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

M. Cho,* M. N. Smit,† L. He,* F. C. Kopmels,‡ and E. Beltranena†,[1]

**Department of Agricultural, Food & Nutritional Science, University of Alberta, Edmonton, AB T6G 2P5, Canada; †Alberta Agriculture and Forestry, Edmonton, AB T6H 5T6, Canada; and ‡Department of Animal Sciences, Wageningen University, 6708 WD Wageningen, Netherlands*

Primary Audience: Animal Nutritionists, Feed Manufacturers, Broiler Producers

SUMMARY

Color-flowered, high-tannin faba bean (**FB**; *Vicia faba*) cultivars are more tolerant to frost around harvest time than white-flowered, zero-tannin cultivars. Tannins concentrated on the seed hull reduce both starch and protein digestibility. We therefore evaluated feeding 2 zero-tannin (Snowbird, Snowdrop) or 2 high-tannin (Fabelle, Malik) FB cultivars and the effect of dehulling to reduce tannin content on broiler growth performance, carcass traits, and yield of saleable cuts. Male Ross 708 chicks (n = 585) were fed 1 of 4 FB cultivars either non-dehulled or dehulled in starter (12%, 0–12 d), grower (24%, 13–25 d), and finisher (36%, 26–41 d) mash diets replacing soybean meal (SBM) and wheat grain (control diet). Overall, daily feed intake was greatest for Snowbird and Fabelle, and lowest for Malik; Snowdrop was intermediate. Daily weight gain was greater for Fabelle than other cultivars, and greater for control than FB cultivars. Gain-to-feed ratio (**G:F**) was greatest for Fabelle but lowest for Snowbird; Snowdrop was not different from Fabelle or Malik, and Malik was not different from Snowbird. Broiler G:F and chilled carcass weight were greater for controls than FB cultivars. Breast meat yield (BMY) was greater for Snowbird, and lower for Fabelle; Malik was not different from Snowbird or Snowdrop; Snowdrop was not different from Fabelle. Dehulling FB lowered BMY. Feeding broilers low-vicine/convicine high-tannin Fabelle resulted in slightly better growth performance but lower BMY than feeding zero-tannin cultivars or high-tannin Malik. Dehulling FB did not improve broiler growth performance or carcass dressing to the level of controls fed SBM-wheat only.

Key words: broiler chicken, carcass trait, convicine, dehulling, faba bean cultivars, growth performance, vicine

2019 J. Appl. Poult. Res. 28:1305–1323
http://dx.doi.org/10.3382/japr/pfz099

[1]Corresponding author: eduardo.beltranena@gov.ab.ca

DESCRIPTION OF THE PROBLEM

Soybean meal (**SBM**) is the most commonly fed protein ingredient in poultry diets worldwide, but relative high cost and long distance transportation to temperate latitudes (north of 50° parallel) where soybean cultivation is not optimal imply consideration of local alternative protein sources. Faba bean (**FB**; *Vicia faba*) is relatively high in both starch (39.7–43.8%; [1]) and protein (24.7–37.2%; [2, 3]) and is locally grown in Canada. Planting pulses is necessary to establish a crop rotation that prevents soil nutrient depletion [4], improves soil health by increasing microbial activity, and reduces the lingering of crop specific diseases and pests [5]. Field pea has been the predominant pulse crop with canola and cereals in crop rotation in Western Canada. Faba bean is gaining popularity not only as the easiest crop to harvest, but also because of its greater yield compared with field pea (approximately 1 tonne more per hectare [6]). Faba bean fixes the most atmospheric nitrogen compared with all annual grain legume crops [7]. Part of this nitrogen remains in soils increasing the yield of subsequent cereal and oilseed crops [8]. However, the presence of anti-nutritional factors such as vicine (6.0 g/kg), convicine (1.6 g/kg), and tannins (6.6 g/kg condensed tannins) limits FB inclusion in poultry diets [2, 3]. Vicine and convicine mostly located in seed cotyledons decrease the apparent metabolizable energy corrected for nitrogen (**AMEn**) value of FB for broiler chickens [3]. Condensed tannins mostly located in seed hull [9] reduce FB protein and amino acid digestibility in broiler chickens by forming tannin–protein complexes [3, 10]. Condensed tannins also reduce starch digestibility resulting in reduced true metabolizable energy corrected for nitrogen value of FB for chicks and cockerels [11]. Broilers fed 30% FB had reduced BW gain possibly because of high levels of condensed tannin [12]. Therefore, FB cultivars that have minimal tannin content (0.1 g/kg; [2]), known as zero-tannin FB, have been developed and could be used for animal feeding [13]. Although white-flowered, zero-tannin FB cultivars have low tannin content, color-flowered high-tannin FB cultivars are more tolerant to frost and therefore have greater yield than zero-tannin FB cultivars [14]. Simple processing (dehulling) of FB could reduce tannin content, and dehulled high-tannin FB cultivars could then be fed to animals.

In our previous experiment, broilers fed 5 to 40% hulled, zero-tannin FB cultivars showed only slightly reduced broiler growth performance and meat yield compared with feeding a SBM-wheat diet [15]. Although feeding dehulled-micronized FB did not have negative effects on lay performance and egg quality in young hens [16], the effects of feeding dehulled FB to broiler chickens on growth performance, carcass traits, and yield of saleable cuts have not been studied.

Our hypothesis was that feeding increasing dietary inclusions by growth phase of zero-tannin vs. high-tannin FB cultivars and dehulling would result in broiler grower performance, carcass traits, and yield of saleable cuts not different from feeding SBM-wheat based diets. We expected that high-tannin FB diets would result in decreased growth performance, reduced carcass weight, and dressing percentage because of reduced starch and protein digestibility. Hence, the objective of this experiment was to investigate the effects of feeding zero-tannin or high-tannin FB cultivars and dehulling on broiler growth performance, carcass traits, and yield of saleable cuts. This experiment directly addresses the lack of information feeding FB to broiler chickens that affects the global feed competitiveness of the Canadian poultry industry and European efforts to enhance the range of protein crops, mainly legumes, to improve the sustainability of European agricultural systems and reduce importation of SBM [17].

MATERIALS AND METHODS

The University of Alberta Animal Care and Use Committee for Livestock approved the animal use and reviewed study procedures. Broilers were reared and cared for following principles established by the Canadian Council of Animal Care [18].

Snowbird and Snowdrop, the zero-tannin FB cultivars, were sourced from Galloway Seeds [19] and Shewchuk Seeds [20], respectively. Fabelle and FB9–4 (hereafter called Malik), the high-tannin FB cultivars, were sourced from

Stamp Seeds [21]. Grain ingredients (wheat, canola seed, and FB) were rolled separately through a tandem twin roller mill [22]. For half of each FB cultivar, hulls were then removed using a combination of blowing air and mesh sieving in a custom-made, pilot-scale seed cleaner at the Environment and Metabolism Unit [23]. Table 1 reports the nutrient content of FB cultivars, SBM, wheat grain, and canola seed.

Animals, Experimental Design, and Diets

Male broiler chicks (Ross 708; n = 585) were sourced from a commercial hatchery [24] and transported to the Poultry Research and Technology Centre [25]. The chicks were individually weighed (42.0 ± 0.2 g) and randomly allocated to 63 cages [26] in 2 batteries [27]. The 63 cages were divided into 7 area blocks based on location in the 2 batteries [28]. During the trial, feed in troughs was pushed down by hand 2 to 3 times per day as broilers aged and consumed more feed to ensure continuous access to feed. At 25 d of age, 1 or 2 broilers per cage with the lowest BW were removed to reduce stocking density to 8 broilers per cage [29] based on National Farm Animal Care Council [30] recommendations. Temperature, humidity, lighting program, and light intensity followed the Ross 708 management guide [31].

Broilers within area block were fed 1 of 9 regimens (Tables 2–4) for 7 replicate cages per treatment from 0 to 41 d of age. Each dietary treatment appeared once in each block for a randomized complete block design. The control regimen was a SBM-wheat grain-based diet, whereas the treatment regimens included 1 of 4 FB cultivars (Snowbird, Snowdrop, Fabelle, or Malik), either non-dehulled or dehulled replacing part of the SBM and wheat grain. In the starter (0–12 d), grower (13–25 d), and finisher phase (26–41 d), treatment diets included 12, 24, and 36% FB, respectively. Diets were formulated without antimicrobials or coccidiostats to provide 3.0, 3.1, and 3.2 Mcal AMEn per kg and 4.3, 3.7, and 3.2 g standardized ileal digestible (**SID**) lysine (**Lys**) per Mcal AMEn in the starter, grower, and finisher phases, respectively. Published AMEn and SID amino acids were used [32]. For FB, proximate and amino acid contents were based on lab results whereas SID amino acid coefficients were taken from AMINODat 5.0. The AMEn value of FB cultivars was assumed to be 2.4 Mcal AMEn/kg based on Sauvant et al. [33]. Other amino acids were formulated as ideal ratio to lysine and methionine or exceeded nutrient recommendations [34] except for isoleucine and arginine that were marginally short in FB diets. To estimate the carbon footprint of diets, carbon intensity values for each ingredient were obtained [35]. Starter diets were mixed in a 60-kg stainless steel horizontal paddle mixer [36], whereas grower and finisher diets were mixed in a 300-kg horizontal paddle mixer [37]. Diets were offered in mash form throughout the trial to represent how most local producers feed broilers.

