Starch and energy digestibility in weaned pigs fed extruded zero-tannin faba bean starch and wheat as an energy source

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Received 21 July 2007, accepted 15 November 2007.

Wierenga, K. T., Beltranena, E., Yáñez, J. L. and Zijlstra, R. T. 2008. **Starch and energy digestibility in weaned pigs fed extruded zero-tannin faba bean starch and wheat as an energy source.** Can. J. Anim. Sci. **88**: 65–69. Digestion of extruded starch is poorly characterized. Two diets containing wheat or faba bean starch were extruded individually or combined 50:50 (wt/wt) and fed to weaned pigs. Ileal starch digestion tended to be higher ($P < 0.10$) for the extruded wheat diet than the extruded faba bean diets, while total tract digestibility of starch and energy was higher ($P < 0.05$) for the two extruded faba bean starch diets than the extruded wheat diet. Feed intake tended to be higher ($P < 0.10$) for extruded faba bean starch diet, but final body weight was not affected by extruded starch source. The in vivo kinetics of starch and energy digestion differed between extruded wheat and faba bean starch diets.

Key words: digestibility, extrusion, faba bean, starch, weaned pig, wheat

Wierenga, K. T., Beltranena, E., Yáñez, J. L. et Zijlstra, R. T. 2008. **Digestibilité de l'amidon et de l'énergie chez les porcelets sevrés recevant de la fécule de fèverole extrudée sans tanin et du blé comme source d'énergie.** Can. J. Anim. Sci. **88**: 65–69. La digestion de l'amidon extrudé est méconnue. Les auteurs ont servi deux rations contenant du blé ou de la fécule de fèverole extrudée séparément ou ensemble (50:50 poids/poids) à des porcelets sevrés. La fécule du blé extrudé semble se digérer davantage ($P < 0,10$) dans l'iléon que la fécule de fèverole, mais la digestibilité globale de l'amidon dans le système gastro-intestinal était plus élevée ($P < 0,05$) pour les deux rations contenant de la fèverole extrudée que pour celle renfermant du blé. La prise alimentaire a tendance à être plus importante ($P < 0,10$) avec les rations contenant de la fécule de fèverole extrudée, mais la source d'amidon n'a aucune incidence sur le poids final des animaux. La cinétique *in vivo* de la fécule et la digestion de l'énergie ne sont pas les mêmes pour le blé et la fèverole extrudés.

Mots clés: Digestibilité, extrusion, fèverole, amidon, porcelets sevrés, blé

Faba bean (*Vicia faba* L.) is an emerging, rotational pulse crop in Western Canada cultivated to provide dietary protein and energy in livestock feeds. The classic faba bean cultivars contained tannin; an anti-nutritional factor that primarily reduced protein digestibility and compromised growth performance (Jansman et al. 1995). Genetic selection stimulated the development of white-flower faba bean cultivars with low tannin content, also known as zero-tannin faba bean. Ground whole white-flowered faba bean can be included up to 40% in late nursery diets (Omogbenigun et al. 2006) without reducing growth performance. Faba bean can be fractionated using air classification into a fraction containing up to 72% crude protein and a second fraction containing up to 40% starch that may have value in feeding programs for animals with high nutritional demands such as weaned pigs.

Even though starch constitutes a high mass in feed, relatively little is known about the kinetics of starch digestion in weaned pigs (Van Kempen et al. 2007), especially for extruded, fractionated faba bean starch. In grower pigs, ileal starch digestion appears lower for faba bean than wheat (Fledderus et al. 2003; Bach Knudsen et al. 2006). Extrusion can gelatinize starch and thereby enhance starch digestion; therefore, differences in kinetics of starch digestion might be small among extruded feedstuffs (Sun et al. 2006). The hypothesis tested in the present study was that weaned pigs fed extruded faba bean starch diets have a similar starch

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Abbreviations: ADFI, average daily feed intake; **ADG**, average daily gain; **DE**, digestible energy; **NSP**, non-starch polysaccharides digestibility to pigs fed an extruded wheat-based diet. The objectives were to characterize and compare the apparent ileal and total-tract starch and energy digestibility in extruded diets containing wheat, fractionated faba bean starch or a blend of both as primary starch and energy sources and quantify their effects on growth performance in piglets after 1 wk post-weaning.

