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Effect of feeding mid- or zero-tannin faba bean cultivars differing in vicine and covicine content on diet nutrient digestibility and growth performance of weaned pigs

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ABSTRACT

To prioritize what cultivars to grow to feed pigs, five faba bean cultivars including three zero-tannin, high vicine and covicine cultivars (Snowbird, Snowdrop, Tabasco), and two medium-tannin, lower vicine and covicine cultivars (Fabelle and Malik) were fed to compare effects on diet nutrient digestibility and growth performance of weaned pigs. A total of 260 pigs (8 ± 1.2 kg), weaned at 20 ± 1 d of age housed 2 barrows and 2 gilts/pen were fed 1 of 5 dietary regimens starting 1-week post-weaning for 4 weeks in a randomized complete block design. Diets including each cultivar at 20% or 30% provided 10.2 and 10.1 MJ net energy (**NE**)/kg and 1.3 and 1.2 g standardized ileal digestible (**SID**) lysine (**Lys**)/MJ NE in phases 1 and 2, respectively. Digestibility data were analyzed using PROC GLIMMIX and growth performance data were analyzed using PROC MIXED with pen as experimental unit. Fabelle contained the most condensed tannins (**CT**; 0.53%) but the least vicine (0.04%) and covicine (0.01%). Zero-tannin cultivars contained little CT (<0.2%) but had the greatest vicine (0.5%) and covicine content (0.4%). For phase 1, diet apparent total tract digestibility (**ATTD**) of dry mater (**DM**), gross energy (**GE**), crude protein (**CP**), digestible energy (**DE**), and NE values did not differ among cultivars. For phase 2, diet ATTD of DM and GE were greatest ($P < 0.05$) for Snowdrop and Tabasco, intermediate for Fabelle, and lowest for Malik; Snowbird was not different from Fabelle or Malik. Diet ATTD of CP was greatest ($P < 0.05$) for Tabasco, intermediate for Snowbird, and lowest for Malik; Snowdrop was not different from Tabasco or Snowbird, and Fabelle was not different from Snowbird or Malik. Diet DE and NE values were greatest ($P < 0.05$) for Tabasco, intermediate for Fabelle and Snowdrop, and lowest for Snowbird; Malik was not different from Fabelle or Snowbird. For the entire trial (d 0–28), daily feed disappearance and weight gain for pigs fed Fabelle were 10% greater ($P < 0.05$) than those fed Malik; pigs fed zero-tannin cultivar diets were intermediate. Pigs fed Fabelle were 1.6 kg heavier ($P < 0.05$) than those fed Malik at the end of the trial; pigs fed zero-tannin cultivar diets were intermediate. In conclusion, growth performance of pigs fed faba bean cultivar diets was more related to feed disappearance than diet nutrient digestibility. Vicine and covicine instead of condensed tannin content of faba bean cultivars seemed more relevant to growth performance in weaned pigs.

Key words: antinutritional factors, condensed tannins, faba bean cultivars, pig, vicine and covicine

INTRODUCTION

Worldwide corn grain and soybean meal are the most common feedstuffs supplying starch and supplemental protein, respectively, in swine diets. However, in northern latitudes where heat units limit corn and soybean production, locally grown alternative ingredients like pulses can provide both starch and protein and present an opportunity to reduce feed cost (Woyengo et al., 2014). Faba bean (*Vicia faba* L.) contains 30%–42% starch (dry matter basis; Cerning et al., 1975) and 25%–37% crude protein (Duc et al., 1999). In contrast to field pea, lentil, and chickpea, faba bean fixes the most atmospheric nitrogen beyond blooming until the plant dries (López-Bellido et al., 2006); thus, it is an excellent rotational pulse crop to grow alternating with cereals and oilseeds.

White-flowered or zero-tannin faba bean cultivars contain less condensed tannin at 0.06%–0.75% than color-flowered cultivars containing 0.40%–2.15% (Cabrera and Martin, 1989). Condensed tannins form insoluble complexes with proline-rich proteins such as collagen, gelatin, salivary proteins, casein, and digestive enzymes that reduce diet nutrient digestibility (Hagerman and Butler, 1980). The astringent sensation of this complexation causing drying and puckering suppressed palatability (Butler et al., 1984). Other relevant antinutritional factors in faba bean are vicine and convicine that cause hemolytic anemia in humans (favism) with an erythrocyte genetic deficiency of glucose-6-phosphate dehydrogenase (Arese et al., 2012). Their aglycones, divicine and isouramil, react with blood oxygen forming reactive oxygen species that increase lipid peroxidation. Decreased liver function may result in insufficient bile acid production for micelle formation affecting lipid digestion thus reducing energy digestibility (Cho et al., 2019). Both white- and color-flowered faba bean cultivars can be included at up to 40% in diets fed to weaned and growing pigs without reducing growth performance (Beltranena et al., 2009; Ivarsson and Neil, 2018). Feeding low vicine and covicine and mid-tannin faba bean cultivars did not reduce nutrient digestibility or growth performance in broiler chickens (Cho et al., 2019). However, variation in content of nutrients, condensed tannins, vicine and convicine in faba bean cultivars and their effect on diet nutrient digestibility and growth performance of weaned pigs needs to be clarified to prioritize what cultivar to grow to feed pigs.

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The null hypothesis of the present study was that feeding diets including faba bean cultivars differing in nutrients, condensed tannins, and vicine and covicine content would not affect nutrient digestibility and growth performance of weaned pigs. The objectives were to compare the apparent total tract digestibility of dry matter, gross energy, crude protein, digestible energy and net energy values, growth performance, and feces consistency of weaned pigs fed diets including five faba bean cultivars differing in nutrient, condensed tannins, and vicine and covicine content.

MATERIALS AND METHODS

Animal use and experimental procedure were reviewed by the University of Alberta Animal Care and Use Committee for Livestock and followed principles established by the Canadian Council on Animal Care (CCAC, 2009). The study was conducted in nursery rooms located at the Swine Research and Technology Centre, University of Alberta (Edmonton, Alberta, Canada).

In total, 260 pigs (Duroc × Large White/Landrace F1; Alliance Genetics Canada, Sand Ridge Farm Ltd., Barrhead, Alberta, Canada) weaned at 20 ± 1 day [**d**] of age, were selected based on post-weaning average daily weight gain (**ADG**) to day 5 after weaning. Pigs within sex were divided into heavy or light body weight (**BW**). One light- and one heavy-gilt and one light- and one heavy-barrow were randomly allocated to each pen within area block. Pigs were fed a common creep diet until 2 days after weaning and then a commercial starter diet for 5 days. Pigs were then fed the phase 1 diets for 2 weeks (d 0–14) and subsequently the phase 2 diets for 2 more weeks (d 14–28).

The three zero-tannin faba bean cultivars Snowbird, Snowdrop, and Tabasco were sourced from Galloway Seeds (Fort Saskatchewan, Alberta, Canada), Shewchuk Seeds (Blaine Lake, Saskatchewan, Canada), and Riddell Seed Company (Warren, Manitoba, Canada), respectively. The two mid-tannin faba bean cultivars Fabelle and Malik were both sourced from Stamp Seeds (Enchant, Alberta, Canada). Faba bean cultivars were ground through a 2.8-mm screen using a hammermill (model Jacobson 5550-113-01, Carter Day International, Minneapolis, MN).

