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Protein and starch concentrates of air-classified field pea and zero-tannin faba bean for weaned pigs¹

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ABSTRACT: Air-classified pulse (non-oilseed legume) protein and starch may replace specialty protein and starch feedstuffs in diets for weaned pigs. In Exp. 1, three specialty protein sources (5% soy protein concentrate, 5% corn gluten meal, and 5% menhaden meal in the control diet) were replaced with 16% zero-tannin hulled or dehulled faba bean, or 17.5% field pea protein concentrate. In total, 192 group-housed pigs (2 gilts and 2 barrows per pen; BW = 7.5 ± 1.4 kg) were fed wheat-based diets (3.60 Mcal/kg of DE and 3.3 g of standardized ileal digestible Lys/Mcal DE) over 28 d for 12 pen observations per each of 4 diets. Overall, protein source did not affect ADFI, ADG, or G:F. Apparent total tract digestibility (ATTD) of DM, GE, and P was greater ($P < 0.05$) for dehulled faba bean and field pea protein concentrate diets than the diet with 3 specialty protein sources. In Exp. 2, faba bean and field pea starch concentrates were compared with corn, wheat, tapioca, and potato starch as dietary energy sources. In total, 36 individually housed barrows (BW = 8.0 ± 1.5 kg) were fed 1 of 6 diets for 15 d. Feces and urine were collected from d 8 to 14, and jugular blood was sampled after overnight fast and refeeding on d 15. Starch source did not affect N retention as a percent-

age of N intake. For d 0 to 14, ADFI of pigs fed field pea starch was greater ($P < 0.05$) than pigs fed corn, wheat, potato, and faba bean starch. Pigs fed tapioca, field pea, wheat, or corn starch grew faster ($P < 0.05$) than those fed faba bean or potato starch. For d 0 to 14, pigs fed corn or wheat starch had a 0.1 greater ($P < 0.05$) G:F than pigs fed faba bean, field pea, or potato starch. The ATTD of DM, GE, CP, and starch and the DE value of potato starch were much less ($P < 0.05$) than those of other starch diets. Postprandial plasma glucose was 4.9, 6.3, and 9 mmol/L greater ($P < 0.05$) for pigs fed tapioca than for pigs fed faba bean, wheat, and potato starch, respectively. However, postprandial plasma insulin tended to be 844 and 577 pmol/L greater ($P < 0.10$) for pigs fed faba bean and corn starch, respectively, than for pigs fed potato starch. The high insulin response of pigs fed faba starch could not be explained. In conclusion, air-classified pulse protein concentrates can replace specialty protein feedstuffs in diets for weaned pigs. Feeding air-classified pulse starch concentrates to starter pigs achieved a similar N retention as a percentage of N intake. The factors responsible for the reduced ADFI associated with feeding faba bean starch remain unclear.

Key words: air-classification, faba bean, field pea, pig, protein, starch

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INTRODUCTION

Zero-tannin faba bean is an emerging pulse (non-oilseed legume) crop in western Canada. With adequate rainfall, seed yield and atmospheric N fixation are greater than field pea (Strydhorst et al., 2008), the standard pulse in Western Canadian swine diets. Faba bean seed also contains more CP (29 vs. 23%), but less starch (44 vs. 50%), than field pea (Barratt, 1982; Ratnayake et al., 2002). White-flowered, zero-tannin cultivars of faba bean contain <1% tannin (Van der Poel et al., 1992a), an anti-nutritional factor (**ANF**) that reduces nutrient digestibility in pigs (Jansman, 1993).

Air classification not only separates pulse flour into protein and starch, but also enriches the fractions (Vose

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et al., 1976). After air classification, the CP content of the protein fraction of faba bean was enriched from 28 to 63%, and that of field pea from 23 to 46% (Gunawardena et al., 2010). Similarly, the starch content of the starch fraction of faba bean was enriched from 46 to 55%, and that of field pea from 50 to 69%. Highly digestible protein and energy feedstuffs are expensive components of diets for weaned pigs that could be replaced with air-classified pulse protein and starch fractions. However, air classification may also concentrate ANF in pulse fractions, thereby reducing growth performance (Van der Poel et al., 1990).

We hypothesized that weaned pigs fed air-classified pulse protein and starch concentrates would respond similarly to pigs fed standard protein and starch sources, respectively. The objective of Exp. 1 was to compare growth performance and apparent total tract digestibility (ATTD) of energy and nutrients of weaned pigs fed pulse protein concentrates and a diet with 3 specialty protein feedstuffs. The objective of Exp. 2 was to compare N retention, growth performance, ATTD of energy and nutrients, and plasma metabolites of weaned pigs fed diets based on air-classified faba bean or field pea starch and aqueous-fractionated starch derived from potato, tapioca, corn, or wheat.

MATERIALS AND METHODS

The animal protocols were approved by the University of Alberta Animal Care and Use Committee for Livestock and followed principles established by the Canadian Council on Animal Care (CCAC, 1993).

The studies were conducted at the Swine Research and Technology Centre, University of Alberta (Edmonton, Alberta, Canada). Crossbred pigs (Duroc sire × Large White/Landrace F₁ dams; Hypor; Regina, Saskatchewan, Canada) weaned at 20 d of age were used.