Measurements and Chemical Analyses

Individual broiler BW, the amount of feed added to each cage feeder during each phase and orts remaining at the end were weighed on days 12, 25, and 41 to calculate average daily gain (**ADG**), average daily feed intake (**ADFI**), and feed efficiency (**G:F**; ADG/ADFI). On day 41 or 42 (late afternoon), broilers were crated and transported (500 m) to the site abattoir where they had no access to feed or water overnight. Broilers were slaughtered early the following morning and processed following commercial conditions (day 42 to 43 of age). Broilers were euthanized by electrically stunning, bled out, and were then scalded, defeathered, and eviscerated. Carcasses were blast-chilled to 4°C (measured in breast) and weighed to calculate dressing percentage. One-half of the carcasses (randomly selected from each cage) were then broken down into saleable cuts (pectoralis major, pectoralis minor, wings, thighs, drums, and trim) and weighed to calculate yield relative to chilled carcass weight.

Pooled feed ingredient and diet samples were subsequently ground through a 0.5 mm screen using a centrifugal mill [38] and were sent for laboratory analysis [39]. Diets and ingredients were analyzed following AOAC [40], American Oil Chemists' Society [41], or Ankom Technology [42] method unless stated otherwise [43]. Feed ingredient and diet particle size were determined using a mechanical sieve shaker [44] following the method of the American Society of Agricultural and Biological Engineers [45].

Table 1. Analyzed Nutrient Content of Soybean Meal (SBM), Faba Bean Cultivars, Canola Seed, and Wheat Grain (As-Is Basis).

		Snowbird[1]	Snowdrop[2]	Fabelle[3]	Malik[3]	Snowbird	Snowdrop	Fabelle	Malik	Canola seed		Wheat grain	
Analyzed nutrients,[4] %	SBM	Non-dehulled	Non-dehulled	Non-dehulled	Non-dehulled	Dehulled	Dehulled	Dehulled	Dehulled	Batch 1[5]	Batch 2[6]	Batch 1[5]	Batch 2[6]
Moisture	9.96	11.23	10.46	10.79	12.22	11.77	10.46	10.66	11.54	5.25	4.44	12.85	13.56
Starch	2.88	43.15	41.89	39.67	36.83	44.19	43.26	40.82	37.49	0.13	0.26	55.40	54.86
Crude protein	44.76	25.85	26.66	28.69	26.58	26.27	26.67	29.66	27.43	25.59	23.53	13.5	14.94
NDF[7]	8.15	5.74	6.72	7.80	8.42	5.06	5.88	5.09	7.97	23.20	24.11	9.56	8.27
ADF[8]	6.65	4.81	6.13	6.64	9.20	4.07	5.42	5.07	7.40	20.73	19.38	3.38	4.12
Crude fiber	3.78	2.85	3.48	3.84	5.52	2.64	3.90	3.12	4.44	17.13	18.81	2.67	1.58
Crude fat	4.00	1.32	1.26	1.08	1.19	1.43	1.20	1.12	1.27	39.33	43.00	2.05	1.59
Ash	5.74	2.94	2.79	2.86	3.46	2.91	2.82	2.84	3.47	4.26	3.55	2.02	1.57
Potassium	2.27	1.27	1.17	1.24	1.39	1.28	1.19	1.24	1.43	0.85	0.81	0.44	0.37
Phosphorous	0.73	0.44	0.45	0.46	0.64	0.44	0.45	0.46	0.64	0.77	0.66	0.39	0.35
Chloride	0.02	0.09	0.06	0.09	0.10	0.09	0.69	0.09	0.10	0.01	0.01	0.07	0.06
Calcium	0.31	0.09	0.09	0.09	0.10	0.09	0.08	0.08	0.09	0.54	0.42	0.21	0.06
Magnesium	0.28	0.12	0.11	0.13	0.14	0.11	0.11	0.13	0.14	0.32	0.30	0.14	0.13
Sodium	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.00
Indispensible amino acids													
Arginine	2.62	1.84	1.84	2.50	2.14	1.71	1.87	2.45	2.00	1.46	1.01	0.59	0.50
Histidine	1.06	0.69	0.58	0.71	0.73	0.61	0.65	0.81	0.64	0.72	0.65	0.39	0.31
Isoleucine	1.63	1.05	0.83	1.05	1.09	0.73	0.83	1.25	0.73	0.95	0.89	0.49	0.46
Leucine	3.03	1.75	1.60	2.00	1.76	1.59	1.61	2.21	1.61	1.74	1.56	0.89	0.86
Lysine	2.09	1.33	1.20	1.46	1.34	1.22	1.20	1.59	1.28	1.21	1.10	0.33	0.34
Methionine	0.58	0.16	0.23	0.21	0.19	0.22	0.21	0.20	0.20	0.52	0.43	0.20	0.23
Phenylalanine	2.14	1.09	0.98	1.21	1.09	0.98	1.00	1.38	0.99	1.07	1.00	0.66	0.59
Threonine	1.37	0.69	0.69	0.83	0.52	0.70	0.70	0.76	0.71	0.90	0.73	0.31	0.34
Tryptophan	0.64	0.31	0.27	0.33	0.28	0.26	0.29	0.27	0.44	0.28	0.27	0.15	0.20
Valine	1.73	1.17	0.94	1.21	1.24	0.82	0.95	1.40	0.85	1.22	1.14	0.60	0.58

Table 1. Continued

		Snowbird[1]	Snowdrop[2]	Fabelle[3]	Malik[3]	Snowbird	Snowdrop	Fabelle	Malik	Canola seed		Wheat grain	
Analyzed nutrients,[4] %	SBM	Non-dehulled	Non-dehulled	Non-dehulled	Non-dehulled	Dehulled	Dehulled	Dehulled	Dehulled	Batch 1[5]	Batch 2[6]	Batch 1[5]	Batch 2[6]
Dispensable amino acids													
Alanine	1.66	0.94	0.88	1.08	1.05	0.91	0.89	1.14	0.95	1.02	0.90	0.45	0.49
Aspartic acid	4.47	2.61	2.44	3.01	2.59	2.58	2.45	3.05	2.62	1.88	1.47	0.69	0.61
Cysteine	0.78	0.81	1.05	0.96	0.82	0.47	0.95	0.95	0.89	0.90	1.52	0.77	0.51
Glutamic acid	6.81	3.76	3.42	4.34	3.84	3.61	3.51	4.39	3.64	4.20	3.63	3.74	3.93
Glycine	1.81	1.06	1.01	1.20	1.11	1.02	1.02	1.30	1.04	1.26	1.22	0.55	0.56
Proline	2.31	1.10	1.04	1.29	1.12	1.08	1.07	1.38	1.09	1.61	1.57	1.46	1.63
Serine	1.92	0.90	1.02	1.21	0.54	1.13	1.03	1.04	1.13	0.97	0.75	0.47	0.83
Tyrosine	1.56	0.81	0.77	0.95	0.8	0.78	0.78	0.76	0.79	0.78	0.69	0.41	0.44
Particle size,[9] μm	686	943	1,346	1,213	1,178	1,453	1,542	1,564	780	577	570	845	1,169
Standard deviation, μm	1.81	2.10	1.66	1.98	1.99	1.82	1.68	1.55	1.99	1.98	1.77	1.83	2.04
Gross energy,[9] kcal/kg	4,332	3,966	3,999	4,026	3,985	3,939	4,027	4,074	4,010	6,479	6,652	3,905	3,918
Proanthocyanidins,[10] g/kg		ND[11]	ND	6.31	5.20	ND	ND	4.97	5.15				
Degree of polymerization				2.71	2.44			2.33	2.35				
Vicine,[12] g/kg		8.30	7.13	0.58	7.33	8.40	7.73	0.61	6.43				
Standard deviation, g/kg		0.17	0.32	0.03	1.07	0.36	0.21	0.03	0.50				
Convicine,[12] g/kg		4.13	6.07	0.16	5.53	6.10	5.83	0.17	5.10				
Standard deviation, g/kg		0.15	0.50	0.01	0.85	0.26	0.50	0.01	0.46				

[1]Galloway Seeds (Fort Saskatchewan, Alberta, Canada).
[2]Shewchuk Seeds (Blaine Lake, Saskatchewan, Canada).
[3]Stamp Seeds (Enchant, Alberta, Canada).
[4]Central Testing Laboratory Ltd. (Winnipeg, Manitoba, Canada).
[5]Starter (0–12 d) and grower phase (13–25 d).
[6]Finisher phase (26–41 d).
[7]Neutral detergent fiber.
[8]Acid detergent fiber.
[9]Alberta Agriculture and Forestry (Edmonton, Alberta, Canada).
[10]Condensed tannin plus monomeric flavan-3-ols (Luke; Jokioinen, Finland).
[11]Not detected ($\leq$0.05 g/kg).
[12]Organic Residue Laboratory, Alberta Agriculture and Forestry (Edmonton, Alberta, Canada).

Table 2. Ingredient Composition and Analyzed Nutrient Content of Starter Diets Fed to Broiler Chickens From 0 to12 d of Age.