Diets and Experimental Design

Five experimental diets were formulated including 20% of 1 of the 5 faba bean cultivars in phase 1 (Table 1) and 30% in phase 2 (Table 2). Diets provided 10.2 and 10.1 MJ net energy (**NE**)/kg and 1.3 and 1.2 g standardized ileal digestible (**SID**) lysine (**Lys**) per MJ NE for phase 1 and phase 2 diets, respectively. Canola oil and L-lysine HCl were added to equalize NE value and SID Lys content, respectively. Other amino acids (**AA**) were formulated as an ideal ratio to Lys (NRC, 2012). The NE value for each faba bean cultivar was calculated using equation 5 of Noblet et al. (1994) including analyzed starch, crude fat, crude protein (**CP**), and acid detergent fiber (**ADF**) content for the same cultivars from a recent study (Cho et al., 2019). Tabulated NRC (2012) data were used to calculate the SID AA content for faba bean cultivars and main ingredients. Celite was included in diets as indigestible marker. Phase 1 diets were mixed in a 300-kg horizontal paddle mixer (model SPC2748, Marion Mixers Inc., Marion, IA) and cold-pelleted (model PM1230, Buskirk Engineering, Ossian, IN). Phase 2 diets were mixed in a 1000-kg vertical mixer (model MFP-2100, Weigh-Tronix, Fairmont, MN) and steam-pelleted (model 1112-4, California Pellet Mill Co., San Francisco, CA).

The study was conducted as a randomized complete block design with 13 blocks. Pens of pigs within area block were randomly fed 1 of the 5 dietary regimens. Pens (1.1 × 1.5 m) were equipped with plastic slatted flooring, a concrete back wall, and pen partitions and front gate made of polyvinyl chloride. Pens were also equipped with a single 4-place adjustable self-feeder (model N4; Crystal Spring, Manitoba, Canada) and an adjustable-height nipple drinker. Rooms were ventilated using negative pressure and heated by convection from hot water pipes. Light tubes provided a 12-h light (0700–1900 h) and 12-h dark cycle. Pigs had free access to feed and water throughout the trial. Individual pigs, pen feed added, and remaining orts were weighed weekly to calculate pen ADG, average daily feed disappearance (**ADFD**), and gain-to-feed ratio (**G:F**). Freshly voided feces were scored for consistency twice daily (at approximately 0800 h and 1600 h) and collected hourly by grab-sampling from pen floors on days 12 and 13 for phase 1, and days 26 and 27 for phase 2. Fresh feces were pooled by pen and frozen at approximately −20 °C. Upon completion of the trial, feces were thawed, homogenized, subsampled, and freeze-dried.

Chemical Analyses and Calculations

Faba bean cultivars, diets, and lyophilized feces samples were ground through a 1-mm screen in a centrifugal mill (Model ZM200, Retch GmbH, Haan, Germany) and were analyzed for dry matter (**DM**; method 930.15; AOAC, 2006), CP by Leco (nitrogen [**N**] × 6.25; method 990.03), and GE using an adiabatic bomb calorimeter (model 5003; Ika-Werke, Staufen, Germany) at the University of Alberta. Cultivar and diet samples were also analyzed for total (method 996.11) and resistant starch (method 2002.02) using Megazyme assay kits and crude fat using a Goldfisch fat extraction apparatus (method 945.16). Cultivars and diets were analyzed for neutral detergent fiber (**NDF**) without a heat-stable amylase and expressed inclusive of residual ash (Holst, 1973), ADF inclusive of residual ash (method 973.18), and ash (method 942.05) at the Agricultural Experiment Station Chemical Laboratories (**ESCL**), University of Missouri (Columbia, MO, USA). Faba bean cultivar samples were also analyzed for total dietary fiber (method 985.29), calcium (method 968.08), phosphorus (method 946.06), and AA [method 982.30E (a–c)] at ESCL. Vicine and covicine of faba bean cultivars were analyzed using a slight modification of the extraction procedure (Purves et al., 2018) at the Organic Residue Laboratory of Alberta Agriculture and Forestry (Edmonton, Alberta, Canada). Condensed tannins (**CT**) analysis was conducted at the Natural Resources Institute Finland using high performance liquid chromatography after thiolytic degradation as described by Ivarsson and Neil (2018). Diets and feces samples were analyzed for acid insoluble ash (Vogtmann et al., 1975 as modified by Newkirk et al., 2003) at the University of Alberta. Particle size of faba bean cultivars was established using a mechanical sieve shaker (Model RX-29, W.S. Tyler, ON, Canada) following the method of the American Society of Agricultural and Biological Engineers (2008).

Based on results of chemical analyses, the apparent total tract digestibility (**ATTD**) of DM, GE, and CP were calculated for each diet using the indicator method according to Adeola (2001):

Table 1. Ingredient composition and analyzed nutrient content (as fed) of diets including 5 faba bean cultivars fed to weaned pigs during phase 1 (days 0–14)[1]

	Snowbird	Snowdrop	Tabasco	Fabelle	Malik
Ingredient, %					
Wheat, Hard Red Spring	40.86	40.73	39.68	40.28	39.75
Snowbird faba bean	20.00	–	–	–	–
Snowdrop faba bean	–	20.00	–	–	–
Tabasco faba bean	–	–	20.00	–	–
Fabelle faba bean	–	–	–	20.00	–
Malik faba bean	–	–	–	–	20.00
Soybean meal	15.00	15.00	15.00	15.00	15.00
Lactose	10.00	10.00	10.00	10.00	10.00
Menhaden fish meal	5.00	5.00	5.00	5.00	5.00
Soy protein concentrate[2]	2.50	2.50	2.50	2.50	2.50
Canola oil	1.50	1.60	2.70	2.10	2.60
Limestone	1.25	1.25	1.25	1.25	1.25
Salt	0.85	0.85	0.85	0.85	0.85
Celite[3]	0.80	0.80	0.80	0.80	0.80
Vitamin premix[4]	0.50	0.50	0.50	0.50	0.50
Trace mineral premix[5]	0.50	0.50	0.50	0.50	0.50
L-Lysine HCl	0.40	0.43	0.37	0.37	0.40
L-Threonine	0.25	0.25	0.25	0.25	0.25
Mono-/di-calcium phosphate	0.20	0.20	0.20	0.20	0.20
DL-Methionine	0.15	0.15	0.15	0.15	0.15
Choline chloride, 60%	0.10	0.10	0.10	0.10	0.10
L-Valine	0.07	0.07	0.07	0.07	0.07
L-Tryptophan	0.06	0.06	0.06	0.06	0.06
Phytase[6]	0.02	0.02	0.02	0.02	0.02
Analyzed nutrient content, %					
Dry matter	88.13	88.18	88.24	88.63	88.74
Starch	31.13	31.36	29.56	30.98	29.40
Crude protein	26.76	25.72	26.38	26.36	26.26
Neutral detergent fiber	8.66	10.66	10.34	15.06	10.80
Acid detergent fiber	5.32	4.95	5.13	4.95	5.20
Crude fiber	3.07	3.13	3.42	3.49	3.45
Crude fat	3.12	3.19	3.96	3.81	4.09
Crude ash	7.10	6.81	7.12	6.63	7.04
Calcium	0.91	0.85	0.81	1.02	0.96
Phosphorus	0.64	0.59	0.67	0.62	0.68
Indispensable amino acid					
Arginine	1.44	1.43	1.54	1.47	1.42
Histidine	0.54	0.54	0.55	0.53	0.52
Isoleucine	0.98	0.96	0.96	0.94	0.91
Leucine	1.62	1.61	1.61	1.59	1.54
Lysine	1.52	1.52	1.51	1.45	1.48
Methionine	0.41	0.43	0.42	0.41	0.42
Phenylalanine	1.08	1.06	1.02	1.05	1.03
Threonine	0.97	0.97	1.11	1.10	1.11
Tryptophan	0.26	0.30	0.29	0.28	0.28
Valine	1.19	1.16	1.11	1.10	1.11
Dispensable amino acid					
Alanine	0.94	0.94	0.95	0.92	0.92
Aspartic acid	2.03	2.01	2.04	1.98	1.98
Cysteine	0.33	0.33	0.32	0.33	0.33
Glutamic acid	4.48	4.47	4.53	4.43	4.30