General Procedures

For Exp. 1, hulled zero-tannin faba bean (var. Snowbird) was milled and subsequently air-classified (POS Pilot Plant Corp., Saskatoon, Saskatchewan, Canada). Dehulled, air-classified zero-tannin faba bean protein concentrate, field pea (Prestige) protein concentrate, and field pea (Probond) starch concentrates were provided by a commercial company (Parrheim Foods, Saskatoon, Saskatchewan, Canada). Acid-insoluble ash (Celite 281, World Minerals Inc., Santa Barbara, CA) was added to the diets as an indigestible marker to calculate nutrient digestibility. Diets in both experiments were formulated using established DE and nutrient values for air-classified pulse protein and starch concentrates (Gunawardena et al., 2010). Collected feces were pooled by pen and frozen at -20°C until freeze-drying. Feed and lyophilized feces were ground through a 1-mm screen using a centrifugal mill (Retsch, Haan, Germany). Feed and feces were analyzed for GE (adiabatic bomb calorimetry, AC-300, Leco Corp., St. Jo-

soph, MI), moisture (method #930.15; AOAC; 2003), and AIA (McCarthy et al., 1974) contents.

Exp. 1

A diet with 3 specialty protein sources, 5% soy protein concentrate (Soycomil, ADM, Decatur, IL), 5% corn gluten meal (Champion Feeds, Barrhead, Alberta, Canada) and 5% menhaden fish meal (Special Select, Omega Protein, Houston, TX) served as control. Diets were formulated to provide 3.60 Mcal/kg of DE, 3.3 g of standardized ileal digestible (SID) Lys/Mcal DE, 0.70% total P, and 0.86% Ca, and to exceed other NRC (1998) nutrient requirements for 10- to 20-kg weaned pigs (Table 1). Other AA were provided as a ratio to Lys (NRC, 1998). Diets were mixed and steam-pelleted through a 3.2-mm die (Champion Feeds, Barrhead, Alberta, Canada).

In total, 96 barrows and 96 gilts out of 240 weaned pigs were selected based on individual ADG for the first week in the nursery after weaning. Pigs were ranked by BW (7.5 ± 1.4 kg at 27 d) and split at the median BW into light and heavy groups. Light and heavy pigs from each sex were then randomly allocated to 48 floor-level nursery pens with 2 gilts and 2 barrows per pen. Pens (1.1×1.5 m) had plastic-slatted flooring and were equipped with a nipple drinker and a 6-space self-feeder. The 4 test diets were randomly allocated to pens within block (area within room) with 12 pen observations per diet. Pigs had ad libitum access to feed and water during the 28-d experiment. Pigs were individually weighed at weaning and d 0, 7, 14, 21, and 28. Feed added and orts were weighed for each 7-d period. Freshly voided feces were collected by grab sampling from 1 randomly selected pig in each pen on d 18, 19, 20, and 21 and pooled by pen.

Feed and feces were analyzed for CP (method 990.03; AOAC, 2003), ether extract (method 920.39; AOAC, 2003), and crude fiber (method 962.09; AOAC, 2003). The inductively coupled plasma method (method 3120 B; American Public Health Association, 1998) was used for Ca and P analysis, after extraction (method 985.01; AOAC, 2003) at a commercial laboratory (Norwest Labs, Lethbridge, Alberta, Canada). Individual pig BW were used to calculate ADG for each week. Feed added and orts were used to calculate ADFI for each week. Efficiency of BW gain was calculated as ADG divided by ADFI. Based on the results of chemical analyses, the ATTD of energy and nutrients was calculated using the AIA concentration of feces relative to feed using the indicator method (Adeola, 2001).

Exp. 2

The test starches were obtained from 6 sources (Table 2). Tuber starches were potato (Avebe, Veendam, the Netherlands) and tapioca starch (Siam Quality starch, Pathumthani, Thailand). Cereal grain starches were corn (Melojel, National Starch, Bridgewater, NJ) and

Table 1. Ingredient composition of the experimental diets and analyzed nutrient content (as-fed basis), Exp. 1

Item	Protein concentrate			
	Hulled faba bean	Dehulled faba bean	Field pea	Specialty proteins
Ingredient, %				
Wheat	57.25	57.25	55.31	57.62
Whey permeate	10.00	10.00	10.00	10.00
Soybean meal	10.00	10.00	10.00	10.00
Hulled faba bean protein concentrate ¹	16.00	—	—	—
Dehulled faba bean protein concentrate ²	—	16.00	—	—
Field pea protein concentrate ³	—	—	17.50	—
Soy protein concentrate ⁴	—	—	—	5.00
Corn gluten meal	—	—	—	5.00
Menhaden meal ⁵	—	—	—	5.00
Canola oil	0.90	0.90	1.05	1.70
Tallow	0.90	0.90	1.05	1.70
Limestone	1.10	1.10	1.15	0.70
Mono/dicalcium phosphate	1.10	1.10	1.03	0.63
AIA ⁶	0.80	0.80	0.80	0.80
Vitamin premix ⁷	0.50	0.50	0.50	0.50
Trace mineral premix ⁸	0.50	0.50	0.50	0.50
Salt	0.50	0.50	0.50	0.50
L-Lys HCl	0.30	0.30	0.30	0.30
L-Thr	0.03	0.03	0.08	0.05
DL-Met	0.09	0.09	0.15	—
L-Trp	0.03	0.03	0.08	—
Analyzed nutrient content				
Moisture, %	7.83	8.06	8.14	7.44
GE, Mcal/kg	4.18	4.00	4.02	4.16
CP, %	25.37	24.20	21.05	22.95
Crude fiber, %	2.58	2.48	2.57	2.41
Ether extract, %	3.69	2.85	3.77	5.00
Ca, %	0.71	1.12	0.98	1.22
P, %	0.63	0.74	0.70	0.74