Ingredient, % as fed	Control	Snowbird Non-dehulled	Snowdrop Non-dehulled	Fabelle Non-dehulled	Malik Non-dehulled	Snowbird Dehulled	Snowdrop Dehulled	Fabelle Dehulled	Malik Dehulled
Wheat	57.05	49.21	49.18	49.25	49.23	49.24	49.25	49.24	49.25
Soybean meal	20.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Snowbird non-hulled[1]		12.00							
Snowdrop non-hulled[2]			12.00						
Fabelle non-hulled[3]				12.00					
Malik non-hulled[3]					12.00				
Snowbird dehulled						12.00			
Snowdrop dehulled							12.00		
Fabelle dehulled								12.00	
Malik dehulled									12.00
Canola seed	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Fish meal	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Canola oil	0.00	0.71	0.74	0.72	0.72	0.72	0.72	0.72	0.72
Limestone	0.59	0.60	0.60	0.60	0.60	0.61	0.60	0.61	0.61
Broiler premix[4]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium bicarbonate	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Mono/dicalcium phosphate	0.35	0.30	0.35	0.31	0.32	0.30	0.32	0.32	0.31
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-Lysine HCl	0.26	0.27	0.23	0.22	0.24	0.23	0.22	0.22	0.22
DL-Methionine	0.26	0.31	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-Threonine	0.17	0.20	0.20	0.20	0.20	0.20	0.20	0.19	0.20
Choline chloride 60%	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Superzyme Plus[5]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
L-Valine	0.02	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Analyzed nutrient contents,[6] %									
Crude protein	28.44	27.80	26.58	27.12	26.26	27.22	26.88	28.02	26.65
NDF[7]	9.53	9.14	9.10	8.52	9.05	8.45	9.10	8.13	8.81
ADF[8]	3.70	4.16	4.43	4.01	4.36	4.24	4.76	4.11	4.92
Crude fiber	2.82	2.77	2.81	2.79	3.05	2.84	2.78	2.35	2.63
Crude fat	7.01	7.80	7.75	7.43	7.36	7.63	7.45	7.70	7.53
Ash	6.50	6.21	6.07	6.06	5.97	6.19	6.07	6.02	6.27
Calcium	1.18	1.17	1.18	1.11	1.08	1.18	1.16	1.17	1.16
Potassium	0.87	0.86	0.87	0.87	0.88	0.88	0.88	0.87	0.89
Phosphorous	0.82	0.82	0.84	0.80	0.82	0.84	0.85	0.83	0.85
Chloride	0.37	0.36	0.35	0.34	0.34	0.36	0.35	0.36	0.37
Sodium	0.27	0.25	0.25	0.23	0.22	0.26	0.24	0.24	0.26
Magnesium	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17

Table 2. Continued

Ingredient, % as fed	Control	Snowbird Non-dehulled	Snowdrop Non-dehulled	Fabelle Non-dehulled	Malik Non-dehulled	Snowbird Dehulled	Snowdrop Dehulled	Fabelle Dehulled	Malik Dehulled
Indispensable amino acids									
Arginine	1.56	1.55	1.55	1.50	1.50	1.50	1.58	1.54	1.52
Histidine	0.74	0.69	0.70	0.66	0.65	0.67	0.68	0.66	0.66
Isoleucine	1.14	1.01	1.12	0.94	1.07	1.07	1.15	1.07	1.12
Leucine	1.91	1.83	1.88	1.74	1.74	1.81	1.85	1.79	1.81
Lysine	1.45	1.52	1.59	1.36	1.42	1.42	1.53	1.42	1.50
Methionine	0.85	0.91	0.77	0.78	0.77	0.79	0.85	0.84	0.89
Phenylalanine	1.33	1.20	1.19	1.14	1.15	1.20	1.18	1.18	1.16
Threonine	0.93	0.97	1.03	0.92	0.77	0.89	0.73	0.91	0.70
Tryptophan	0.36	0.35	0.30	0.33	0.35	0.34	0.36	0.33	0.34
Valine	1.33	1.27	1.42	1.20	1.34	1.34	1.46	1.34	1.42
Average particle size,[9] μm	626	659	722	726	764	765	834	769	759
Standard deviation, μm	2.31	2.26	2.16	2.10	2.07	2.05	2.06	2.11	2.00
Gross energy,[9] kcal/kg	4,303	4,286	4,282	4,242	4,228	4,254	4,249	4,257	4,305
Carbon intensity,[10] kg CO_2-eq/kg feed	0.95	0.88	0.88	0.87	0.88	0.88	0.88	0.88	0.88

[1]Galloway Seeds (Fort Saskatchewan, Alberta, Canada).

[2]Shewchuk Seeds (Blaine Lake, Saskatchewan, Canada).

[3]Stamp Seeds (Enchant, Alberta, Canada).

[4]Trouw Nutrition (Ponoka, Alberta, Canada). Provided the following per kg of feed: vitamin D_3 (vitamin D_3 500), 4,000 IU; vitamin A (vitamin A 1000), 10,000 IU; vitamin E (vitamin E 500), 50 IU; thiamine (thiamine monohydrate 99%), 4 mg; riboflavin (riboflavin 80%), 10 mg; pantothenic acid (calcium pantothenate 98%), 15 mg; biotin (biotin 2% premix), 0.2 mg; folic acid (folic acid 98%), 2 mg; vitamin B12 (vitamin B12 0.1% premix), 0.02 mg; niacin (niacin 99%), 65 mg; vitamin K (vitamin K_3 [MNB] 43%), 4 mg; pyridoxine (pyridoxine 99%), 5 mg; manganese (manganous oxide 60%), 120 mg; iron (ferrous sulfate 30%), 80 mg; copper (copper sulfate 25%), 20 mg; zinc (zinc oxide 72%), 100 mg; selenium (Selplex 2000), 0.3 mg; iodine (EDDI), 1.65 mg.

[5]Canadian Bio-Systems Inc. (Calgary, Alberta, Canada). Provided the following enzyme activity per kg of feed: xylanase, 1,200 U; glucanase, 150 U; invertase, 700 U; protease, 1,200 U; cellulase, 500 U; amylase, 12,000 U; mannase, 60 U; phytase 1,000 U.

[6]Central Testing Laboratory Ltd. (Winnipeg, Manitoba, Canada). Standardized to 11% moisture.

[7]Neutral detergent fiber.

[8]Acid detergent fiber.

[9]Alberta Agriculture and Forestry (Edmonton, Alberta, Canada).

[10]ECO-ALIM feedstuff database (INRA, Paris, France).

Table 3. Ingredient Composition and Analyzed Nutrient Content of Grower Diets Fed to Broiler Chickens From 13 to 25 d of Age.

Ingredient, % as fed	Control	Snowbird Non-dehulled	Snowdrop Non-dehulled	Fabelle Non-dehulled	Malik Non-dehulled	Snowbird Dehulled	Snowdrop Dehulled	Fabelle Dehulled	Malik Dehulled
Wheat	56.81	41.16	41.14	41.22	41.19	41.21	41.17	41.19	41.23
Snowbird non-hulled[1]		24.00							
Snowdrop non-hulled[2]			24.00						
Fabelle non-hulled[3]				24.00					
Malik non-hulled[3]					24.00				
Snowbird dehulled						24.00			
Snowdrop dehulled							24.00		
Fabelle dehulled								24.00	
Malik dehulled									24.00
Soybean meal	20.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Canola seed	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Fish meal	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Canola oil	0.00	1.44	1.49	1.47	1.47	1.46	1.49	1.49	1.48
Limestone	0.87	0.96	0.95	0.92	0.96	0.98	0.96	0.97	1.00
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mono/dicalcium phosphate	0.50	0.35	0.43	0.42	0.38	0.34	0.42	0.41	0.35
Broiler premix[4]	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
L-Lysine HCl	0.26	0.27	0.19	0.17	0.20	0.19	0.16	0.17	0.16
Sodium bicarbonate	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
DL-Methionine	0.18	0.28	0.26	0.26	0.26	0.27	0.26	0.26	0.25
L-Threonine	0.13	0.19	0.19	0.19	0.19	0.20	0.19	0.17	0.18
L-Valine	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Choline chloride 60%	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Superzyme Plus[5]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Analyzed nutrient contents,[6] %									
Crude protein	24.56	23.92	23.82	24.88	24.23	24.21	24.59	24.58	24.54
NDF[7]	9.64	9.94	9.77	9.86	10.59	9.67	10.01	10.20	11.20
ADF[8]	5.03	5.26	5.50	4.61	5.35	4.42	5.75	5.83	5.92
Crude fiber	3.22	4.55	4.01	3.65	4.28	3.03	3.75	3.66	3.61
Crude fat	8.75	9.87	9.71	9.93	10.27	10.04	10.11	9.98	10.15
Ash	5.73	5.53	5.68	5.54	5.84	5.71	5.84	5.70	6.17
Calcium	1.02	1.00	1.03	1.07	1.01	1.04	1.08	1.06	1.19
Potassium	0.89	0.87	0.87	0.86	0.91	0.86	0.87	0.89	0.93
Phosphorous	0.77	0.69	0.70	0.72	0.75	0.68	0.73	0.72	0.77
Chloride	0.45	0.43	0.43	0.48	0.46	0.46	0.47	0.43	0.45
Sodium	0.26	0.24	0.27	0.28	0.27	0.26	0.28	0.26	0.28
Magnesium	0.20	0.17	0.18	0.18	0.18	0.17	0.18	0.18	0.18