Table 1. Continued

	Snowbird	Snowdrop	Tabasco	Fabelle	Malik
Glycine	1.02	1.01	1.03	1.00	1.00
Proline	1.30	1.34	1.28	1.29	1.30
Serine	0.85	0.86	0.99	0.86	0.84
Tyrosine	0.72	0.71	0.69	0.69	0.67
Gross energy, MJ/kg	16.47	16.63	16.68	16.59	16.77

[1]Diets were formulated to provide 10.2 MJ NE/kg, and 1.3 g SID Lys/MJ NE.
[2]HP300 (Hamlet Protein Inc., Findlay, OH).
[3]Celite 281 (World Minerals Inc., Santa Barbara, CA).
[4]Supplied per kilogram of diet: 7,500 IU of vitamin A, 750 IU of vitamin D, 76 IU of vitamin E, 60 mg of niacin, 21 mg of pantothenic acid, 2.8 mg of folacin, 6 mg of riboflavin, 4.8 mg of thiamine, 1,000 mg of choline, 4 mg of vitamin K, 0.33 mg of biotin, and 3 mg of vitamin B_{12}.
[5]Supplied per kilogram of diet: 149 mg of Zn as $ZnSO_4$, 53.9 mg of Cu as $CuSO_4$, 199 mg of Fe as $FeSO_4$, 49 mg of Mn as $MnSO_4$, 0.5 mg of I as Ca $(IO_3)_2$, and 0.3 mg of Se as Na_2SeO_3.
[6]Ronozyme HiPhos 2500 (DSM Ronozyme Hyphos–GT; North Dumfries, Ontario, Canada).

$$\text{ATTD} = \left(1 - \frac{\textit{Indigestible marker in feed} \times \textit{content of component in feces}}{\textit{Indigestible marker in feces} \times \textit{content of component in feed}}\right) \times 100$$

The DE value of diets was calculated by multiplying GE by its digestibility coefficient (Adeola, 2001). The NE value of diets was calculated using equation (5) in Noblet et al. (1994) with the determined diet DE value and analyzed content of ADF, CP, crude fat, and starch.

Statistical Analyses

Nutrient digestibility data were analyzed using PROC GLIMMIX and growth performance data were analyzed using PROC MIXED (version 9.4; SAS Inst. Inc., Cary, NC) with diet, week or phase, and interactions as fixed effects, block as a random term, and pen as the experimental unit. Normality and homogeneity of residuals for each item were confirmed first using PROC UNIVARIATE with 'Normal' option and PROC GLM with 'Hovtest = Levene' option, respectively. Growth performance data were analyzed as repeated measures using weekly pen data with the best covariance structure based on fit statistics and initial BW as a covariate if significant. The *P* values were adjusted with the Tukey option for multiple comparisons among treatments. Feces consistency scores were averaged weekly from the daily greatest score of pen observations and were analyzed using PROC GLIMMIX with a Gaussian distribution and Identity link function options.

RESULTS

For phase 1 diets, analyzed starch content ranged from 29.4% to 31.4%, and CP from 25.7% to 26.8% (Table 1). The Snowbird diet had the lowest NDF content (8.7%) whereas the Fabelle diet had the greatest (15.1%); ADF content ranged from 5.0% to 5.3%. Gross energy values ranged from 16.5 to 16.8 MJ/kg. Lysine content ranged from 1.45% to 1.52%.

For phase 2 diets, analyzed starch content ranged from 37.2% to 41.2%, CP from 25.9% to 27.5%, NDF from 10.4% to 15.1%, and ADF from 6.1% to 6.7% (Table 2). Gross energy values ranged from 16.5 to 17.0 MJ/kg. Lysine content ranged from 1.40% to 1.53%.

For faba bean cultivars, starch content ranged from 30.7% to 36.1% with about 48% as resistant starch (Table 3). Crude protein content ranged from 29.4% to 31.9%, NDF from 13.1% to 17.1%, ADF from 10.4% to 12.9%. Gross energy values ranged from 16.3 to 17.0 MJ/kg. Lysine content ranged from 1.87% to 2.05%. Between color-flowered cultivars, Fabelle contained twice as much CT as Malik, and both contained more CT than white-flowered cultivars (Snowbird, Snowdrop and Tabasco; < 0.2%). Between color-flowered cultivars, Fabelle contained less vicine and covicine than Malik, whereas white-flowered cultivars averaged 0.53% vicine and 0.40% covicine.

For phase 1 diets, ATTD of DM, GE, CP, and DE and NE values did not differ among cultivars (Table 4). For phase 2 diets, ATTD of DM and GE were greatest ($P < 0.05$) for Snowdrop and Tabasco, intermediate for Fabelle, and lowest for Malik; Snowbird was not different from Fabelle or Malik. Diet ATTD of CP was greatest ($P < 0.05$) for Tabasco, intermediate for Snowbird, and lowest for Malik; Snowdrop was not different from Tabasco or Snowbird, and Fabelle was not different from Snowbird or Malik. Diet DE and NE values were greatest ($P < 0.05$) for Tabasco, intermediate for Fabelle and Snowdrop, and lowest for Snowbird; Malik was not different from Fabelle or Snowbird.

For the entire trial (d 0–28), ADFD and ADG for pigs fed Fabelle were 10% greater ($P < 0.05$) than those fed Malik; pigs fed zero-tannin cultivar diets were intermediate (Table 5). Gain-to-feed did not differ among pigs fed the five cultivar diets. Pigs fed Fabelle were 1.6 kg heavier ($P < 0.05$) than those fed Malik at the end of the trial; pigs fed zero-tannin cultivar diets were intermediate. Feces scores did not differ among pigs fed the five faba bean cultivar diets for the entire trial or each week (Table 6).