¹POS Pilot Plant Corporation (Saskatoon, Saskatchewan, Canada).

²Parrheim Foods (Saskatoon, Saskatchewan, Canada).

³Prestige, Parrheim Foods (Saskatoon, Saskatchewan, Canada).

⁴Soycomil, ADM (Decatur, IL).

⁵Special Select Menhaden fish meal, Omega Protein Inc. (Houston, TX).

⁶Celite 281, World Minerals Inc. (Santa Barbara, CA).

⁷Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 8,250 IU; vitamin D, 825 IU; vitamin E, 40.0 mg; vitamin K, 4.0 mg; vitamin B₁₂, 0.025 mg; riboflavin, 5.0 mg; thiamine, 1.0 mg; pantothenic acid, 15.0 mg; niacin, 35.0 mg; biotin, 0.20 mg; and folic acid, 2.0 mg.

⁸Provided the following quantities of minerals per kilogram of complete diet: Zn, 100 mg as ZnSO₄; Fe, 80.0 mg as FeSO₄; Cu, 50.0 mg as CuSO₄; Mn, 25.0 mg as MnSO₄; I, 0.50 mg as Ca(IO₃)₂; and Se, 0.10 mg as Na₂SeO₃.

wheat (Aytex-P, Talas, NY) starch. Pulse starches were dehulled and air-classified products, whereas the cereal and tuber starches were aqueous-fractionated products of food-grade purity. The experimental diets (3.3 g of SID Lys/Mcal of DE) were formulated to be similar in starch and protein content and exceeded requirements

for other nutrients for 5- to 10-kg weaned pigs (NRC, 1998).

Pigs were housed in individual metabolism pens (length, 1.19 m; width, 0.52 m; height, 0.75 m) that were raised 0.75 m to fit galvanized metal trays for urine collection underneath. Pens had walls of solid

Table 2. Analyzed nutrient content of the experimental ingredients (as-is basis), Exp. 2

Item	Starch concentrate					
	Faba bean	Field pea	Corn	Wheat	Tapioca	Potato
Moisture, %	11.00	9.92	9.81	10.70	10.40	15.30
GE, Mcal/kg	3.88	3.79	3.76	3.72	3.68	3.49
CP, %	19.80	7.74	2.03	2.00	2.26	1.71
Starch, %	47.6	68.1	83.0	77.2	76.4	71.2

Table 3. Ingredient composition and analyzed nutrient content of the experimental diets (as-fed basis), Exp. 2

Item	Starch concentrate					
	Faba bean	Field pea	Corn	Wheat	Tapioca	Potato
Ingredient, %						
Faba bean starch concentrate	84.29	—	—	—	—	—
Field pea starch concentrate ¹	—	71.21	—	—	—	—
Corn starch concentrate ²	—	—	63.92	—	—	—
Potato starch concentrate ³	—	—	—	—	—	63.90
Tapioca starch concentrate ⁴	—	—	—	—	63.90	—
Wheat starch concentrate ⁵	—	—	—	63.90	—	—
Menhaden meal ⁶	—	15.00	23.00	23.00	23.00	23.00
Soybean meal	10.00	10.00	10.00	10.00	10.00	10.00
Mono/dicalcium phosphate	2.10	0.60	—	—	—	—
AIA ⁷	0.80	0.80	0.80	0.80	0.80	0.80
Canola oil	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix ⁸	0.50	0.50	0.50	0.50	0.50	0.50
Trace mineral premix ⁹	0.50	0.50	0.50	0.50	0.50	0.50
DL-Met	0.32	0.14	0.10	0.10	0.10	0.10
L-Thr	0.20	0.12	0.10	0.10	0.10	0.10
L-Lys HCl	0.19	0.03	—	—	—	—
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05
L-Trp	0.05	0.05	0.03	0.05	0.05	0.05
Analyzed nutrient content						
Moisture, %	10.54	9.03	8.85	9.36	9.13	11.87
GE, Mcal/kg	3.81	3.88	3.90	3.89	3.88	3.73
CP, %	20.28	21.12	18.97	23.89	20.69	17.38
Starch, %	41.55	50.03	53.23	53.80	56.03	50.43

¹Probond (Parrheim Foods, Saskatoon, Saskatchewan, Canada).

²Melojel (National Starch and Chemical Co., Bridgewater, NJ).

³AVEBE (Veendam, The Netherlands).

⁴Siam AVEBE (Siam Quality starch, Pathumthani, Thailand).

⁵Aytex-P wheat starch concentrate (Talas, NY).

