keady (2001). Extrusion of corn at 125°C also has been reported to increase the digestibility of energy (Herkelman et al., 1990). Thus, the results of the present experiment showing an increase in energy digestibility in diets that were extruded or pelleted agree with previous data.

The magnitude of the increase in the AID for energy, as a result of extrusion, was greater than the increase in ATTD for energy. The reason for this observation is most likely that the values for AID are a reflection of the disappearance of starch and AA in the small intestine. Amino acids that are not absorbed from the small intestine will be converted to microbial protein in the large intestine and excreted and thus make no contribution to the energy or protein status of the pig. However, starch that is not digested in the small intestine will be fermented in the large intestine, and VFA will be absorbed. Although the efficiency of this process is lower than when glucose is absorbed from the small intestine, the energy in the starch entering the large intestine is not lost, as is the case with AA, and therefore the ATTD for starch is not different among treatments. This in turn will reduce the differences in energy digestibility among treatments, which explains why the difference between the control diet and the extruded diets for the ATTD of energy is smaller than for AID.

The greatest improvement in ATTD for energy obtained in this experiment was 4.3 percentage units. Because the only energy-containing ingredients other than field peas in the diets were dextrose and soybean oil, it is assumed that the improvement in energy digestibility in the diets was a result of improved energy digestibility in field peas. Based on the improvement in ATTD for energy in the diets, it can be calculated that the digestibility of the field peas increased by approximately 5% upon extrusion at 115°C. If field peas contain approximately 4,100 kcal of GE per kilogram (Stein et al., 2004), this increase in ATTD for energy represents an increase in the DE of field peas of approximately 205 kcal per kilogram. This increase in DE in extruded peas may be the reason why an improved G:F ratio for pigs fed diets containing extruded field peas has been reported (O'Doherty and Keady, 2001; Owusu-Asiedu et al., 2002).

In conclusion, data from the present experiment indicate that extrusion of field peas at a temperature close to 115°C increases AID of AA, starch, and energy and the SID of AA. Likewise, the ATTD of energy is also increased if field peas are extruded at 115°C. Extrusion at a temperature of 155°C does not improve digestibility of energy or AA compared with extrusion at 115°C. The increase in AA digestibility represents an opportunity to formulate diets with a decreased concentration of AA, which will reduce the ingredient cost of the diet and the quantities of N excreted by pigs. The increased energy digestibility in field peas that are extruded or pelleted will improve the feed conversion of pigs fed these diets. However, whether extrusion of field peas is economical or not depends on the cost of extrusion compared with savings from diet formulations and the improved G:F ratio.

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