Table 3. Continued

Ingredient, % as fed	Control	Snowbird Non-dehulled	Snowdrop Non-dehulled	Fabelle Non-dehulled	Malik Non-dehulled	Snowbird Dehulled	Snowdrop Dehulled	Fabelle Dehulled	Malik Dehulled
Indispensable amino acid									
Arginine	1.36	1.40	1.40	1.50	1.35	1.30	1.61	1.38	1.40
Histidine	0.66	0.61	0.61	0.69	0.57	0.60	0.69	0.59	0.63
Isoleucine	1.01	0.93	0.92	1.03	0.93	0.94	1.06	0.91	0.94
Leucine	1.69	1.61	1.58	1.67	1.52	1.55	1.82	1.52	1.57
Lysine	1.31	1.29	1.25	1.22	1.16	1.17	1.28	1.07	1.17
Methionine	0.65	0.71	0.66	0.69	0.69	0.69	0.73	0.63	0.69
Phenylalanine	1.16	1.08	1.04	1.12	1.02	1.04	1.25	1.01	1.03
Threonine	0.78	0.85	0.78	0.58	0.69	0.67	0.90	0.71	0.77
Tryptophan	0.33	0.28	0.28	0.36	0.33	0.35	0.39	0.30	0.36
Valine	1.17	1.18	1.17	1.27	1.16	1.18	1.34	1.12	1.18
Average particle size,[9] μm	717	884	908	905	925	974	1058	1061	957
Standard deviation, μm	2.24	2.10	1.96	1.94	1.91	1.83	1.69	1.77	1.75
Gross energy,[9] kcal/kg	4,325	4,351	4,346	4,434	4,381	4,360	4,373	4,413	4,342
Carbon intensity,[10] kg CO_2-eq/kg feed	0.88	0.73	0.72	0.71	0.72	0.73	0.73	0.72	0.72

[1]Galloway Seeds (Fort Saskatchewan, Alberta, Canada).

[2]Shewchuk Seeds (Blaine Lake, Saskatchewan, Canada).

[3]Stamp Seeds (Enchant, Alberta, Canada).

[4]Trouw Nutrition (Ponoka, Alberta, Canada). Provided the following per kg of feed: vitamin D_3 (vitamin D_3 500), 3,200 IU; vitamin A (vitamin A 1,000), 8,000 IU; vitamin E (vitamin E 500), 40 IU; thiamine (thiamine monohydrate 99%), 3.2 mg; riboflavin (riboflavin 80%), 8 mg; pantothenic acid (calcium pantothenate 98%), 12 mg; biotin (biotin 2% premix), 0.16 mg; folic acid (folic acid 98%), 1.6 mg; vitamin B12 (vitamin B12 0.1% premix), 0.016 mg; niacin (niacin 99%), 52 mg; vitamin K (vitamin K_3 [MNB] 43%), 3.2 mg; pyridoxine (pyridoxine 99%), 4 mg; manganese (manganous oxide 60%), 96 mg; iron (ferrous sulfate 30%), 64 mg; copper (copper sulfate 25%), 16 mg; zinc (zinc oxide 72%), 80 mg; selenium (Selplex 2000), 0.24 mg; iodine (EDDI), 1.32 mg.

[5]Canadian Bio-Systems Inc. (Calgary, Alberta, Canada). Provided the following enzyme activity per kg of feed: xylanase, 720 U; glucanase, 90 U; invertase, 420 U; protease, 720 U; cellulase, 300 U; amylase, 7200 U; mannase, 36 U; phytase 600 U.

[6]Central Testing Laboratory Ltd. (Winnipeg, Manitoba, Canada). Standardized to 11% moisture.

[7]Neutral detergent fiber.

[8]Acid detergent fiber.

[9]Alberta Agriculture and Forestry (Edmonton, Alberta, Canada).

[10]ECO-ALIM feedstuff database (INRA, Paris, France).

Table 4. Ingredient Composition and Analyzed Nutrient Content of Finisher Diets Fed to Broiler Chickens from 26 to 41 d of Age.

Ingredient, % as fed	Control	Snowbird Non-dehulled	Snowdrop Non-dehulled	Fabelle Non-dehulled	Malik Non-dehulled	Snowbird Dehulled	Snowdrop Dehulled	Fabelle Dehulled	Malik Dehulled
Wheat	55.91	32.44	32.45	32.57	32.51	32.56	32.51	32.52	32.58
Snowbird non-hulled[1]		36.00							
Snowdrop non-hulled[2]			36.00						
Fabelle non-hulled[3]				36.00					
Malik non-hulled[3]					36.00				
Snowbird dehulled						36.00			
Snowdrop dehulled							36.00		
Fabelle dehulled								36.00	
Malik dehulled									36.00
Canola seed	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Soybean meal	20.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Canola oil	0.40	2.59	2.65	2.62	2.62	2.61	2.65	2.66	2.63
Limestone	1.16	1.24	1.25	1.20	1.27	1.30	1.27	1.28	1.33
Mono/dicalcium phosphate	0.97	0.80	0.87	0.87	0.80	0.75	0.85	0.85	0.75
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-Lysine HCl	0.27	0.29	0.17	0.14	0.18	0.16	0.13	0.13	0.12
Broiler premix[4]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Sodium bicarbonate	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
DL-Methionine	0.11	0.27	0.24	0.24	0.24	0.25	0.23	0.23	0.23
L-Threonine	0.11	0.20	0.20	0.19	0.20	0.20	0.19	0.16	0.18
L-Valine	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Choline chloride 60%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Superzyme Plus[5]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Analyzed nutrient content,[6] %									
Crude protein	22.66	21.31	21.84	22.61	22.53	22.24	21.97	22.67	22.30
NDF[7]	11.10	11.53	11.77	11.80	12.14	10.85	11.40	11.47	10.99
ADF[8]	5.03	8.32	6.15	6.11	6.74	5.74	6.42	5.99	6.11
Crude fiber	3.43	5.02	4.52	5.36	4.87	3.37	4.65	3.80	4.72
Crude fat	10.67	12.26	12.26	12.36	12.49	12.37	12.41	12.88	12.68
Ash	5.94	4.84	5.25	5.13	5.51	5.13	4.99	5.07	5.34
Calcium	1.09	0.96	0.97	0.93	1.01	0.93	0.93	0.90	1.00
Potassium	0.88	0.85	0.84	0.85	0.92	0.88	0.84	0.84	0.92
Phosphorous	0.75	0.64	0.68	0.68	0.74	0.63	0.63	0.62	0.70
Chloride	0.45	0.47	0.44	0.37	0.42	0.42	0.38	0.42	0.41
Sodium	0.23	0.23	0.24	0.21	0.22	0.21	0.22	0.22	0.23
Magnesium	0.20	0.18	0.18	0.19	0.19	0.17	0.17	0.17	0.18

Table 4. Continued

Ingredient, % as fed	Control	Snowbird Non-dehulled	Snowdrop Non-dehulled	Fabelle Non-dehulled	Malik Non-dehulled	Snowbird Dehulled	Snowdrop Dehulled	Fabelle Dehulled	Malik Dehulled
Indispensable amino acid									
Arginine	1.09	1.25	1.29	1.86	1.43	1.30	1.33	1.55	1.37
Histidine	0.54	0.55	0.54	0.66	0.58	0.57	0.59	0.59	0.60
Isoleucine	0.76	0.64	0.69	0.82	0.73	0.78	0.84	0.81	0.75
Leucine	1.38	1.37	1.33	1.73	1.44	1.42	1.41	1.52	1.41
Lysine	0.93	1.11	0.99	1.35	1.10	1.09	0.98	1.13	1.01
Methionine	0.50	0.54	0.48	0.51	0.50	0.54	0.50	0.48	0.42
Phenylalanine	0.98	0.91	0.85	1.07	0.94	0.93	0.93	0.98	0.93
Threonine	0.69	0.80	0.76	1.01	0.77	0.77	0.67	0.80	0.80
Tryptophan	0.29	0.25	0.26	0.28	0.26	0.26	0.28	0.31	0.25
Valine	0.89	0.85	0.91	1.11	0.98	1.02	1.07	1.07	0.97
Average particle size,[9] μm	881	1,068	1,114	1,121	1,106	1,234	1,286	1,274	1,133
Standard deviation, μm	2.05	1.96	1.69	1.71	1.75	1.73	1.68	1.70	1.70
Gross energy,[9] kcal/kg	4,345	4,547	4,538	4,539	4,454	4,492	4,582	4,537	4,515
Carbon intensity,[10] kg CO_2-eq/kg feed	0.82	0.59	0.57	0.56	0.57	0.59	0.58	0.58	0.58