⁶Special Select Menhaden fish meal (Omega Protein Inc., Houston, TX).

⁷Celite 281, World Minerals Inc. (Santa Barbara, CA).

⁸Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 8,250 IU; vitamin D, 825 IU; vitamin E, 40.0 mg; niacin, 35.0 mg; pantothenic acid, 15.0 mg; riboflavin, 5.0 mg; vitamin K, 4.0 mg; folic acid, 2.0 mg; thiamine, 1.0 mg; vitamin B₁₂, 0.025 mg; and biotin, 0.20 mg.

⁹Provided the following quantities of minerals per kilogram of complete diet: Zn, 100 mg as ZnSO₄; Fe, 80.0 mg as FeSO₄; Cu, 50.0 mg as CuSO₄; Mn, 25.0 mg as MnSO₄; I, 0.50 mg as Ca(IO₃)₂; and Se, 0.10 mg as Na₂SeO₃.

polyvinyl chloride planking and plastic slatted floors. A cup drinker was attached to the side wall and a single-spaced dry feeder (height, 0.625 m; length, 0.25 m; wide, 0.20 m; Crystal Spring, Ste. Agathe, Manitoba, Canada) was attached to the front wall. In total, 36 crossbred barrows were selected based on BW at 7 d postweaning (8.03 ± 1.50 kg at 27 d; d 0). Pigs were divided in 3 weekly groups of 12 (2 room area blocks of 6 pigs per week) and were randomly fed 1 of 6 diets containing a specific starch source (Table 3). Pigs had free access to feed and water during the entire experiment.

Pigs were weighed at weaning and on d 0, 7, and 14. Feed added and orts were weighed daily. For d 8 to 14, feces were collected continuously using plastic bags attached to the pig around the anus using a ring system (van Kleef et al., 1994). Urine was collected continuously using trays that drained into bottles containing 20 mL of H₂SO₄ (25%, vol/vol) to prevent atmospheric loss of N. Each day, collected feces and 5% of collected urine were pooled by pig and stored at -20°C . On d 15,

blood (3 to 5 mL) was collected by jugular venipuncture in heparinized tubes (12×75 mm). Blood was sampled immediately before feeding after an overnight fast (preprandial) and approximately 1.5 h after feeding (postprandial). The blood samples were centrifuged at $3,000 \times g$ for 10 min to separate the plasma. Blood samples were collected, handled, and centrifuged at room temperature.

Feed and feces were analyzed for N (TruSpec CN Determinator, Leco Corp., St. Joseph, MI), and starch by spectrophotometry (Jenway 6300, Jenway Ltd., Essex, UK) using an enzyme assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland; method 996.11; AOAC, 2003). Urine N was analyzed by Kjeldahl method (Labconco, Kansas City, MO; Bradstreet, 1965), and CP was calculated ($N \times 6.25$). Plasma was analyzed for glucose (Gluco-quant Glucose/Hexokinase, Roche/Hitachi 912 Autoanalyzer, Roche Diagnostics GmbH, Mannheim, Germany), urea-N (kinetic UV assay, Roche/Hitachi 912 Autoanalyzer, Roche Diagnostics GmbH; Prairie Diagnostic Services Inc., Saskatoon,

Saskatchewan, Canada) and insulin (25 and 7% CV for preprandial and postprandial samples, respectively; Coat-A-Count Insulin, Siemens Medical Solutions Diagnostics, Erlangen, Germany; Endocrine Laboratory, Western College of Veterinary Medicine, Saskatoon, Saskatchewan, Canada). Porcine insulin (Calbiochem, La Jolla, CA) was used as a standard.

Based on the results of chemical analyses, the ATTD of energy and nutrients was calculated using the AIA concentration of feces relative to feed using the indicator method (Adeola, 2001). Urinary and fecal N output of individual pigs were used to calculate N retention [$N \text{ intake} - (N \text{ in urine} + N \text{ in feces})$] (Adeola, 2001). The ADFI was calculated by averaging the daily amount of feed added minus orts. Individual pigs were weighed weekly and BW was used to calculate ADG for each week.

Statistical Analyses

For both experiments, the MIXED procedure (SAS Inst. Inc., Cary, NC) was used. The performance variables were analyzed as repeated measures (Wang and Goonewardene, 2004) using the following model:

$$Y_{ijkl} = \mu + D_i + P_j + DP_{ij} + \text{Pen}_{k(i)} \\ + \text{Cov} + B_l + E_{ijkl},$$

where Y_{ijkl} is the response variable; μ is the sample mean; D_i is the diet; P_j is period; DP_{ij} is the interaction (diet \times period); $\text{Pen}_{k(i)}$ is the pen or pig within diet; Cov is the covariate; B_l is the block, considered a random effect; and E_{ijkl} is the error. For Exp. 1, initial pen BW was the covariate and the experimental unit was the pen. For Exp. 2, initial pig BW was the covariate and the experimental unit was the pig. The Bayesian information criterion (Schwarz, 1978) was used to identify the covariance structure of best fit for each repeated effect in the model. A smaller value indicated a better fit.