Twenty-four piglets were fed one of three extruded diets containing either wheat, faba bean starch, or a 50:50 (wt/wt) blend of both diets (Table 1). The diets contained soybean meal, whey permeate, menhaden fish meal, and soy protein concentrate (Soycomil, ADM, Decatur, IL) as supplemental protein sources to acquire an adequate amino acid balance [National Research Council (NRC) 1998], and acid-insoluble ash as a marker of digestibility. The wheat and fababean starch diets were formulated to provide 3.40 Mcal digestible energy (DE) kg^{-1} and 3.5 g apparent ileal digestible lysine $Mcal^{-1}$ DE. A premix was added to meet or exceed mineral and vitamin requirements (NRC 1998). Following mixing, diets were extruded using a twin-screw extruder (Model ZSK 57-M 50/2, Werner & Pfleiderer, Stuttgart, Germany) at the Food Science and Technology Centre (Alberta Agriculture and Food, Brooks, AB).

The animal protocol for the study was approved by the University of Alberta Faculty Animal Policy and Welfare Committee, and followed principles established

Table 1. Ingredients and nutrient composition of the diets for weaned pigs (as-fed basis)[z]

Item	Wheat	Zero-tannin faba bean starch
Ingredients (%)		
Wheat	59.73	8.30
Zero-tannin faba bean starch	–	59.40
Soybean meal	19.80	11.88
Whey permeate	9.90	9.90
Menhaden fish meal	4.46	4.46
Soy protein concentrate[y]	2.48	2.48
Mineral and vitamin premix[x]	2.48	2.48
L-Lysine HCl	0.15	0.10
Acid-insoluble ash[w]	1.00	1.00
Analyzed nutrient content (% as is)[v]		
Starch	29.8	32.0
Crude protein	23.8	24.1
Ca	1.25	1.25
P	0.86	0.89

[z]A wheat and faba bean starch diet was created by blending the wheat and zero-tannin faba bean starch diets 50:50 (wt/wt) in feeder of the extruder.
[y]Soycomil (ADM, Decatur, IL).
[x]Provided per kg of diet: Ca, 0.58%; P, 0.20%; K, 0.004%; Na, 0.12%; Cl, 0.18%; S, 0.007%; Mg, 0.007%; Fe, 174 mg; Zn, 91 mg; Mn, 37 mg; Cu, 10 mg; Co, 0.55 mg; I, 0.30 mg; Se, 0.25 mg; vitamin E, 7370 IU; vitamin D, 820 IU; vitamin E, 20 IU; vitamin B_{12}, 0.006 mg; riboflavin, 4 mg; pantothenic acid, 10, mg; niacin, 18 mg; choline, 150 mg.
[w]Celite 281 (World Minerals, Santa Barbara, CA).
[v]Analyzed content of the wheat and zero-tannin faba bean starch diet was (% as is): starch, 29.8, crude protein, 23.8; Ca, 1.13; and P, 0.84.

by the Canadian Council on Animal Care (1993). The experiment was conducted at the Swine Research and Technology Centre at the University of Alberta (Edmonton, AB, Canada). Twelve barrows and 12 gilts (Duroc sire × Large White/Landrace F_1; Genex Hybrid; Hypor, Regina, SK) were selected based on a similar weaning weight (7.6 ± 0.77 kg) and average daily gain [(ADG); 0.14 ± 0.115 kg] and randomized within gender to reach eight pigs per diet. Pigs were weaned at 21 d of age and started 5 d post-weaning an 11-d experiment including a 7-d adaptation to the diets, followed by a 4-d collection of faeces.

The pigs were housed in individual metabolism pens that allowed freedom of movement (0.54 m wide, 1.21 m long, 0.77 m high; raised 0.76 m). The pens were equipped with a galvanized water dish, feed trough, and plastic walls and slatted flooring. Pigs had free access to feed and water during the entire experiment. During faeces collection, freshly voided faeces from 0800 to 1600 were collected by grab sampling. At completion of the 11-d trial, pigs were sedated using an intramuscular injection of ketamine, xylazine, and azaperone, and then euthanized using an intracardiac injection of sodium pentobarbital. Subsequently, digesta were promptly collected from the small intestine divided into three segments of similar length: segment 1 (duodenum), segment 2 (jejunum), and segment 3 (ileum) using the slaughter technique (Bach Knudsen et al. 2006). Faeces and digesta samples were quickly frozen at −20°C and subsequently freeze-dried. Feed and faeces were ground through a 1-mm screen and digesta was ground in a coffee grinder due to small sample quantity.