[1]Galloway Seeds (Fort Saskatchewan, Alberta, Canada).
[2]Shewchuk Seeds (Blaine Lake, Saskatchewan, Canada).
[3]Stamp Seeds (Enchant, Alberta, Canada).
[4]Trouw Nutrition (Ponoka, Alberta, Canada). Provided per kg of feed: vitamin D_3 (vitamin D_3 500), 2,400 IU; vitamin A (vitamin A 1,000), 6,000 IU; vitamin E (vitamin E 500), 30 IU; thiamine (thiamine monohydrate 99%), 2.4 mg; riboflavin (riboflavin 80%), 6 mg; pantothenic acid (calcium pantothenate 98%), 9 mg; biotin (biotin 2% premix), 0.12 mg; folic acid (folic acid 98%), 1.2 mg; vitamin B12 (vitamin B12 0.1% premix), 0.012 mg; niacin (niacin 99%), 39 mg; vitamin K (vitamin K_3 [MNB] 43%), 2.4 mg; pyridoxine (pyridoxine 99%), 3 mg; manganese (manganous oxide 60%), 72 mg; iron (ferrous sulfate 30%), 48 mg; copper (copper sulfate 25%), 12 mg; zinc (zinc oxide 72%), 60 mg; selenium (Selplex 2000), 0.18 mg; iodine (EDDI), 0.99 mg.
[5]Canadian Bio-Systems Inc. (Calgary, Alberta, Canada). Provided the following enzyme activity per kg of feed: xylanase, 720 U; glucanase, 90 U; invertase, 420 U; protease, 720 U; cellulase, 300 U; amylase, 7,200 U; mannase, 36 U; phytase 600 U.
[6]Central Testing Laboratory Ltd. (Winnipeg, Manitoba, Canada). Standardized to 11% moisture.
[7]Neutral detergent fiber.
[8]Acid detergent fiber.
[9]Alberta Agriculture and Forestry (Edmonton, Alberta, Canada).
[10]ECO-ALIM feedstuff database (INRA, Paris, France).

The FB samples, both non-dehulled and dehulled, were analyzed for vicine and convicine contents using a slight modification of the extraction procedure described by Purves et al. [46] at our lab [47, 48].

The FB samples, both non-dehulled and dehulled, were also analyzed [49] for proanthocyanidins (CT; mostly condensed tannin plus some monomeric flavan-3-ols) using HPLC after thiolytic degradation, as described by Ivarsson and Neil [50].

Statistical Analyses

Data residuals were tested for normality using the univariate procedure of SAS version 9.4 [51]. Growth performance, carcass weight, and yield of saleable cuts data were analyzed with a generalized linear model (GLIMMIX procedure) using a normal distribution and the identity link function. Overall trial growth performance variables (ADFI, ADG, and G:F) were analyzed using closeout data. Pen was the experimental unit for all growth performance variables, and individual carcass was the sampling unit for carcass data. Data were analyzed as a 4 (Snowbird, Snowdrop, Fabelle, and Malik) × 2 (non-dehulled or dehulled) factorial and included a contrast statement comparing FB diets to control diet. Block was the random term in all models. For carcass yield, the beta distribution and log-link function were used because dressing was expressed as percentage. Mean separation was performed using least-square means, and treatment differences were considered significant if $P < 0.05$, and a trend if $P < 0.10$.

RESULTS AND DISCUSSION

Ingredients and Diets

The chemical composition of FB cultivars in our study was generally comparable to the literature [52–54] except for neutral detergent fiber (**NDF**), acid detergent fiber (**ADF**), and crude fiber (**CF**) content. On average, our 4 non-dehulled FB cultivars tested lower in NDF (7.2%; Table 1), ADF (6.7%), and CF (3.9%) compared with other studies (12.2–19.8% NDF; 9.6–10.2% ADF; 7.8–19.7% CF; [52–54]). The reason could be between-laboratory variability despite similar analytical methods. Lab results for NDF showed the greatest variation. Lower NDF and ADF content in non-dehulled FB compared with dehulled FB in some diets was unexpected. Therefore, NDF and ADF values reported in Table 1 should be interpreted with caution. Crude fiber results, which were more consistent, are discussed instead.

Increasing FB inclusion per growth phase in test diets resulted in a formulation challenge regarding valine, isoleucine, and arginine content. Digestible leucine to lysine ratio exceeded the 1.1:1 requirement [34] for all phase diets. Now commercially available L-valine was supplemented to meet the 0.76:1 digestible valine: lysine requirement. Analyzed total isoleucine (Tables 2 and 3 values) generally exceeded the requirement in starter (0.97%) and grower diets (0.89%), respectively, but was slightly deficient in some FB finisher diets (Table 4 values vs. 0.80% requirement). Total isoleucine to lysine ratio in finisher diets ranging from 0.58 to 0.73 in diets did not affect broiler growth performance and breast meat yield (**BMY**) from 28 to 42 d [55]. Our FB finisher diets in the current study averaged 0.63, so total isoleucine to lysine ratio did not likely affect broiler growth, carcass traits, and yield of saleable cuts. Formulated arginine content was below the requirement for all starter, grower, and finisher phase diets (1.07:1 digestible arginine: lysine ratio). However, analyzed total arginine generally met the requirement for the starter (Table 2 values vs. 1.52% requirement) and grower (Table 3 values vs. 1.37% requirement) phases, and exceeded it for the finisher phase (Table 4 values vs. 1.21% requirement). Therefore, either dietary arginine content or digestibility was underestimated in the amino acid matrix we used for FB cultivars in our study. Body weight gain and feed intake were not affected when broilers were fed dietary total arginine ranging from 1.0 to 1.6% from 21 to 35 d [56].

Particle size of starter, grower, and finisher diets ranged from 626 to 1,286 μm. Studies have shown that medium (600–1,000 μm) and coarse (over 1,000 μm) particle sizes in mash diets increased broiler growth performance compared with feeding fine particle size (<600 μm; [57–59]). Particle size in the range we observed for our study diets likely had no effect on broiler growth performance.

Growth Performance

For all growth performance variables analyzed, there was no cultivar × dehulling interaction. Consequently, the results of the main factors are presented separately (Table 5). For the overall trial and finisher phase, broilers fed Snowbird and Fabelle had the greatest ADFI and Malik the lowest; Snowdrop was intermediate ($P < 0.05$). Tannins in FB have a bitter taste that reduced feed intake in weaner pigs [50]. Fabelle (2.0 g/kg CT) and Malik (1.9 g/kg CT) diets had similar CT content. Yet broilers fed Fabelle had greater ADFI compared with broilers fed Malik. This finding indicates that reduced ADFI from broilers fed Malik was not likely because of tannin content. Malik diets instead had the greatest fiber content (3.9% CF on average for all Malik diets fed across phases) compared with other FB diets (3.2–3.8% CF on average across all phase diets). When broilers were fed diets containing 50% FB, there were no feed intake differences between high (5.8% CF) and low fiber diets (2.9% CF) from 22 to 42 d of age [60]. The CF content from our study diets was within the CF range reported by Diaz et al. [60]. We did not expect differences in feed intake among FB cultivars and reduced ADFI from broilers consuming Malik diets may not entirely relate to greater fiber content. Broilers fed dehulled FB had greater ADFI but lower G:F than those fed non-dehulled FB for the grower phase only ($P < 0.01$). Because of this dehulling effect limited to the grower phase only, reduced overall broiler ADFI was not likely due to hull tannin content.

For the overall trial, broilers fed Fabelle diets had greater ADG compared with broilers fed other FB cultivars ($P < 0.01$; Table 5). Overall G:F was greatest for Fabelle and lowest for broilers fed Snowbird ($P < 0.01$); Snowdrop was not different from Fabelle or Malik, and Malik was not different from Snowbird. Broilers fed Fabelle had greater antemortem BW ($P < 0.01$; Table 6) than those fed Snowbird and Malik; Snowdrop was intermediate. An important finding of our study was that feeding Fabelle, a high-tannin but low-vicine and convicine cultivar, resulted in the greatest ADG and G:F, even compared with zero-tannin cultivars (Snowbird, Snowdrop). Faba bean diets high in vicine and convicine content (4.7–5.4 g/kg) fed to broilers had decreased AMEn value compared with broilers fed FB diet low in vicine and convicine content (0.3–0.4 g/kg; [3]). Vicine and convicine are converted by an enzyme, beta-glycosidase, produced from anaerobic bacteria in the intestine and ceca to divicine and isouramil, respectively [61, 62]. Divicine and isouramil are absorbed into the blood stream and reactive oxygen species (**ROS**) form when reacting with blood oxygen [63]. Generation of ROS can result in increased lipid peroxidation and reduced glutathione concentration in chicken liver that can cause ROS-induced liver damage [64, 65]. Damaged liver may reduce its function and produce insufficient bile acid for lipid digestion and micelle formation [66] resulting in reduced dietary energy digestibility. Fabelle diets had the lowest vicine and convicine content (0.2 g/kg). Therefore, Fabelle likely had the greatest energy digestibility resulting in slightly increased ADG compared with broilers fed other FB cultivars. Growth performance differences between our study and those of Moschini et al. [67] and Diaz et al. [60] could be due to vicine and convicine content in diets. Vicine and convicine content was not reported by these researchers.