The ATTD of diets, N retention, and plasma metabolite data were analyzed as a randomized complete block. The model included diet as the fixed effect and block as the random effect. Postprandial plasma values were analyzed with the preprandial value as a covariate. Means for both experiments were separated using the probability of difference ($P < 0.05$).

RESULTS AND DISCUSSION

To the best of our knowledge, the present studies are the first to report the growth performance of pigs fed protein and starch concentrates from air-classified zero-tannin faba bean. We also offer the first comparison of air-classified pulse starches to cereal and tuber starches of greater purity to discern the potential of the former as feed-grade starches and their suitability for young pigs. Our intent was to demonstrate the comparable

nutritional value of simple, air-classified pulse fractions with more costly, aqueous-fractionated products.

Protein Concentrates (Exp. 1)

Dietary protein concentrate did not affect the growth performance of weaned pigs, except for a greater ADFI for pigs fed the field pea protein concentrate diet for the last week on trial ($P < 0.05$; Table 4). There was no diet \times period interaction for performance variables. In contrast to these results, Valencia et al. (2008) reported that weaned pigs aged 26 to 48 d fed soy protein concentrate tended to have greater ADG and ADFI than pigs fed air-classified field pea protein concentrate. Thus, the difference in growth responses between studies might be due to cultivar of field pea used, variability of nutrient content (Gdala and Buraczewska, 1997), or variable ANF content (Grosjean et al., 2000). No reports could be found regarding feeding faba bean protein concentrate to weaned pigs. We have previously reported that starter pigs fed up to 40% ground raw, hulled zero-tannin faba bean (var. Snowbird) had similar growth performance as pigs fed soybean meal (Beltranena et al., 2009). Pulse protein concentrates can therefore replace the combined 3 specialty protein feedstuffs fed in nursery diets for weaned pigs.

The ATTD of energy and dietary nutrients differed among protein concentrate diets (Table 5). The ATTD of DM, GE, Ca, and P was greater, and the DE value and ATTD of ether extract were less for the field pea protein concentrate diet vs. the specialty proteins diet ($P < 0.05$). These results are in contrast to Valencia et al. (2008), who reported that the AID of energy was greater for the soy protein concentrate diet than for the field pea protein concentrate diet, whereas the AID of CP and ATTD of energy, ether extract, and CP were not different among diets.

The ATTD of DM, GE, CP, fiber, and P of the dehulled faba bean protein concentrate diet was greater than that of the specialty proteins diet ($P < 0.05$; Table 5). This greater energy and nutrient digestibility of dehulled faba bean confirms our previous results in grower pigs. Air-classified faba bean protein concentrate had greater ATTD and AID of GE, CP, starch, DM, and OM and greater SID Lys than soy protein concentrate (Gunawardena et al., 2010).

The diet containing hulled faba bean generally had less nutrient digestibility than the other pulse protein and control diets ($P < 0.10$; Table 5). Van der Poel et al. (1992b) reported that the AID and ATTD of DM were depressed in grower pigs fed 30% raw hulled vs. dehulled faba bean that likely resulted from indigestible fiber in the hull. Indeed, the content of nonstarch polysaccharides is greater in hulls than the cotyledon of legume seed (Longstaff and McNab, 1991). Apart from nonstarch polysaccharides, ANF may explain additional differences in nutrient digestibility between hulled and dehulled faba bean concentrates (Jansman et al., 1995). The content of condensed tannins is greater in hulls

Table 4. Effect of feeding different protein concentrates on growth performance of weaned pigs,¹ Exp. 1

Item	Protein concentrate					P-value
	Hulled faba bean	Dehulled faba bean	Field pea	Specialty proteins	Pooled SEM ²	
ADFI, g						
d 0 to 7	304	314	321	318	11	0.76
d 8 to 14	577	583	605	563	28	0.75
d 15 to 21	770	804	772	777	27	0.80
d 22 to 28	939 ^b	917 ^b	1,038 ^a	995 ^{ab}	30	0.03
d 0 to 28	649	653	684	663	16	0.41
ADG, g						
d 0 to 7	243	254	263	241	12	0.52
d 8 to 14	421	438	463	425	22	0.54
d 15 to 21	575	675	570	571	23	0.66
d 22 to 28	693	640	715	710	28	0.23
d 0 to 28	483	484	503	487	12	0.57
G:F						
d 0 to 7	0.80	0.81	0.82	0.75	0.03	0.24
d 8 to 14	0.74	0.74	0.77	0.76	0.02	0.69
d 15 to 21	0.75	0.75	0.74	0.74	0.02	0.93
d 22 to 28	0.75	0.71	0.69	0.72	0.04	0.73
d 0 to 28	0.76	0.76	0.75	0.75	0.01	0.59

^{a,b}Means within a row without a common superscript letter differ ($P < 0.05$).

¹Initial BW, 7.5 ± 1.4 kg at 27 d of age.