DISCUSSION

Chemical Characteristics of Faba Bean Cultivars

Level of nutrients and antinutritional factors can differ among faba bean cultivars (Ivarsson and Neil, 2018). Therefore, it is of importance to screen for these compounds and evaluate their effect on nutrient digestibility and growth performance to prioritize cultivars that are best suited for swine production. Generally, chemical composition of faba bean cultivars in the present study was similar to previous reports (Duc et al., 1999; Sauvant et al., 2004). As expected, color-flowered cultivars (Fabelle and Malik) contained more condensed tannin than white-flowered cultivars (Snowbird, Snowdrop, and Tabasco; Cho et al., 2019). Variation in vicine and covicine content

Table 2. Ingredient composition and analyzed nutrient content (as fed) of diets including five faba bean cultivars fed to weaned pigs during phase 2 (days 14–28)[1]

	Snowbird	Snowdrop	Tabasco	Fabelle	Malik
Ingredient, %					
Wheat, Hard Red Spring	49.63	49.48	47.96	48.86	48.12
Snowbird faba bean	30.00	–	–	–	–
Snowdrop faba bean	–	30.00	–	–	–
Tabasco faba bean	–	–	30.00	–	–
Fabelle faba bean	–	–	–	30.00	–
Malik faba bean	–	–	–	–	30.00
Soybean meal	10.00	10.00	10.00	10.00	10.00
Menhaden fish meal	2.50	2.50	2.50	2.50	2.50
Soy protein concentrate[2]	2.50	2.50	2.50	2.50	2.50
Canola oil	0.90	1.00	2.60	1.70	2.40
Limestone	1.30	1.30	1.30	1.30	1.30
Celite[3]	0.80	0.80	0.80	0.80	0.80
Salt	0.70	0.70	0.70	0.70	0.70
Vitamin premix[4]	0.40	0.40	0.40	0.40	0.40
Trace mineral premix[5]	0.40	0.40	0.40	0.40	0.40
L-Lysine HCl	0.36	0.40	0.32	0.32	0.36
L -Threonine	0.16	0.16	0.16	0.16	0.16
Mono-/di-calcium phosphate	0.15	0.15	0.15	0.15	0.15
DL-Methionine	0.11	0.11	0.11	0.11	0.11
Choline chloride, 60%	0.05	0.05	0.05	0.05	0.05
L -Tryptophan	0.03	0.03	0.03	0.03	0.03
Phytase[6]	0.02	0.02	0.02	0.02	0.02
Analyzed nutrient content, %					
Dry matter	89.19	88.83	89.22	89.01	89.31
Starch	38.30	40.46	37.87	41.22	37.20
Crude protein	26.63	26.33	27.46	26.98	25.92
Neutral detergent fiber	10.41	12.05	13.53	15.07	11.65
Acid detergent fiber	6.08	6.72	6.48	6.14	6.61
Crude fiber	3.98	4.30	4.09	4.19	4.34
Crude fat	3.10	4.04	3.81	2.81	3.97
Crude ash	6.33	6.40	6.50	6.33	6.22
Calcium	0.72	0.68	0.73	0.69	0.71
Phosphorus	0.57	0.58	0.63	0.59	0.64
Indispensable amino acid					
Arginine	1.52	1.47	1.58	1.58	1.54
Histidine	0.55	0.54	0.54	0.55	0.55
Isoleucine	0.95	0.94	0.95	0.95	0.95
Leucine	1.64	1.60	1.64	1.63	1.61
Lysine	1.53	1.49	1.43	1.40	1.45
Methionine	0.35	0.36	0.36	0.33	0.36
Phenylalanine	1.10	1.07	1.11	1.08	1.09
Threonine	0.89	0.88	0.86	0.86	0.88
Tryptophan	0.27	0.26	0.29	0.25	0.26
Valine	1.05	1.04	1.02	1.06	1.04
Dispensable amino acid					
Alanine	0.92	0.91	0.89	0.91	0.90
Aspartic acid	2.03	1.95	1.97	1.98	2.01
Cysteine	0.36	0.34	0.36	0.34	0.35
Glutamic acid	4.85	4.66	4.62	4.76	4.75
Glycine	1.01	1.00	1.00	1.01	0.97
Proline	1.43	1.39	1.33	1.40	1.39

Table 2. Continued

	Snowbird	Snowdrop	Tabasco	Fabelle	Malik
Serine	0.95	0.90	0.87	0.87	0.88
Tyrosine	0.73	0.68	0.79	0.70	0.71
Gross energy, MJ/kg	16.66	16.54	16.87	16.78	17.03

[1]Diets were formulated to provide 10.1 MJ NE/kg, and 1.2 g SID Lys/MJ NE.
[2]HP300 (Hamlet Protein Inc., Findlay, OH).
[3]Celite 281 (World Minerals Inc., Santa Barbara, CA).
[4]Supplied per kilogram of diet: 6,000 IU of vitamin A, 600 IU of vitamin D, 46 IU of vitamin E, 56 mg of niacin, 21 mg of pantothenic acid, 2.8 mg of folacin, 6 mg of riboflavin, 4.8 mg of thiamine, 1,000 mg of choline, 3.2 mg of vitamin K, 0.28 mg of biotin, and 3 mg of vitamin B12.
[5]Supplied per kilogram of diet: 122 mg of Zn as $ZnSO_4$, 43.2 mg of Cu as $CuSO_4$, 173 mg of Fe as $FeSO_4$, 44 mg of Mn as $MnSO_4$, 0.4 mg of I as Ca $(IO_3)_2$, and 0.24 mg of Se as Na_2SeO_3.
[6]Ronozyme HiPhos 2500 (DSM Ronozyme Hyphos –GT; North Dumfries, Ontario, Canada).

among cultivars is likely because of varying concentration or activity of guanosine triphosphate cyclohydrase II, a key enzyme modulating their synthesis (Björnsdotter et al., 2021).

Among macronutrients, starch was the major constituent that differed among faba bean cultivars irrespective of being color- or white-flowered. Starch content was slightly lower than 37%–44% DM previously reported (Duc et al., 1999; Ivarsson and Neil, 2018). Variation in starch content may be attributed in part to laboratory assay variability despite similar analytical methods. Similar to other pulses, nearly half of total starch in faba bean grain fed in the present study was resistant starch. Greater resistant starch (46.7%) as compared with slower digestible starch (34.5%) and smaller amount of rapid digestible starch (15.3%) content in faba bean (Bello-Pérez et al., 2007) indicate that a large portion of starch is resistant to enzymatic hydrolysis in the small intestine.

Crude protein and lysine content were more consistent among faba bean cultivars. Crude protein content of cultivars in the present study was 3%-units greater than the 27% reported for the same cultivars previously (Cho et al., 2019) and was within the 24%–37% range reported by Duc et al. (1999). In comparison with cereal grains, faba bean cultivars fed in the present study contained more lysine but less sulfur-containing amino acids (methionine + cystine) and tryptophan than soybean meal (Duc et al., 1999). Consequently, diets fed in the present study were supplemented with crystalline amino acids and included soybean meal, fish meal, and soy protein concentrate to complement their profile. Amino acid composition generally varies among faba bean cultivars (Jezierny et al., 2010).

The third constituent by mass in faba bean was fiber. Neutral detergent fiber was greater than 10.9%–12.6% DM reported by Ivarsson and Neil (2018), but similar to 12.6%–16.5% reported by Jezierny et al. (2010). On an average, color-flowered cultivars (Fabelle and Malik) contained slightly more total dietary fiber than white-flowered cultivars (23.3% vs. 19.1%), matching their greater soluble fiber content, suggesting slightly greater fermentation potential (Tan et al., 2018).