For the overall trial and finisher phase, broilers fed FB had lower ADG and G:F than controls ($P < 0.05$; Table 5). Broilers fed FB had also decreased carcass weight and dressing percentage compared with controls ($P < 0.05$; Table 6). A consistent finding in our trials feeding FB to broilers has been slightly reduced ADG and G:F compared with SBM [15]. We fed raw FB merely rolled to reduce particle size whereas SBM is a highly processed meal in comparison. Soybean seed goes through multiple processing steps to produce SBM encompassing flaking, dehulling, heating, pressing, hexane-washing, and desolventizing [68]. Heat treatment of soybean not only reduces trypsin inhibitor, but also increases amino acid digestibility [68, 69]. Broilers fed a SBM diet showed increased BW and reduced feed conversion ratio compared with broilers fed a diet that replaced SBM with 12% raw soybean [69]. Therefore, it was no surprise to us to observe somewhat reduced growth performance for

Table 5. Effect of Faba Bean Cultivar and Dehulling on Pen Average Body Weight (BW), Daily Feed Intake (ADFI), Daily Weight Gain (ADG), and Feed Efficiency (G:F) of Broiler Chickens.[1]

		Faba bean cultivar					Dehulling			*P* value		
	Control	Snowbird	Snowdrop	Fabelle	Malik	SEM[2]	Non-dehulled	Dehulled	SEM[2]	Cultivar[2]	Dehulling[2]	Faba bean vs. control[3]
BW, g/bird												
0 d	43.47	40.93	42.54	42.75	41.94	0.85	41.79	42.29	0.76	0.0816	0.3383	0.0790
12 d	352.55	333.65	340.68	351.53	337.50	11.57	341.50	340.18	10.80	0.1183	0.8028	0.1623
25 d	1301.16	1255.41	1265.37	1305.22	1234.66	25.94	1268.01	1262.32	20.87	0.0930	0.7733	0.1999
41 d	2851.17	2736.63	2825.99	2869.01	2722.92	63.38	2800.69	2776.59	54.19	0.0740	0.5906	0.3328
ADFI, g/bird												
0–12 d[4]	29.60	28.55	29.99	30.60	29.59	0.67	29.55	29.81	0.55	0.0627	0.6164	0.8924
13–25 d[5]	133.60	141.41	135.41	138.25	135.00	6.83	133.37	141.66	6.62	0.2148	0.0012	0.2753
26–41 d[6]	171.07	181.89^{a}	170.11^{b,c}	178.25^{a,b}	166.74^{c}	4.04	174.58	173.91	2.80	0.0354	0.8659	0.5694
Overall	112.28	118.40^{a}	112.29^{b,c}	116.50^{a,b}	111.04^{c}	3.94	113.36	115.75	3.70	0.0264	0.2077	0.3986
ADG, g/bird												
0–12 d	22.90	21.79	22.17	22.83	21.99	0.61	22.26	22.13	0.53	0.2419	0.7202	0.2302
13–25 d	72.82	70.17	71.19	72.88	68.97	1.53	71.03	70.57	1.14	0.2485	0.7427	0.2948
26–41 d	83.62	70.48	71.76	79.07	66.47	5.43	71.55	72.33	4.57	0.1567	0.8366	0.0376
Overall	60.16	54.35^{b}	55.22^{b}	59.66^{a}	52.69^{b}	2.14	55.72	55.24	1.89	0.0060	0.7228	0.0218
G:F, g:g												
0–12 d	0.77	0.75	0.74	0.75	0.74	0.02	0.75	0.73	0.02	0.9648	0.1893	0.1072
13–25 d	0.55	0.50	0.53	0.53	0.52	0.03	0.54	0.51	0.02	0.1833	0.0083	0.1353
26–41 d	0.49	0.39	0.42	0.44	0.40	0.03	0.42	0.41	0.02	0.2089	0.4180	0.0038
Overall	0.54	0.47^{c}	0.50^{a,b}	0.51^{a}	0.48^{b,c}	0.01	0.49	0.48	0.01	0.0078	0.4911	<0.0001

[a-c]Means in a row without a common superscript differ ($P < 0.05$).

[1]No interaction between faba bean cultivar and dehulling ($P > 0.05$).

[2]SEM and *P*-value for 4 faba bean cultivars and dehulling.

[3]*P*-value for the contrast between faba bean cultivars and control.

[4]Starter phase.

[5]Grower phase.

[6]Finisher phase.

Table 6. Effect of Faba Bean Cultivar and Dehulling on Antemortem BW, Chilled Carcass Weight, Carcass Dressing, and Portion Yield of Broiler Chickens (41–42 d of Age).[1]

		Faba bean cultivar					Dehulling			*P* value		
	Control	Snowbird	Snowdrop	Fabelle	Malik	SEM[2]	Non-dehulled	Dehulled	SEM[2]	Cultivar[2]	Dehulling[2]	Faba bean vs. control[3]
Antemortem BW, g	2776.4	2655.8[b]	2723.2[a,b]	2796.4[a]	2630.9[b]	55.7	2709.1	2694.1	49.2	0.0095	0.5230	0.1466
Carcass weight, g	2082.2	1948.1	1987.8	2042.1	1935.8	43.9	1978.0	1978.9	38.4	0.0586	0.9765	0.0131
Carcass dressing, %	74.01	72.97	72.93	73.14	73.20	0.22	73.07	73.05	0.16	0.7893	0.9486	0.0027
Pectoralis major, g/kg	308.05	313.62[a]	303.65[b,c]	299.14[c]	310.44[a,b]	4.33	310.08	303.34	3.79	0.0041	0.0246	0.8102
Pectoralis minor, g/kg	62.67	65.02	63.43	63.57	63.28	0.87	64.23	63.42	0.66	0.4064	0.3245	0.3318
Total breast,[4] g/kg	371.04	378.89 [a]	367.21[b,c]	362.95[c]	374.06 [a,b]	4.83	374.66	366.90	4.20	0.0069	0.0231	0.9953
Thigh, g/kg	156.17	157.78[a]	158.47[a]	158.70[a]	152.57[b]	2.08	155.97	157.79	1.72	0.0300	0.2482	0.6741
Drumstick, g/kg	128.76	131.24	132.63	133.55	132.46	1.22	131.75	133.18	0.85	0.5969	0.2405	0.0479
Wings, g/kg	98.36	98.95	97.90	98.71	98.23	1.14	98.24	98.65	0.92	0.8574	0.6676	0.8619
Trim,[5] g/kg	246.55	233.93[b]	246.32[a]	248.38[a]	242.29[a]	5.39	241.11	244.35	4.98	0.0042	0.2601	0.2968

[a-c]Means in a row without a common superscript differ ($P < 0.05$).

[1]No interaction between faba bean cultivar and dehulling ($P > 0.05$).

[2]SEM and *P*-value for 4 faba bean cultivars and dehulling.

[3]*P*-value for the contrast between faba bean cultivars and control.

[4]Total breast included pectoralis major and pectoralis minor.

[5]Trim calculated as chilled carcass weight minus the sum of portion weight (breast, thighs, drumsticks, wings).

broilers fed raw-rolled FB compared with controls fed highly processed SBM. Comparing FB to raw soybean seed would have been a fairer comparison, but SBM is the worldwide standard protein meal. Despite the slight decrease in ADG and G:F feeding FB diets, BW at the end of each growth phase and antemortem BW was not different from controls. Hence, the 4 FB cultivars tested in this experiment can be readily fed to broilers at the increasing inclusion levels tested (12, 24, and 36% for the starter, grower, and finisher phases).

Carcass Traits and Yield of Saleable Cuts

For all variables analyzed, there was no cultivar × dehulling interaction on carcass traits and yield of saleable cuts. Consequently, the results of the main factors are presented separately (Table 6). Broilers fed Snowbird had the greatest BMY and pectoralis major yield, and Fabelle had the lowest ($P < 0.01$); Snowdrop was not different from Fabelle, and Malik was not different from Snowbird and Snowdrop. Trim yield for broilers fed Snowbird was lower than other FB cultivars ($P < 0.05$). Fabelle diet had a moderate dietary tannin content (1.4 g/kg) with little vicine and convicine (0.2 g/kg). If this moderate dietary tannin content in Fabelle diet caused some decreased amino acid digestibility in broilers due to tannin–protein complex formation [3, 10], then broilers fed Fabelle diet would have slightly reduced amino acid digestibility for the dietary energy level. This slight amino acid shortage would result in broilers with reduced BMY compared with feeding the other FB diets. Fabelle and Malik diets had a close CT content but reduced BMY was not seen in broilers fed Malik. Hence, it is unlikely that tannin content in Fabelle would have caused changes in yield of saleable cuts. High FB content of vicine and convicine decreased energy digestibility in broiler chickens [3]. Hence, low vicine and covicine in Fabelle diets would have slightly increased energy digestibility. That may result in broilers with slightly greater fat content and therefore reduced BMY compared with feeding other FB diets.