²Based on 12 observations per diet.

than the cotyledon of legume seed (Van der Poel et al., 1991; Jansman, 1993). Even though faba bean protein concentrates were derived from a zero-tannin cultivar of faba bean (<1 vs. >7% for traditional cultivars), the hulled faba bean protein concentrate fed contained only 1.2% tannin (Gunawardena et al., 2010). Most likely, the greater tannin content in hulls (Jansman et al., 1995) was concentrated in the protein fraction by the air classification process. In the dehulled zero-tannin faba bean protein concentrate, the tannin content decreased because removal of seed hull (Gunawardena et al., 2010). Trypsin inhibitor activity and lectin contents are low in faba bean; therefore, in the air-classified protein fraction, these ANF did not affect productive responses. In chicks, Marquardt et al. (1976) reported that trypsin inhibitor, lectin, some other heat-labile

proteins, and vicine were not growth depressing factors of faba bean.

These results indicate that when feeds are formulated to equal energy and Lys content, differences in growth performance between weaned pigs fed air-classified pulse proteins or aqueous-fractionated specialty proteins were not observed. Our findings therefore confirm that these air-classified pulse protein concentrates are nutritionally suitable feedstuffs for weaned pigs.

Starch Concentrates (Exp. 2)

The N and DE intake differed among starch diets ($P < 0.05$), but starch source did not affect fecal and total N excretion expressed as a percentage of N intake (Ta-

Table 5. Effect of protein concentrate on apparent total tract nutrient digestibility and DE content (as-fed basis) in weaned pigs, Exp. 1

Item	Protein concentrate					P-value
	Hulled faba bean	Dehulled faba bean	Field pea	Specialty proteins	Pooled SEM ¹	
DM, %	83.9 ^b	86.0 ^a	86.2 ^a	84.3 ^b	0.4	0.01
GE, %	84.3 ^c	87.5 ^a	87.4 ^a	85.9 ^b	0.4	0.01
DE, Mcal/kg	3.52 ^b	3.50 ^b	3.51 ^b	3.57 ^a	0.02	0.01
CP, %	81.7 ^c	85.2 ^a	84.3 ^b	83.6 ^b	0.6	0.01
Ether extract, %	87.3 ^c	86.2 ^d	88.9 ^b	90.6 ^a	0.4	0.01
Crude fiber, %	21.4 ^b	32.4 ^a	26.7 ^{ab}	23.0 ^b	4.0	0.04
Ca, %	51.7 ^a	49.2 ^{ab}	50.6 ^a	45.0 ^b	2.0	0.09
P, %	51.2 ^a	51.4 ^a	53.0 ^a	46.9 ^b	1.2	0.07

^{a-d}Means within a row without a common superscript letter differ ($P < 0.05$).

¹Based on 12 observations per diet.

Table 6. Nitrogen balance of weaned barrows fed diets containing different starch sources, Exp. 2

N balance	Starch concentrate						Pooled SEM ¹	P-value
	Faba bean	Field pea	Corn	Wheat	Tapioca	Potato		
N intake, g/d	19.3 ^{bc}	25.0 ^a	20.4 ^{bc}	27.1 ^a	23.0 ^{ab}	17.3 ^c	1.8	0.01
DE intake, Mcal/d	1.93 ^b	2.47 ^a	2.21 ^{ab}	2.06 ^b	2.26 ^{ab}	1.44 ^c	0.14	0.01
Excretion, % of intake								
Feces	23.5	28.5	25.3	23.4	26.9	29.1	3.7	0.73
Urine	19.7 ^a	8.25 ^c	10.6 ^{bc}	10.1 ^{bc}	9.03 ^c	13.5 ^b	1.4	0.01
Total	43.2	36.7	35.8	33.5	35.9	42.5	3.9	0.34
Absorbed, g/d	15.3 ^{bc}	18.0 ^{ab}	15.4 ^{bc}	21.0 ^a	17.1 ^{abc}	12.5 ^c	2.0	0.02
Absorbed, %	76.5	71.6	74.7	76.6	73.2	70.9	3.7	0.73
Retention, g/d	11.5 ^{cd}	15.9 ^{ab}	13.3 ^{bcd}	18.3 ^a	15.1 ^{abc}	10.2 ^d	1.8	0.01
Retention, %	57.8	63.3	64.2	66.5	64.1	57.5	3.9	0.34

^{a-d}Means within a row without a common superscript letter differ ($P < 0.05$).

¹Based on 6 observations per diet.

ble 6). The faba bean starch diet resulted in a greater urinary N excretion than cereal and tuber starches ($P < 0.05$). Greater CP content and greater ATTD of CP of the faba bean starch diet may have resulted in AA absorption above the requirements for protein synthesis. Excess AA were likely deaminated, leading to production of urea via the urea cycle in the liver (Rodwell, 1996), followed by excretion in urine. Starch sources with a predicted fast (tapioca and cereal starch diets), intermediate (pulse starch diets), or slow rate of digestion (potato starch diet; Weurding et al., 2001) did not affect N retention expressed as percentage of N intake, indicating that asynchrony between AA and glucose absorption did not influence efficiency of N utilization in the present study with pigs having free access to feed. Therefore, we hypothesize that to detect an asynchrony between glucose and AA absorption, the dietary AA content should be below the AA requirement, which was not the case in the present study.

Starch diet affected or tended to affect growth performance variables of weaned pigs ($P < 0.10$; Table 7).