Diet Nutrient and Energy Digestibility

Condensed tannins in faba bean are considered major antinutritional factors for monogastric species (Jezierny, 2009). In vitro digestibility of dry matter was 4.7% greater for white- than color-flowered faba bean cultivars presumably because lower grain tannin content (Bond, 1976). We fed diets including the same phase level of white- and color- flowered faba bean cultivars to weaned pigs so that effects of variation in tannin, vicine and covicine content, if contributing to differences in nutrient and energy digestibility, could be detected. Lack of extreme differences in condensed tannin content between zero- and mid-tannin cultivars in this study was not likely a large factor affecting total tract digestibility of nutrients or energy (Ivarsson and Neil, 2018).

Tannins interact with carbohydrates, particularly starch, thereby reducing energy digestibility (Jansman, 1993). However, their affinity for starch seems to be less than that for protein. Tannins may not only reduce energy digestibility by interacting with starch but also bind α-amylase and lipase thus reducing starch and fat hydrolysis, respectively (Griffiths, 1979). Pigs fed the color-flowered Malik diet in phase 2 had the lowest dry matter and energy digestibility but not different from zero-tannin Snowbird. Moreover, Malik contained less tannins than Fabelle, indicating that reasons other than tannin content in Malik should explain its low energy digestibility. Instead, the presence of vicine and covicine, greater total dietary fiber, and the greatest resistant starch content in Malik could have collectively reduced its energy digestibility. Following ingestion by pigs, vicine and covicine can be hydrolyzed by a ß-glycosidase-like enzyme produced by anaerobic bacteria in the colon (Hegazy and Marquardt, 1984). Vicine is converted into divicine and covicine into isouramil that are both absorbed and subsequently react with blood oxygen, thereby generating reactive oxygen species such as hydrogen peroxide (Chevion et al., 1982). Lipid peroxidation that may reduce energy digestibility due to insufficient bile acid production for lipid digestion (Losowsky and Walker, 1969).

Similar to other legume grains, carbohydrates in faba bean may pose digestibility concerns in young pigs. Faba bean starch is mainly type C with greater amylose content, which is more resistant than amylopectin to porcine pancreatic α-amylase hydrolysis (Hoover and Zhou, 2003). Greater inclusion rate of faba bean in phase 2 diets thus likely contributed to higher dietary resistant starch and nonfermentable nonstarch polysaccharides that collectively reduced total tract digestibility of energy more than in Phase 1 diets. Furthermore, faba bean as legume grain contains more soluble oligosaccharides (α-galactosides) than cereal grains (Jezierny et al., 2010). Excessive consumption of α-galactosides may increase rate of passage and loosen feces or even stimulate diarrhea and flatulence in pigs due to excessive fermentation (Fleming et al., 1988). Still, dietary changes, presence of oligosaccharides, and variation in fiber content among faba bean cultivars in this experiment did not result in differences in fecal consistency

Table 3. Analyzed chemical composition (as is) of five faba bean cultivars

Item, %	Snowbird	Snowdrop	Tabasco	Fabelle	Malik
Dry matter	89.50	87.80	89.38	90.40	89.72
Starch	30.70	36.09	33.29	33.36	31.83
Resistant Starch	12.77	16.64	16.05	17.50	16.92
Crude protein	31.84	28.97	30.95	31.86	29.39
Total dietary fiber	19.67	21.35	16.10	22.01	24.50
Soluble dietary fiber	1.22	1.53	0.33	1.82	1.71
Neutral detergent fiber	15.12	13.10	17.10	15.89	14.34
Acid detergent fiber	11.85	10.55	11.52	10.36	12.91
Crude fiber	10.64	8.01	9.59	9.91	10.55
Crude fat	1.03	0.75	0.71	0.57	0.47
Crude ash	3.96	3.34	3.47	3.39	4.04
Calcium	0.13	0.11	0.07	0.10	0.12
Phosphorus	0.56	0.46	0.57	0.46	0.65
Indispensable amino acids					
Arginine	2.48	2.49	3.05	3.06	2.61
Histidine	0.75	0.73	0.76	0.81	0.73
Isoleucine	1.33	1.28	1.32	1.40	1.23
Leucine	2.27	2.13	2.23	2.39	2.07
Lysine	2.00	1.87	1.90	2.05	1.90
Methionine	0.20	0.19	0.19	0.20	0.19
Phenylalanine	1.38	1.26	1.28	1.39	1.23
Threonine	1.02	0.99	0.99	1.08	0.97
Tryptophan	0.22	0.21	0.23	0.18	0.16
Valine	1.41	1.37	1.41	1.53	1.36
Dispensable amino acids					
Alanine	1.20	1.18	1.20	1.31	1.17
Aspartic acid	3.26	3.06	3.13	3.47	3.07
Cysteine	0.38	0.38	0.37	0.39	0.36
Glutamic acid	4.89	4.63	4.83	5.31	4.58
Glycine	1.29	1.25	1.27	1.34	1.21
Proline	1.16	1.16	1.23	1.23	1.13
Serine	1.20	1.14	1.17	1.30	1.11
Tyrosine	1.02	0.89	0.97	1.01	0.84
Total amino acids	27.86	26.51	27.83	29.76	26.21
Anti-nutritional factors					
Vicine	0.60	0.58	0.42	0.04	0.43
Covicine	0.39	0.40	0.42	0.01	0.42
Condensed tannins[1]	ND[2]	ND	ND	0.53	0.27
Average particle size, µm	596	447	594	519	625
Standard deviation, µm	2.49	2.54	2.19	2.38	2.37
Gross energy, MJ/kg	16.34	16.62	16.85	16.97	16.83

[1]Detection limit for condensed tannins was 0.20%.
[2]ND, not detected.

scores. The greatest total tract digestibility of gross energy and digestible energy values in the Tabasco phase 2 diet might be because of its greater dietary starch and hemicellulose content (NDF – ADF) (Noblet and Perez, 1993). Conversely, Malik phase 2 diet had the lowest total tract digestibility of gross energy, matching its greatest fiber content. Likewise, the greatest fiber content of the Malik diet likely contributed to increased nonfermentable fiber thereby reducing its energy digestibility. The greatest calculated net energy value in the Tabasco phase 2 diet was likely due to its digestible energy value (Noblet et al., 1994). Conversely, the lowest net energy value in Snowbird phase 2 diet was consistent with its lowest digestible energy value.