Diet and faeces were analyzed for moisture [method 930.15; Association of Official Analytical Chemists (AOAC) 1990], acid-insoluble ash (McCarthy et al. 1974), gross energy by bomb calorimetry, and starch (Karkalas 1985). Briefly, starch was measured by an enzymatic method after samples were gelatinized with sodium hydroxide; glucose concentration was measured using glucose oxidase/peroxidase enzyme, and dihydrochloride. Absorbance was determined with a microplate reader at 450 nm (Silveira et al. 2007). Dietary starch was confirmed using the amyloglucosidase/α-amylase method with a final glucose analysis using a spectrophotometer at 510 nm (AOAC Method 996.11).

Based on the results of the chemical analyses, apparent digestibility of starch and energy was calculated using the acid insoluble ash concentration of feed, digesta, and faeces using the indicator or index method (Adeola 2001). Ileal digestibility was deducted from total tract digestibility to determine large intestine digestibility or bacterial fermentation. To calculate ADG, pigs were weighed at the start and end of the 11-d study.

The pig was considered the experimental unit. The general linear models procedure of SAS (SAS Institute, Inc. 1996) was used to analyze the variance of the variables, except for starch digestibility in the small

Table 2. Effects of extruded starch source on starch and energy digestibility

Variable	Wheat	Wheat and zero-tannin faba bean starch	Zero-tannin faba bean starch	Pooled SEM
Energy digestibility (%)				
Ileum	73.46*A*	71.99*AB*	59.79*B*	5.07
Total tract	83.70*bb*	85.63*aa*	86.36*aa*	0.38
Total tract – ileum	10.19*c*	14.43*b*	28.36*a*	5.33
DE content (Mcal kg^{-1})				
Ileum	3.18	3.12	2.64	0.22
Total tract	3.62*cc*	3.72*bb*	3.82*aa*	0.02
Total tract – ileum	0.44*b*	0.63*ab*	1.25*a*	0.24
Starch digestibility (%)				
Segment 1 – duodenum	80.66*a*	79. 23*a*	73.07*b*	1.23
Segment 2 – jejunum	91.75	89.03	91.64	0.84
Segment 3 – ileum	95.79*A*	95.04*AB*	93.04*B*	0.62
Total tract	98.17*b*	98.45*a*	98.38*a*	0.06
Total tract – ileum	2.42*b*	3.61*ab*	5.38*a*	0.94

a, b Within a row, means without a common letter differ ($P < 0.05$). *aa–cc* indicates differences ($P < 0.001$) and *A–B* indicates trends ($P < 0.10$).

intestine, which was analyzed as a repeated measures using the MIXED procedure (Wang and Goonewardene 2004). The statistical model included the effect of diet and initial body weight as covariate. Means were separated using the probability of difference ($P < 0.05$), and trends ($0.05 < P < 0.10$) were reported. Data were reported as least-square means.

Total tract energy digestibility was 2.7 and 1.9% units higher ($P < 0.001$; Table 2) for the faba bean starch and the wheat/faba starch diet, respectively, than for the wheat diet. Ileal energy digestibility tended to be 13.7% units lower ($P < 0.10$) for faba bean starch diet than the wheat diet. The calculated difference between total tract and ileal energy digestibility was highest ($P < 0.05$) for the faba bean starch diet, followed by the wheat/faba starch and wheat diets. The total tract DE content was highest for faba bean starch diet ($P < 0.001$), followed by wheat/faba bean starch, and wheat diets. Differences in ileal DE content were not observed. The difference between total tract and ileal DE content was highest ($P < 0.05$) for faba bean starch diet, followed by the wheat/faba starch and wheat diets.

Total tract starch digestibility was 0.2 and 0.3% units higher ($P < 0.05$; Table 2) for the faba bean starch and the wheat/faba starch diets than for the wheat diet. Duodenal starch digestibility was higher ($P < 0.05$) for the wheat and wheat/faba starch diets than the faba bean starch diet. Ileal starch digestibility tended to be higher ($P < 0.10$) for the wheat than the faba bean starch diet. Differences among diets were not observed ($P > 0.10$) for starch digestibility in the jejunal segment. The difference between total tract and ileal starch digestibility was higher ($P < 0.05$) for the faba bean starch than for the wheat diet.

Starch source in the diet did not affect final body weight, ADG, or gain:feed (Table 3). During the entire 11 d, ADFI of pigs fed the wheat/faba bean starch diet tended to be 20% higher ($P < 0.10$) than pigs fed the wheat diet.