In comparison with pigs fed cereal starches, pigs fed the field pea starch diet consumed the most feed followed by pigs fed tapioca starch ($P < 0.05$). Pigs fed the faba bean and potato starch diets gained less BW than pigs fed corn, field pea, wheat, and tapioca starch diets ($P < 0.05$). These differences might be due to unequal DE content among diets (Table 8) and variable quality of protein sources among diets. The generally accepted paradigm is that pigs strive to meet energy requirements (Nyachoti et al., 2004). Thus, the reduced DE content of the faba bean and potato starch diets compared with the corn starch and tapioca diets (Table 8) could have been compensated for by increasing ADFI to maintain intake of DE. However, this compensation was not observed possibly due to the slower rate of starch digestion that affected satiety for potato starch and to a lesser extent for faba starch-fed pigs.

The ATTD of DM, GE, and CP differed among starch diets ($P < 0.05$; Table 8). Generally, corn had the greatest ATTD of nutrients and energy, immediately followed by tapioca starch. Wheat, field pea, and

Table 7. Effect of dietary starch source on growth performance of weaned pigs,¹ Exp. 2

Item	Starch concentrate						Pooled SEM ²	P-value
	Faba bean	Field pea	Corn	Wheat	Tapioca	Potato		
ADFI, g								
d 0 to 7	521 ^b	672 ^a	519 ^b	513 ^b	541 ^b	522 ^b	33	0.01
d 8 to 14	576 ^b	732 ^a	684 ^{ab}	683 ^{ab}	754 ^a	608 ^b	41	0.03
d 0 to 14	549 ^c	702 ^a	601 ^{bc}	598 ^{bc}	647 ^{ab}	565 ^{bc}	30	0.01
ADG, g								
d 0 to 7	259	374	322	337	334	258	33	0.11
d 8 to 14	371 ^c	485 ^{ab}	513 ^a	499 ^a	540 ^a	404 ^{bc}	33	0.07
d 0 to 14	315 ^b	429 ^a	418 ^a	418 ^a	437 ^a	331 ^b	22	0.01
G:F								
d 0 to 7	0.50 ^b	0.56 ^{ab}	0.62 ^{ab}	0.66 ^a	0.62 ^{ab}	0.49 ^b	0.05	0.08
d 8 to 14	0.65	0.67	0.76	0.73	0.71	0.67	0.04	0.35
d 0 to 14	0.58 ^c	0.61 ^{bc}	0.69 ^a	0.69 ^a	0.67 ^{ab}	0.58 ^c	0.02	0.01

^{a-c}Means within a row without a common superscript letter differ ($P < 0.05$).

¹Initial BW, 8.03 ± 1.5 kg at 27 d of age.

²Based on 6 observations per diet.

Table 8. Apparent total tract digestibility of nutrients and DE content (as-fed basis) of the experimental diets, Exp. 2

Item	Starch concentrate						Pooled SEM ¹	P-value
	Faba bean	Field pea	Corn	Wheat	Tapioca	Potato		
DM, %	89.7 ^{ab}	89.7 ^{ab}	91.7 ^a	88.4 ^b	90.4 ^{ab}	67.9 ^c	1.0	0.01
GE, %	90.0 ^b	90.0 ^b	93.2 ^a	90.4 ^b	92.1 ^{ab}	68.5 ^c	1.0	0.01
DE, Mcal/kg	3.43 ^c	3.49 ^{bc}	3.63 ^a	3.52 ^{bc}	3.57 ^{ab}	2.55 ^d	0.04	0.01
CP, %	84.9 ^a	79.6 ^b	84.5 ^a	81.6 ^{ab}	82.3 ^{ab}	65.2 ^c	1.4	0.01
Starch, %	99.8 ^a	99.6 ^a	99.9 ^a	99.8 ^a	99.9 ^a	76.3 ^b	1.4	0.01

^{a-d}Means within a row without a common superscript letter differ ($P < 0.05$).

¹Based on 6 observations per diet.

faba bean starch ranked less, and potato starch ranked the least of all. This ranking might reflect starch digestion rates (Weurding et al., 2001) that were not fully realized in our study because digesta was not collected along different points of the small intestine and cecum. Various botanical sources of starch contain different starch granular structures or polymorphs (Zobel, 1988; Gernat et al., 1990). With x-ray diffraction crystallography, starch granules are separated into 3 categories: type A, B, and C. The amylopectin chain length is important in defining these starch types (Hizukuri, 1985). Corn, wheat, and tapioca starch granules are type A (short chains), potato starch is type B (long chains), and pulse starches are type C (intermediate chain length), which is a combination of types A and B (Sarko and Wu, 1978; Lorenz, 1979; Zobel, 1988). These structural differences may be partly responsible for differences in starch and energy digestibility measured in the present study (Cummings and Englyst, 1995) and, consequently, differences in growth performance observed. A high amylose to amylopectin ratio reduces starch digestibility (Hoover and Zhou, 2003). A starch with a high amylose content reduced ADFI and ADG in weaned pigs (Li et al., 2007). Furthermore, wheat, tapioca, and corn starch have a greater susceptibility to porcine and bacterial α -amylase than potato starch (Gallant et al., 1982; Hoover and Sosulski, 1985). The decreased digestibility of pulse starch as compared with cereal starch has been also attributed to the lesser accessibility of the pulse starch granules to digestive enzymes (Wursch et al., 1986; Svihus et al., 2005). The comparatively greater starch digestibility measured in faba bean starch in the present study may be partially due to fine milling required for air classification that partially broke down starch granules. As a result, enzymatic digestion of starch was likely enhanced (Colonna et al., 1980). The ranking of ATTD of energy observed in the present study could not be used to discern differences in rate of starch digestion among cereal, pulse, and tapioca starches, but the rates for these starches were clearly much faster than for potato starch (Bach Knudsen et al., 2006).