Feeding diets containing high tannin faba bean to broiler chickens and pigs may decrease digestibility of crude protein (Jansman et al., 1993). Tannins can bind both dietary protein and digestive enzymes, thereby reducing activity of trypsin and chymotrypsin (Griffiths, 1979), thus increase endogenous

Table 4. Apparent total tract digestibility (ATTD) of dry matter (DM), gross energy (GE) and crude protein (CP), and digestible energy (DE), and net energy (NE) values of diets including five faba bean cultivars fed to weaned pigs in phase 1 (days 0–14) and phase 2 (days 14–28)[1]

Variable	Diet					SEM[2]	*P*-value
	Snowbird	Snowdrop	Tabasco	Fabelle	Malik		
ATTD of DM, %							
Phase 1	84.6	84.9	84.3	84.2	84.1	0.36	0.168
Phase 2	83.1^{bc}	84.3^{a}	84.3^{a}	83.3^{b}	82.1^{c}	0.34	<0.001
ATTD of GE, %							
Phase 1	85.5	85.6	85.4	85.2	85.1	0.41	0.155
Phase 2	83.5^{bc}	84.7^{a}	85.0^{a}	83.7^{b}	82.6^{c}	0.34	<0.001
ATTD of CP, %							
Phase 1	81.7	81.3	81.7	80.9	80.1	0.69	0.636
Phase 2	83.7^{bc}	84.5^{ab}	85.3^{a}	82.5^{cd}	81.3^{d}	0.55	<0.001
DE, MJ/kg, DM							
Phase 1	16.15	16.15	16.28	16.11	16.19	0.079	0.412
Phase 2	15.65^{c}	15.86^{b}	16.11^{a}	15.86^{b}	15.73^{bc}	0.063	<0.001
NE[2], MJ/kg, DM							
Phase 1	10.92	10.96	11.04	10.97	11.00	0.056	0.289
Phase 2	10.73^{d}	10.97^{ab}	11.04^{a}	10.90^{bc}	10.81^{cd}	0.045	<0.001

$^{a\text{ to }d}$Means within a row without a common superscript differ ($P < 0.05$).
[1]Least-squares means based on 13 pen observations per diet.
[2]Diet NE values calculated using Eq. (5) from Noblet et al. (1994).

Table 5. Average daily feed disappearance (ADFD), average daily weight gain (ADG), gain-to-feed (G:F), and final body weight (BW) of weaned pigs fed diets including five faba bean cultivars starting one-week post-weaning[1]

Variable	Snowbird	Snowdrop	Tabasco	Fabelle	Malik	SEM[3]	*P*-value
ADFD[2], g							
d 0–7	422	409	429	435	407	16.8	0.393
d 7–14	702	703	727	779	697	30.9	0.057
d 14–21	926	938	933	990	916	33.9	0.226
d 21–28	1254	1254	1251	1307	1182	40.3	0.058
d 0–28	826^{ab}	826^{ab}	835^{ab}	878^{a}	801^{b}	22.2	0.020
ADG[2], g							
d 0–7	362	350	370	377	336	20.9	0.328
d 7–14	533	527	538	584	526	31.9	0.351
d 14–21	630	652	663	681	623	27.6	0.218
d 21–28	823^{ab}	789^{ab}	781^{ab}	835^{a}	753^{b}	27.8	0.033
d 0–28	587^{ab}	579^{b}	588^{ab}	619^{a}	559^{b}	14.1	0.002
G:F[2], g:g							
d 0–7	0.849	0.851	0.866	0.864	0.822	0.035	0.723
d 7–14	0.763	0.748	0.738	0.749	0.756	0.027	0.911
d 14–21	0.678	0.697	0.712	0.687	0.677	0.022	0.484
d 21–28	0.661	0.632	0.623	0.639	0.640	0.021	0.458
d 0–28	0.706	0.704	0.705	0.704	0.697	0.008	0.817
Final BW, kg							
d 28	24.96^{ab}	24.77^{ab}	24.92^{ab}	25.60^{a}	24.01^{b}	0.48	0.038

$^{a\text{ to }c}$Means within a row without a common superscript differ ($P < 0.05$).
[1]Least-squares means based on 13 pen observations per diet.
[2]Week effect for ADFD, ADG, and G:F ($P < 0.05$).

nitrogen losses. Despite lower tannin content than Fabelle, Malik phase 2 diet had the lowest digestibility of dietary protein. On the other hand, digestibility of protein of phase 2 diets did not differ between Fabelle with the greatest tannin content and zero-tannin Snowbird, indicating that tannin level in color-flowered faba bean did not affect protein digestibility

Table 6. Feces consistency scores[1] from pigs fed five faba beans cultivar diets[2]

Period[3]	Snowbird	Snowdrop	Tabasco	Fabelle	Malik	SEM	*P*-value
d 0–7	3.91	3.97	3.88	3.92	3.88	0.103	0.908
d 7–14	3.86	3.85	3.88	3.91	3.78	0.103	0.778
d 14–21	3.39	3.43	3.42	3.38	3.45	0.103	0.956
d 21–28	3.12	3.16	3.12	3.16	3.12	0.103	0.989
d 0–28	3.57	3.60	3.57	3.59	3.56	0.052	0.912

[1]Score 1 = hard, dry, and pellet-like; 2 = firm but not hard, segmented appearance; 3 = log-like, moist surface; 4 = moist/soggy, distinct log shape; 5 = moist, distinct shape, present in piles rather than logs; 6 = has texture, but not defined shape; 7 = watery, no texture, flat, occurs as puddles; 8 = liquid, with a slight brown or yellow tinge.
[2]Least-squares means based on 13 pen observations per diet.
[3]Week effect ($P < 0.05$).

greatly. Previously, a diet containing up to 3.3% of condensed tannins in faba bean hulls reduced apparent total tract digestibility of protein and amino acids (Jansman et al., 1993). In another study (Myrie et al., 2008), 1.5% condensed tannins in diets fed to weaned pigs did not reduce nitrogen retention despite reduced apparent ileal digestibility of threonine. The greatest fiber content in Malik phase 2 diet and total dietary fiber in Malik faba bean was likely associated with increased dietary fermentable fiber thereby reducing protein digestibility. Fermentation of resistant starch and fiber in the hindgut may shift nitrogen excretion from urine to feces (Younes et al., 1995) thereby reducing the digestibility of dietary protein and energy (Bach Knudsen et al., 1993). Lower digestibility of protein in phase 1 than phase 2 could be due to less developed proteolytic capacity of the digestive tract in pigs soon after weaning (Randy et al., 1982).

Growth Performance

One concern with tannin content in color-flowered faba bean cultivars is that voluntary feed intake might be reduced due to bitter or astringent taste that affects palatability (Jansman, 1993). In the present study, however, feed disappearance was greatest for pigs fed Fabelle diets despite its greater tannin content than Malik or zero-tannin faba bean cultivars. Similarly, the lowest feed disappearance for pigs fed the Malik diet in phase 2 was not likely due to tannin content. In addition, because diets were balanced to equal net energy value, greater feed disappearance of diets containing Fabelle to compensate for its low energy value was not likely the reason. Nonetheless, low dietary tannin content increased feed intake and thereby increased performance in monogastric animals (Huang et al., 2018). Given the astringent nature of tannins thereby reducing palatability, increased feed disappearance associated with low concentration of dietary tannins is not clear. Furthermore, pigs are more resistant to toxic effects of dietary tannins than chickens (Hassan et al., 2020). This ability to resist toxic effects of dietary tannins is likely due to parotid gland hypertrophy and salivary secretion of proline-rich proteins that bind and neutralize tannins (Cappai et al., 2010). Lowest feed disappearance for the Malik phase 2 diet might be explained by its greater fiber content. High dietary fermentable fiber and resistant starch can depress voluntary feed intake in pigs by stimulating satiety due to increased gastric retention time (Kyriazakis and Emmans, 1995). Between color-flowered cultivars, feed disappearance was greater for Fabelle (low vicine and covicine) than the Malik (high vicine and covicine) diet. Effects of vicine and covicine on feed intake of pigs are not clearly understood but might be linked to oxidative stress caused by divicine in red blood cells (Jollow and McMillan, 2001).