Feeding non-dehulled FB increased total BMY and pectoralis major compared with dehulled FB ($P < 0.05$; Table 6). Dehulling FB did not affect dressing percentage or chilled carcass weight likely because fiber content of non-dehulled (4.0% CF) and dehulled (3.4% CF) FB diets was relatively close. Broilers fed dehulled FB diets had only slightly lower total lysine intake (56.5 g; 0–41 d) compared with broilers fed non-dehulled FB diets (58.9 g), so it is unlikely that decreased lysine intake explains the decreased BMY feeding dehulled FB. The differences in CT content between non-dehulled and dehulled Fabelle and Malik were only 1.34 and 0.05 g CT/kg, respectively, indicating that dehulling was not effective in removing CT from FB. Hence, the reason for the lack of overall dehulling effect on growth performance, carcass traits, and yield of saleable cuts could be the relatively close CT content between non-dehulled and dehulled FB. On the other hand, Snowbird, Snowdrop, Fabelle, and Malik diets only had up to 0, 0, 2.0, and 1.9 g/kg CT content, respectively. Reduced BW gain and G:F were observed when broiler chickens were fed diets with greater CT content (50% FB in diet with up to 3.7 g/kg condensed tannin) compared with no or low FB diet (up to 0.3 g/kg condensed tannin) from 7 to 28 d of age [70]. Therefore, the relatively low CT content of FB cultivars in our study likely had no effect on broiler growth performance, carcass traits, and yield of saleable cuts because FB diets had under 3.7 g/kg CT. This finding suggests that broilers fed FB with CT contents $\leq$2.0 g/kg do not affect overall growth performance, carcass trait, and yield of saleable cuts, which means that dehulling FB would not be necessary to reduce CT content in these diets. Our results clearly indicate that these modern FB cultivars (Snowbird, Snowdrop, Fabelle, Malik) can be fed to broilers without the need for dehulling to reduce tannin and (or) fiber content.

The carbon intensity of feed ingredients largely depends on crop inputs during production (fertilizers, pesticides), cultivation (irrigation), and harvesting (energy sources), as well as transport of unprocessed products and drying and processing of co-products [71]. Considering that SBM is by far a much more processed meal than feeding raw FB, and that it is trucked from the US Midwest to eastern or western Canada vs. locally grown FB, it was not surprising that FB had a smaller carbon footprint than SBM. Overall trial feed carbon intensity decreased by 17.2, 18.9, 19.5, and 18.8% feeding Snowbird, Snowdrop, Fabelle, and Malik, respectively, irrespective of dehulling, relative to the SBM-wheat control regimen. Therefore, feeding locally grown raw FB to broilers can reduce carbon footprint vs. feeding highly processed and long-hauled SBM.

CONCLUSIONS AND APPLICATIONS

1. Broilers fed FB Fabelle had the greatest ADG and feed efficiency (G:F) possibly because this feeding regimen had the lowest vicine and convicine content. Hence, vicine and convicine content should be of greater consideration than tannin content when formulating poultry diets with modern FB cultivars.
2. Other than slightly increasing (3%) breast yield (pectoralis major), dehulling FB and therefore hull tannin and(or) fiber content had no effect on broiler growth performance, chilled carcass weight, dressing percentage, and yield of other saleable cuts. Therefore, FB can be readily fed to broiler chickens without the need for dehulling.
3. Feeding FB diets slightly reduced ADG, G:F, chilled carcass weight, and dressing percentage compared with the SBM-wheat control regimen. These results indicate that the 4 FB cultivars tested (Snowbird, Snowdrop, Fabelle, and Malik) can be fed to broilers up to 12, 24, and 36% in the starter (0–12 d), grower (13–25 d), and finisher phase (26–41 d) when diets are formulated to the same SID lysine to AMEn ratio.

REFERENCES AND NOTES

1. Hejdysz, M., S. A. Kaczmarek, and A. Rutkowski. 2016. Extrusion cooking improves the metabolisable energy of faba beans and the amino acid digestibility in broilers. Anim. Feed Sci. Technol. 212:100–111.

2. 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.

3. Vilariño, M., J. P. Métayer, K. Crépon, and G. Duc. 2009. Effects of varying vicine, convicine and tannin contents of faba bean seeds (*Vicia faba L.)* on nutritional values for broiler chicken. Anim. Feed Sci. Technol. 150:114–121.

4. Williams, C. M., J. R. King, S. M. Ross, M. A. Olson, C. F. Hoy, and K. J. Lopetinsky. 2014. Effects of three pulse crops on subsequent barley, canola, and wheat. Agron. J. 106:343–350.

5. Lupwayi, N. Z., and A. C. Kennedy. 2007. Grain legumes in Northern Great Plains. Agron. J. 99:1700–1709.

6. Faulkner, J. S. 1985. A comparison of faba beans and peas as whole-crop forages. GrassForage. Sci. 40:161–169.

7. Hossain, Z., X. Wang, C. Hamel, J. D. Knight, M. J. Morrison, and Y. Gan. 2017. Biological nitrogen fixation by pulse crops on semiarid Canadian prairies. Can. J. Plant Sci. 97:119–131.

8. Luce, St., M. S., C. A. Grant, B. J. Zebarth, N. Ziadi, J. T. O'Donovan, R. E. Blackshaw, K. N. Harker, E. N. Johnson, Y. Gan, G. P. Lafond, W. E. May, M. Khakbazan, and E. G. Smith. 2015. Legumes can reduce economic optimum nitrogen rates and increase yields in a wheat–canola cropping sequence in western Canada. Field Crops Res. 179:12–25.

9. Van der Poel, A. F. B., S. Gravendeel, and H. Boer. 1991. Effect of different processing methods on tannin content and in vitro protein digestibility of faba bean (*Vicia faba L.*). Anim. Feed Sci. Technol. 33:49–58.

10. Woyengo, T. A., and C. M. Nyachoti. 2012. Ileal digestibility of amino acids for zero-tannin faba bean (*Vicia faba L.*) fed to broiler chicks. Poult. Sci. 91:439–443.

11. Flores, M. P., J. I. R. Castañon, and J. M. McNab. 1994. Effect of tannins on starch digestibility and TMEn of triticale and semipurified starches from triticale and field beans. Br. Poult. Sci. 35:281–286.

12. Ivarsson, E., and H. Wall. 2017. Effects of toasting, inclusion levels and different enzyme supplementations of faba beans on growth performance of broiler chickens. J. Appl. Poult. Res. 26:467–475.

13. Crépon, K., P. Marget, C. Peyronnet, B. Carrouée, P. Arese, and G. Duc. 2010. Nutritional value of faba bean (*Vicia faba L.*) seeds for feed and food. Field Crops Res. 115:329–339.

14. Henriquez, B., M. Olson, C. Hoy, M. Jackson, and T. Wouda. 2018. Frost tolerance of faba bean cultivars (*Vicia faba L.*) in central Alberta. Can. J. Plant Sci. 98:509–514.

15. Kopmels, F., M. N. Smit, M. Cho, L. He., and E. Beltranena. 2019. Effect of feeding 3 zero-tannin faba bean cultivars at 3 increasing inclusion patterns on growth performance, carcass traits and yield of saleable cuts of broiler chickens. J. Appl. Poult. Res. Submitted manuscript JAPR-19-02005.

16. Laudadio, V., and V. Tufarelli. 2010. Treated fava bean (*Vicia faba* var. minor) as substitute for soybean meal in diet of early phase laying hens: Egg-laying performance and egg quality. Poult. Sci. 89:2299–2303.

17. Schreuder, R., and C. de Visser. 2014. EIP-AGRI Focus Group Protein Crops: final report. Accessed August 30, 2019. https://ec.europa.eu/eip/agriculture/en/publications/eip-agri-focus-group-protein-crops-final-report.

18. Canadian Council on Animal Care. 2009. CCAC Guidelines on: The Care and Use of Farm Animals in Research, Teaching and Testing. 1st Ed. Ottawa, Ontario, Canada.

19. Fort Saskatchewan, Alberta, Canada.

20. Blaine Lake, Saskatchewan, Canada.

21. Enchant, Alberta, Canada.

22. Model CHD 8.5 × 12, Iowa Farm Automation Ltd., Stanly, IA.

23. University of Alberta, South Campus, Edmonton, Canada.

24. Lilydale, Spruce Grove, Alberta, Canada.

25. University of Alberta, South Campus, Edmonton, Alberta, Canada.

26. 119.4 cm length x 53.3 cm width x 43.2 cm height; 9 to 10 chicks per cage.

27. Specht-Ten Elsen GmbH, Sonsbeck, Germany.

28. Each battery provided 32 cages arranged as 4 tiers, 2 sides and 4 cages per side. Cages had wire flooring (2 cm x 2 cm) with nipple drinkers on an adjustable height bar (4 nipples/cage) and a feed trough running the entire length of the cage. Plastic mesh mats (1 cm x 1 cm) were placed on top of the wire flooring in each cage until 7 d of age and were then removed. From 0 to 4 d, parchment paper was placed on top of the floorings with weighed feed sprinkled on next to the feed trough to entice early feed consumption.

29. Aiming to $\leq$ 35 kg BW/m^2 at 42 d.

30. National Farm Animal Care Council. 2016. Code of practice for the care and handling of hatching eggs, breeders, chicken and turkeys. Accessed August 30, 2019. https://www.nfacc.ca/pdfs/codes/poultry_code_EN.pdf.

31. Aviagen. 2019. Ross 708 Performance Objectives. Aviagen Inc., Huntsville, AL, USA. Accessed August 30, 2019. http://en.aviagen.com/tech-center/download/1340/Ross-708-BroilerPO2019-EN.pdf.

32. AMINODat 5.0, Evonik Degussa GmbH; Hanau-Wolfgang, Germany.

33. 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 Academic Publishers, Wageningen, the Netherlands.

34. Aviagen. 2019. Ross 708 Nutrition Specification. Aviagen Inc., Huntsville, AL, USA. Accesed August 30, 2019. http://en.aviagen.com/assets/Tech_Center/Ross_Broiler/RossBroilerNutritionSpecs2019-EN.pdf.