The kinetics of starch digestion differs among raw feedstuffs (Fledderus et al. 2003; Bach Knudsen et al. 2006). Starch source and digestibility should be important considerations for the formulation of diets for weaned pigs (Van Kempen et al. 2007). The gastrointestinal tract of the weaned pig is still developing and adjusting to dietary changes, which might affect starch and energy digestibility. In the present study, starch and energy digestibility and fermentability differed among the three extruded diets containing ground wheat, air-classified faba bean starch or a 50:50 blend of both diets. The differences in starch digestibility were likely due to the starch structure and characteristics of the two extruded starch sources. Faba bean starch has a higher amylose content compared with wheat starch

Table 3. Effects of extruded starch source on growth performance of weaned pigs

Variable	Wheat	Wheat and zero-tannin faba bean starch	Zero-tannin faba bean starch	Pooled SEM
ADG (kg d^{-1})	0.175	0.228	0.215	0.022
ADFI (kg d^{-1})	0.302*B*	0.361*A*	0.345*AB*	0.022
Gain:feed	0.572	0.622	0.618	0.038
Final BW	9.52	10.10	9.97	0.244

A–B Within a row, means without a common letter differ ($P < 0.10$).

(Lorenz 1979); wheat starch contains more amylopectin. The amylopectin is more rapidly digestible in the gut than amylose, explaining the increased ileal starch and energy digestibility and increased total tract starch digestibility for the wheat-based diet compared with the faba bean diet. The increased fermentation in the large intestine of the extruded faba bean starch and energy is due to more resistant starch remaining from amylose. Extruded wheat grain starch thus yielded a higher proportion of absorbed glucose, whereas extruded faba bean starch yielded a higher proportion of volatile fatty acids. The net energy content of the extruded wheat diet was thus higher than for the extruded faba bean starch diets, even though total tract energy digestibility and DE content was higher for the extruded faba bean starch diets. Nevertheless, ADG was equivalent for two extruded starch sources indicating that factors other than dietary energy content are important for achieved growth performance.

Dietary energy intake is considered the limiting factor for the growth of young pigs. The major energy-yielding substrate in swine feed is starch, and starch digestion rate should be important for the energy balance (Wiseman 2006) and thus tissue growth. Still, changes in starch digestion via feedstuff selection or processing do not consistently relate to changes in growth performance. For example, extrusion of corn and therefore starch gelatinization did not consistently increase ADG (Hongtrakul et al. 1998; Lv et al. 2006), indicating that gaps of knowledge exist on the underlying mechanisms that relate starch digestion to ADG. In the present study, ADG did not differ among the three extruded diets, even though changes in starch and energy digestion were observed. Starch fermented in the large intestine from extruded faba bean could have contributed significantly to the overall energy balance and thereby masked the lower ileal starch digestibility resulting in an equivalent energy intake, even though starch digestion in the small intestine as opposed to starch bacterial fermentation in the large intestine is considered more effective to provide energy to support protein deposition. A reduced rate of starch digestion may provide energy to the distal small intestine, and perhaps serves a role in the sparing of amino acids (Weurding et al. 2003). Finally, a sustained but reduced rate of starch digestion and thus a reduced glycemic index (Van der Meulen 1997) may prolong the insulin response coinciding with a prolonged protein synthesis.

Overall, ADFI tended to be higher for the extruded wheat/faba bean starch and faba bean starch diets than the wheat diet. Palatability might have played a role, but the texture of the wheat/faba and faba bean starch diets was slightly more granular than that of the wheat diet, which was more powdery, perhaps allowing for easier consumption at the feeder. Nutritionally, a reduced glycemic index in swine may reduce the insulin response, thereby reducing the inhibitory effect of elevated plasma insulin concentrations on feed intake (Deetz and Wangsness 1980; Van Kempen et al. 2007), providing an alternative hypothesis for the elevated feed intake for diets containing extruded faba bean starch, indicating that not only nutrient digestibility but also effects on feed intake must be considered to explain ADG. A combination of these factors may therefore explain a lack of an effect of starch source on ADG.

In summary, the in vivo kinetics of starch and energy digestion differed for the extruded wheat and zero tannin faba bean starch diets. The impact of the kinetics of starch digestion on growth performance variables was not conclusive, but reduced starch digestion in the small intestine coincided with a trend for increased voluntary feed intake in weaned pigs.

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