Tannins can reduce nitrogen retention due to increased endogenous losses (Mansoori and Acamovic, 2007) that would reduce whole-body protein retention thereby lowering weight gain. In the present study, pigs fed Fabelle diets that contained the most tannins had the greatest weight gain, indicating that tannin content did not affect weight gain. Instead, the greatest weight gain observed for Fabelle diets could be attributed to sustained greater feed disappearance (Zijlstra et al., 2009) despite lower nutrient digestibility than Snowbird, Snowdrop, and Tabasco diets. Furthermore, beneficial effects of tannins inhibiting pathogenic bacteria in weaned pigs might be associated with greater growth performance in pigs fed the Fabelle diet (Hassan et al., 2020). Lowest pig weight gain for Malik could be attributed to both low energy and protein digestibility and feed disappearance. Digestibility of essential amino acid, particularly lysine might be a concern for growth performance. However, we formulated diets to be equal in digestible amino acid content; thus, variations in feed disappearance and growth performance due to varying dietary amino acid content did not likely happen (Schiavon et al., 2018).

In conclusion, the level of condensed tannins in color-flowered faba bean cultivars fed in the present study did not prominently affect diet nutrient and energy digestibility nor growth performance. Pigs fed Fabelle had greater feed disappearance and weight gain than those fed Malik likely associated with its lowest vicine and covicine. Therefore, between mid-tannin cultivars, Fabelle should be prioritized to be grown to feed to pigs. Furthermore, vicine and covicine, and not tannin content should be of greater consideration in prioritizing modern faba bean cultivars to grow to feed to pigs. Across cultivars, variations in dietary fiber and starch content among faba bean cultivars contributed to differences in dry matter and energy digestibility and growth performance of pigs. Inclusion of up to 30% of either white- or color-flowered faba bean in nutritionally balanced weaned pig diets may reduce dry matter and energy digestibility but it is unlikely to affect overall growth performance and feces consistency.

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Conflict of interest statement

None declared.

LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. In: Lewis, A. J., and L. L. Southern, editors. *Swine nutrition*. Boca Raton, FL: CRC Press; p. 903–916.

American Society of Agricultural and Biological Engineers. 2008. *Methods of determining and expressing fineness of feed materials by sieving*. MI: Publ. S319.4 Am Soc Agric Biol Eng. St. Joseph.

AOAC. 2006. *Official methods of analysis of AOAC International*. 18th ed. Arlington, VA: Association of Official Analytical Chemists.

Arese, P., V. Gallo, A. Pantaleo, and F. Turrini. 2012. Life and death of Glucose-6-Phosphate Dehydrogenase (G6PD) deficient erythrocytes – role of redox stress and band 3 modifications. *Transfus. Med. Hemother*. 39:328–334. doi:10.1159/000343123.

Bach Knudsen, K. E., B. B. Jensen, and I. Hansen. 1993. Digestion of polysaccharides and other major components in the small and large intestine of pigs fed on diets consisting of oat fractions rich in β-D-glucan. *Br. J. Nutr*. 70:537–556. doi:10.1079/BJN19930147.

Bello-Pérez, L. A., J. J. Islas-Hernández, J. R. Rendón-Villalobos, E. Agama-Acevedo, L. Morales-Franco, and J. Tovar. 2007. *In vitro* starch digestibility of fresh and sun-dried faba beans (*Vicia faba* L.). *J. Sci. Food Agric*. 87:1517–1522. doi:10.1002/jsfa.2876.

Beltranena, E., S. Hooda, and R. T. Zijlstra. 2009. Zero-tannin faba bean as a replacement for soybean meal in diets for starter pigs. *Can. J. Anim. Sci*. 89:489–492. doi:10.4141/CJAS09034.

Björnsdotter, E., M. Nadzieja, W. Chang, L. Escobar-Herrera, D. Mancinotti, D. Angra, X. Xia, R. Tacke, H. Khazaei, C. Crocoll, A. Vandenberg, W. Link, F. L. Stoddard, D.M. O'Sullivan, J. Stougaard, A. H. Schulman, S. U. Andersen, and F. Geu-Flores. 2021. VC1 catalyses a key step in the biosynthesis of vicine in faba bean. *Nat. Plants*. 7:923–931. doi: 10.1038/s41477-021-00950-w

Bond, D. A. 1976. In vitro digestibility of the testa in tannin-free field bean (*Vicia faba* L.). *J. Agric. Sci*. 86:561–566. doi:10.1017/S0021859600061104.

Butler, L. G., D. J. Riedl, D. G. Lebryk, and H. J. Blytt. 1984. Interaction of proteins with sorghum tannins: mechanism, specificity and significance. *J. Am. Oil Chem. Soc*. 61:916–920. doi:10.1007/BF02542166.

Cabrera, A., and A. Martin. 1989. Genetics of tannin content and its relationship with flower and testa colors in *Vicia faba*. *J. Agric. Sci*. 113:93–98. doi:10.1017/S0021859600084665.

Canadian Council on Animal Care in Science (CCAC). 2009. *The care and use of farm animals in research, teaching and testing*. Ottawa, ON, Canada: Canadian Council on Animal Care in Science.

Cappai, M. G., P. Wolf, V. Große Liesner, A. Kastner, G. Nieddu, W. Pinna, and J. Kamphues. 2010. Effect of whole acorns (*Quercus pubescens*) shred based diet on parotid gland in growing pigs in relation to tannins. *Livest. Sci*. 134:183–186. doi:10.1016/j.livsci.2010.06.136.

Cerning, J., A. Saposnik, and A. Guilbot. 1975. Carbohydrate composition of horse beans (*Vicia faba*) of different origins. *Cereal Chem*. 52:125–137.

Chevion, M., T. Navok, G. Glaser, and J. Mager. 1982. The chemistry of favism-inducing compounds. The properties of isouramil and divicine and their reaction with glutathione. *Eur. J. Biochem*. 127:405–409. doi:10.1111/j.1432-1033.1982.tb06886.x.

Cho, M., M. N. Smit, L. He, F. C. Kopmels, and E. Beltranena. 2019. Effect of feeding zero- or high-tannin faba bean cultivars and dehulling on growth performance, carcass traits and yield of saleable cuts of broiler chickens. *J. Appl. Poult. Res*. 28:1305–1323. doi:10.3382/japr/pfz099.

Duc, G., P. Marget, R. Esnault, J. Le Guen, and D. Bastianelli. 1999. Genetic variability for feeding value of faba bean seeds (*Vicia faba*): comparative chemical composition of isogenics involving zero-tannin and zero-vicine genes. *J. Agric. Sci* 133:185–196. doi:10.1017/S0021859699006905.

Fleming, S. E., M. D. Fitch, and D. W. Stanley. 1988. Influence of processing on physical form of beans and on intestinal fermentation. *J. Food Sci*. 53:777–782. doi:10.1111/j.1365-2621.1988.tb08954.x.

Griffiths, D. W. 1979. The inhibition of digestive enzymes by extracts of field bean (*Vicia faba*). *J. Sci. Food Agric*. 30:458–462. doi:10.1002/jsfa.2740300503.

Hagerman, A. E., and L. G. Butler. 1980. Condensed tannin purification and characterization of tannin-associated proteins. *J. Agric. Food Chem*. 28:947–952. doi:10.1021/jf60231a011.