35. Wilfart, A., S. Espagnol, S. Dauguet, A. Tailleur, A. Gac, and F. Garcia-Launay. 2016. ECOALIM: a dataset of environmental impacts of feed ingredients used in french animal production. PLoS One 11:e0167343.

36. Model PB35, A&M Process Equipment Ltd., Ajax, Ontario, Canada.

37. Model SPC-2748, Marion Process Solutions, Marion, IA, USA.

38. ZM 200, Retsch GmbH, Haan, Germany.

39. Central Testing Laboratory Ltd., Winnipeg, Manitoba, Canada.

40. AOAC. 2016. Official Methods of Analysis. 20th ed. Rockville, MD.

41. American Oil Chemists' Society. 2017. Official Methods and Recommended Practices of the AOCS. 7th ed. Urbana, IL.

42. Ankom Technology. 2017. Analytical methods for Fiber Analyzer A2000. Accessed August 30, 2019. https://www.ankom.com/analytical-methods-support/fiber-analyzer-a2000.

43. Diets and ingredients were analyzed for DM (AOAC 930.15), CP (AOAC 990.03[M]), amino acids (AOAC 994.12), starch (enzymatic UV method, Cat. No. 10207748035; R-Biopharm, Darmstadt, Germany), CF (AOCS BA 6a-05), NDF (Ankom method 13[M]), ADF (Ankom method 12[M]), ash (AOAC 923.03), calcium, chloride, magnesium, phosphorus, potassium, and sodium (AOAC 985.01 [M], AOAC 968.08 [M], and AOAC 935.13a [M]) content. Gross energy for diet and feed ingredient samples was measured in duplicates using bomb calorimetry (Model 6050, Parr Instrument Company, Moline, IL) in our laboratory (Alberta Agriculture and Forestry, Edmonton, Canada).

44. Ro-Tap, model RX-29, W.S. Tyler, ON, Canada.

45. American Society of Agricultural and Biological Engineers. 2008. Methods of Determining and Expressing Fineness of Feed Materials by Sieving. Publ. S319.4 Am. Soc. Agric. Biol. Eng., St. Joseph, MI.

46. Purves, R. W., H. Khazaei, and A. Vandenberg. 2018. Toward a high-throughput method for determining vicine and convicine levels in faba bean seeds using flow injection analysis combined with tandem mass spectrometry. Food Chem. 256:219–227.

47. Organic Residue Laboratory, Alberta Agriculture and Forestry, Edmonton, Alberta, Canada). Briefly, a 0.20 ± 0.01 g sample of ground FB was spiked with an internal standard solution containing uridine and subsequently extracted with 10 mL of water containing 1% (vol/vol) formic acid. A 10 μL aliquot of the extract was diluted with 990 μL of 4:1 acetonitrile:water containing 1% (vol/vol) formic acid. All samples and calibration standards were analyzed using liquid chromatography-tandem mass spectrometry (**LC-MS/MS**). The LC-MS/MS method included the use of a hydrophilic interaction liquid chromatography (**HILIC**) separation and was based on the procedure reported by Purves et al. [48] with minor modification. The LC separation was performed using a Kinetex HILIC column (100 × 2.1 mm length x internal diameter; 1.7 μm particle diameter) with a binary gradient elution program employing water and 95% acetonitrile:water (vol/vol), each containing 5 mM ammonium formate plus 0.1% (vol/vol) formic acid, as the mobile phases. The tandem mass spectrometry analysis was performed in the selected reaction monitoring mode (**SRM**) with 2 SRM transitions selected for each analyte (one transition was used for quantitation while the other was used for confirmation of compound identity). Quantitation was performed using internal standard calibration with uridine. Due to the lack of availability of a commercial standard of convicine, quantification of this analyte was performed using the calibration curve obtained for a reference standard of vicine. The calibration curve used for the analysis covered a working range from 0.01 to 10 mg/g of vicine.

48. 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.

49. Natural Resources Institute Finland (Luke; Jokioinen, Finland).

50. 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.

51. SAS Institute. 2017. SAS User Guide. Version 9.4. SAS Inst. Inc., Cary, NC.

52. Zijlstra, R. T., K. Lopetinsky, and E. Beltranena. 2008. The nutritional value of zero-tannin faba bean for grower-finisher pigs. Can. J. Anim. Sci. 88:293–302.

53. Nalle, C. L., V. Ravindran, and G. Ravindran. 2010. Nutritional value of faba beans (*Vicia faba L.*) for

broilers: apparent metabolisable energy, ileal amino acid digestibility and production performance. Anim. Feed Sci. Technol. 156:104–111.

54. Przywitowski, M., D. Mikulski, Z. Zdunczyk, A. Rogiewicz, and J. Jankowski. 2016. The effect of dietary high-tannin and low-tannin faba bean (Vicia faba L.) on the growth performance, carcass traits and breast meat characteristics of finisher turkeys. Anim. Feed Sci. Technol. 221:124–136.

55. Mejia, L., C. D. Zumwalt, E. J. Kim, P. B. Tillman, and A. Corzo. 2011. Digestible isoleucine-to-lysine ratio effects in diets for broilers from 4 to 6 weeks posthatch. J. Appl. Poult. Res. 20:485–490.

56. Corzo, A., and M. T. Kidd. 2003. Arginine needs of the chick and growing broiler. Int. J. Poult. Sci. 2:379–382.

57. Proudfoot, F. G., and H. W. Hulan. 1989. Feed texture effects on the performance of roaster chickens. Can. J. Anim. Sci. 69:801–807.

58. Nir, I., R. Hillel, G. Shefet, and Z. Nitsan. 1994. Effect of grain particle size on performance. 2. Grain texture interactions. Poult. Sci. 73:781–791.

59. Hamilton, R. M. G., and F. G. Proudfoot. 1995. Ingredient particle size and feed texture: effects on the performance of broiler chickens. Anim. Feed Sci. Technol. 51:203–210.

60. Diaz, D., M. Morlacchini, F. Masoero, M. Moschini, G. Fusconi, and G. Piva. 2006. Pea seeds (*Pisum sativum*), faba beans (*Vicia faba* var. minor) and lupin seeds (*Lupinus albus* var. multitalia) as protein sources in broiler diets: effect of extrusion on growth performance. Ital. J. Anim. Sci. 5:43–53.

61. 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.

62. Frohlich, A. A., and R. R. Marquardt. 1983. Turnover and hydrolysis of vicine and convicine in avian tissues and digesta. J. Sci. Food Agric. 34:153–163.

63. 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.

64. Muduuli, D. S., R. R. Marquardt, and W. Guenter. 1981. Effect of dietary vicine on the productive performance of laying chickens. Can. J. Anim. Sci. 61:757–764.

65. Yang, L., G-Y. Tan, Y-Q. Fu, J-H. Feng, and M-H. Zhang. 2010. Effects of acute heat stress and subsequent stress removal on function of hepatic mitochondrial respiration, ROS production and lipid peroxidation in broiler chickens. Comp. Biochem. Physiol. C: Toxicol. Pharmacol. 151:204–208.

66. Losowsky, M. S., and B. E. Walker. 1969. Liver disease and malabsorption. Gastroenterology. 56:589–600.

67. Moschini, M., F. Masoero, A. Prandini, G. Fusconi, M. Morlacchini, and G. Piva. 2005. Raw Pea (*Pisum sativum*), raw Faba bean (*Vicia faba* var. minor) and raw Lupin (*Lupinus albus* var. multitalia) as alternative protein sources in broiler diets. Ital. J. Anim. Sci. 4:59–69.

68. Wright, K. N. 1981. Soybean meal processing and quality control. J. Am. Oil Chem. Soc. 58:294–300.

69. Rada, V., M. Lichovnikova, and I. Safarik. 2017. The effect of soybean meal replacement with raw full-fat soybean in diets for broiler chickens. J. Appl. Poult. Res. 45:112–117.

70. Helsper, J. P. F. G., Y. P. J. van Loon, R. P. Kwakkel, A. van Norel, and A. F. B van der Poel. 1996. Growth of broiler chicks fed diets containing tannin-free and tannin-containing near-isogenic lines of faba bean (*Vicia faba L.*). J. Agric. Food Chem. 44:1070–1075.

71. Van Middelaar, C. E., C. Cederberg, T. V. Vellinga, H. M. G. van der Werf, and I. J. M. de Boer. 2013. Exploring variability in methods and data sensitivity in carbon footprints of feed ingredients. Int. J. Life Cycle Assess. 18:768–782.

Acknowledgments

The authors acknowledge funding from Alberta Agriculture and Forestry (Edmonton, Alberta, Canada) and Saskatchewan Pulse Growers (Saskatoon, Saskatchewan, Canada), and marketing quota donation by the Alberta Chicken Producers (Edmonton, Alberta, Canada). We thank Ajinomoto (Raleigh, NC) and Halchemix Canada Inc. (Port Perry, Ontario, Canada) for donating the L-valine and Canadian Bio-Systems Inc. (Calgary, Alberta, Canada) for donating the Superzyme Plus. We also thank Tom Thompson and Johan van den Heever (Organic Residue Laboratory, Alberta Agriculture and Forestry, Edmonton, Alberta, Canada) for conducting the vicine and convicine analysis.