Palatability of the powdery, high-starch diets may have also affected feed intake in the present study. The faba bean starch diet, unlike the other diets, did not

contain fish meal, because faba bean starch concentrate contained 19% CP. Fish meal was not needed to meet the AA requirements, but the lack of fish meal may have reduced palatability and thereby feed intake and ADG of pigs fed the faba bean starch concentrate diet (Stoner et al., 1990). Extrusion of faba bean starch diets may allow weaned pigs to maintain feed intake (Wirerenga et al., 2008). The ATTD of CP was greater in faba bean starch diet and was not different than CP digestibility of the corn, tapioca, and wheat starch diets, indicating that the CP in faba bean starch concentrate was digested to a similar extent as menhaden fish meal. The ATTD of CP in the faba starch diet established in the present study was close to the ATTD of CP in the dehulled faba bean protein diet fed to similar aged pigs in Exp. 1. Together, they endorse our digestibility results from a previous study (Gunawardena et al., 2010). The reduced ATTD of CP in the field pea starch diet ($P < 0.05$; Table 8) could have been partly due to the greater feed intake. Increased feed intake may coincide with a greater digesta passage rate and reduced nutrient absorption (Parker and Clawson, 1967).

In the present study, postprandial plasma glucose was greatest for the tapioca and corn starch diets, followed by the field pea, then by the faba bean and wheat starch diets, and was least for the potato starch diet ($P < 0.05$; Table 9). However, postprandial plasma insulin was the greatest for pigs fed the faba bean starch diet and least for pigs fed the potato starch diet ($P < 0.10$). Pigs fed faba bean and potato starch also had less overall ADFI. This discrepancy indicates that satiety might have been triggered by different mechanisms: insulin acting as a satiety signal to the brain (Woods et al., 2004) in the faba bean starch vs. slow digestible potato starch in the lumen of the gut. Glycemic index is a ranking of carbohydrates according to their effect on blood glucose concentrations (Groper et al., 2009). Postprandial plasma glucose concentrations in the present study provided further support that faba starch has a glycemic index less than tapioca starch, but greater than potato starch. The presence of esterified phosphate groups in potato starch amylopectin (Whistler and Daniels, 1984) may also reduce digestibility of potato starch (Knuckles and Betschart, 1987), leading to reduced plasma glucose.

Table 9. Postprandial plasma metabolite concentrations of weaned pigs fed different starch sources, Exp. 2

Item	Starch concentrate						Pooled SEM ¹	P-value
	Faba bean	Field pea	Corn	Wheat	Tapioca	Potato		
Glucose, mmol/L	12.66 ^{bc}	14.89 ^{abc}	16.31 ^{ab}	11.26 ^{cd}	17.58 ^a	8.59 ^d	1.49	0.01
Insulin, pmol/L	1,024 ^a	662 ^{ab}	757 ^a	658 ^{ab}	660 ^{ab}	180 ^b	179	0.06
Urea N, mmol/L	10.48 ^{ab}	9.34 ^c	8.76 ^c	9.62 ^{bc}	8.92 ^c	10.60 ^a	0.36	0.01

^{a-d}Means within a row without a common superscript letter differ ($P < 0.05$).

¹Based on 6 observations per diet.

The decreased ADFI, intermediate level of nutrient digestibility, and intermediate DE intake for the faba bean starch diet may have been additive in reducing ADG. As discussed before, deamination of the protein content of the faba bean starch concentrate (19.8%) could have resulted in greater plasma urea N and also caused gluconeogenesis to occur more rapidly. However, greater plasma urea N was also observed in pigs fed the potato starch diet, indicating excess dietary protein in both diets, but the latter provided 3% less CP than the faba bean diet. Insulin may also respond to greater AA uptake, but the pigs fed faba bean and potato starch had the least ADG. Therefore, the specific mechanism that caused the reduced feed intake and growth of pigs fed faba bean starch is difficult to identify in the animal model used in our study. Likely, more advanced animal models such as portal-vein catheterized pigs are required. In pigs fed potato starch, the DE content of the diet was reduced, but these pigs also had a reduced ADFI and thus a reduced DE intake. Similarly, raw potato starch supported less ADG and energy retention (Schrama and Bakker, 1999) and a decreased ATTD for OM, starch, and CP than corn starch in grower pigs (Martinez-Puig et al., 2003).

In conclusion, air-classified dehulled or hulled zero-tannin faba bean and field pea protein concentrates are suitable replacements of specialty protein feedstuffs for weaned pigs in nursery diets. Weaned pigs can be fed air-classified pulse starch concentrates to achieve a similar N retention as a percentage of N intake. However, the factors responsible for the decreased feed intake associated with feeding faba bean starch are yet to be identified.

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