Hassan, Z. M., T. G. Manyelo, L. Selaledi, and M. Mabelebele. 2020. The effects of tannins in monogastric animals with special reference to alternative feed ingredients. *Molecules* 25:4680. doi:10.3390/molecules25204680.

Hegazy, M. I., and R. R. Marquardt. 1984. Metabolism of vicine and convicine in rat tissues: absorption and excretion patterns and sites of hydrolysis. *J. Sci. Food Agric*. 35:139–146. doi:10.1002/jsfa.2740350204.

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. *J. Assoc. Off. Anal. Chem*. 56:1352–1356.

Hoover, R., and Y. Zhou. 2003. In vitro and in vivo hydrolysis of legume starches by α-amylase and resistant starch formation in legumes—a review. *Carbohydr. Polym*. 54:401–417. doi:10.1016/S0144-8617(03)00180-2.

Huang, Q., X. Liu, G. Zhao, T. Hu, and Y. Wang. 2018. Potential and challenges of tannins as an alternative to in-feed antibiotics for farm animal production. *Anim. Nutr*. 4:137–150. doi:10.1016/j.aninu.2017.09.004.

Ivarsson, E., and M. Neil. 2018. Variations in nutritional and antinutritional contents among faba bean cultivars and effects on growth performance of weaner pigs. *Livest. Sci*. 212:14–21. doi:10.1016/j.livsci.2018.03.017.

Jansman, A. J. M. 1993. *Tannins in faba beans (Vicia faba L.) -antinutritional properties in monogastric animals* [*Ph.D. thesis*]. Wageningen, The Netherlands: Wageningen Univ. https://edepot.wur.nl/200980.

Jansman, A. J. M., M. W. A. Verstegen, and J. Huisman. 1993. Effects of dietary inclusion of hulls of faba beans (*Vicia faba* L.) with a low and high content of condensed tannins on digestion and some physiological parameters in piglets. *Anim. Feed Sci. Tech*. 43:239–257. doi: 10.1016/0377-8401(93)90080-4

Jezierny, D. 2009. *In vivo and in vitro studies with growing pigs on standardised ileal amino acid digestibilities in grain legumes* [*Ph.D. thesis*]. Stuttgart, Cuvillier Verlag Göttingen, Germany: University of Hohenheim.

Jezierny, D., R. Mosenthin, and E. Bauer. 2010. The use of grain legumes as a protein source in pig nutrition: a review. *Anim. Feed Sci. Tech*. 157:111–128. doi: 10.1016/j.anifeedsci.2010.03.001

Jollow, D. J., and D. C. McMillan. 2001. Oxidative stress, glucose-6-phosphate dehydrogenase and the red cell. In: Dansette, P. M., *et al*., (eds) Biological Reactive Intermediates VI. *Adv. Exp. Med. Biol*. 500:595–605. doi: 10.1007/978-1-4615-0667-6_88

Kyriazakis, I., and G. C. Emmans. 1995. The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. *Br. J. Nutr*. 73:191–207. doi:10.1079/BJN19950023.

López-Bellido, L., R. J. López-Bellido, R. Redondo, and J. Benítez. 2006. Faba bean nitrogen fixation in a wheat-based rotation under rainfed Mediterranean conditions: effect of tillage system. *Field Crops Res*. 98:253–260. doi:10.1016/j.fcr.2006.03.001.

Losowsky, M. S., and B. E. Walker. 1969. Liver disease and malabsorption. *Gastroenterology* 56:589–600. doi:10.1016/S0016-5085(69)80169-1.

Mansoori, B., and T. Acamovic. 2007. The effect of tannic acid on the excretion of endogenous methionine, histidine and lysine with broilers. *Anim. Feed Sci. Tech*. 134:198–210. doi: 10.1016/j.anifeedsci.2006.07.007

Myrie, B., R. F. Bertolo, W. C. Sauer, and R. O. Ball. 2008. Effect of common antinutritive factors and fibrous feedstuffs in pig diets on amino acid digestibilities with special emphasis on threonine. *J. Anim. Sci*. 86:609–619. doi:10.2527/jas.2006-793.

Newkirk, R. W., H. L. Classen, T. A. Scott, and M. J. Edney. 2003. The digestibility and content of amino acids in toasted and non-toasted canola meals. *Can. J. Anim. Sci*. 83:131–139. doi:10.4141/A02-028.

Noblet, J., H. Fortune, X. S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. *J. Anim. Sci*. 72:344–354. doi:10.2527/1994.722344x.

Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. *J. Anim. Sci*. 71:3389–3398. doi:10.2527/1993.71123389x.

NRC. 2012. *Nutrient requirements of swine*. 11th ed. Washington, DC: Natl. Acad. Press.

Purves, R. W., H. Khazaei, and A. Vandenberg. 2018. Quantification of vicine and convicine in faba bean seeds using hydrophilic interaction liquid chromatography. *Food Chem*. 240:1137–1145. doi:10.1016/j.foodchem.2017.08.040.

Randy, C. E., W. D. Armstrong, and D. L. Herman. 1982. The development of digestive capacity in young pigs: effects of age and weaning system. *J. Anim. Sci*. 55:1380–1387. doi:10.2527/jas1982.5561380x.

Sauvant, D., J. Perez, and G. Tran. 2004. *Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish*. Wageningen, The Netherlands: Wageningen Academic Publishers. doi: 10.3920/978-90-8686-668-7

Schiavon, S., M. Dalla Bona, G. Carcò, L. Carraro, L. Bunger, and L. Gallo. 2018. Effects of feed allowance and indispensable amino acid reduction on feed intake, growth performance and carcass characteristics of growing pigs. *PLoS One*. 13:e0195645. doi:10.1371/journal.pone.0195645.

Tan, C. Q., H. Q. Sun, H. K. Wei, J. J. Tan, G. Long, S. W. Jiang, and J. Peng. 2018. Effects of soluble fiber inclusion in gestation diets with varying fermentation characteristics on lactational feed intake of sows over two successive parities. *Animal*. 12:1388–1395. doi:10.1017/S1751731117003019.

Vogtmann, H., H. P. Pfirter, and A. L. Prabucki. 1975. A new method of determining metabolisability of energy and digestibility of fatty acids in broiler diets. *Br. Poult. Sci*. 16:531–534. doi:10.1080/00071667508416222.

Woyengo, T. A., E. Beltranena, and R. T. Zijlstra. 2014. Nonruminant nutrition symposium: controlling feed cost by including alternative ingredients into pig diets: a review. *J. Anim. Sci*. 92:1293–1305. doi:10.2527/jas.2013–7169.

Younes, H., K. Garleb, S. Behr, C. Rémésy, and C. Demigné. 1995. Fermentable fibers or oligosaccharides reduce urinary nitrogen-excretion by increasing urea disposal in the rat cecum. *J. Nutr*. 125:1010–1016. doi:10.1093/jn/125.4.1010.

Zijlstra, R. T., S. Tibble, and T. A. T. G. van Kempen. 2009. Feed manufacturing technology and feed intake in young pigs. In: Torrallardona, D., and E. Roura, editors. *Voluntary feed intake in pigs*. Wageningen, The Netherlands: Wageningen Academic Publishers; p. 277–291.