Brassica napus and *Brassica juncea* extruded-expelled cake and solvent-extracted meal as feedstuffs for laying hens: Lay performance, egg quality, and nutrient digestibility

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ABSTRACT Two experiments evaluated feeding *Brassica* (**B.**) *napus* (canola) or *B. juncea* co-products to brown-shelled egg laying hens. In Exp. 1, diets including 20% *B. napus* or *B. juncea* extruded-expelled cakes (**NC, JC**) or solvent-extracted meals (**NM, JM**) compared to a control diet with no *Brassica* co-products, were fed to 120 hens (4 hens/cage, n = 6) for 36 wk. In Exp. 2, DM, gross energy, CP and amino acid (**AA**) retention/digestibility was determined by feeding diets containing 30% *B. napus* or *B. juncea* cakes or meals and basal diet to 240 hens (8 hens/pair of cages, n = 6) for 7 d. Cakes averaged 40 g/kg lower moisture, 28 g/kg lower CP, and 84 g/kg greater fat content compared with meals. In Exp. 1, there was no effect of diet on lay percentage or BW throughout the experiment. Feed consumption was 3.5 g/d lower in layers fed JM compared with controls and egg: feed was reduced by 14 mg egg/g feed in layers fed JC ($P < 0.01$). Although eggs from layers fed NM were 0.7 g heavier than controls, eggs from layers fed NC, JM or JC were 1.4 g lighter than controls ($P < 0.01$). Eggs from layers fed *Brassica* diets contained a greater proportion (1.6%-points) of monounsaturated fatty acids compared with controls ($P < 0.01$). Eggs from layers fed *B. juncea* had a relatively greater proportion (0.2%-points) of C18:3 (n3) compared with those of layers fed *B. napus* diets ($P < 0.01$). Feeding *Brassica* diets reduced digestibility of DM (5%-points), gross energy (7%-points) and CP (4%-points) vs. basal ($P < 0.01$). The digestibility of indispensable AA except tryptophan, was reduced feeding *Brassica* diets vs. basal ($P < 0.01$). We concluded that feeding *B. napus* and *B. juncea* extruded-expelled cakes and solvent-extracted meal at 20% of diets to hens supported acceptable lay performance and egg quality over a 36 wk production cycle. Digestibility data indicated that indispensable AA in *Brassica* co-products had moderately high (75 to 85%) apparent ileal digestibility.

Key words: *Brassica juncea*, *Brassica napus*, extruded-expelled cake, solvent-extracted meal, laying hen

2020 Poultry Science 99:350–363
http://dx.doi.org/10.3382/ps/pez501

INTRODUCTION

Solvent-extracted canola (*Brassica [B.] napus*) meal can be fed as a nutritious and cost effective dietary supplemental protein source to laying hens. The level of inclusion of canola meal in layer diets is limited, however, by a relatively high fiber content and anti-nutritional factors. Glucosinolates are the most noteworthy anti-nutritional factors (Canola Council of Canada, 2015) that can reduce feed intake and affect metabolism (Woyengo et al., 2016). Solvent-extracted meal produced from Indian mustard (*Brassica juncea*), which is closely related to *B. napus*, has greater energy value and protein content and lower fiber content compared with canola (Newkirk et al., 1997), but greater total glucosinolate content (Newkirk et al., 2003; Smit et al., 2014). It was recently reported that feeding of up to 20% canola meal or *B. juncea* meal had little effect on laying hen performance and egg quality compared with soybean meal (Savary et al., 2017). Some adverse effects of feeding 20% *B. juncea* meal to laying hens, however, were observed in the study of Cheva-Isarakul et al. (2001).

In recent years, there has been an increase of farm-scale canola crushing in Western Canada, which serves as an alternative marketing stream for sub-optimal quality seed. The resulting oilseed cake, which typically ranges from 10 to 15% remaining oil, is then marketed as a higher energy alternative to solvent-extracted oilseed meals. Despite increasing availability of these co-products, there is comparatively little information to support their feeding to laying hens. Further, there is no information available regarding the variation in nutrient content of small-scale crushing plant co-products comparable to the information available for commercially-available solvent-extracted co-products (Adewole et al., 2016). Increasing dietary inclusion of

Received February 16, 2019.
Accepted August 20, 2019.
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extruded-expelled *B. juncea* cake reduced feed intake in pigs, presumably because of increased glucosinolate content (Zhou et al., 2014). However, chickens compared with pigs show a lower sensitivity to glucosinolates (Rouraa et al., 2013). High temperature achieved during extrusion could inactivate intrinsic thioglucosidase enzymes in the seed that catalyze the hydrolysis of glucosinolates into less palatable isothiocyanate and nitrile metabolites (Huang et al., 1995). At the same time, extrusion may also increase nutrient digestibility, as we have reported for other high-protein, high-fiber co-product feedstuffs (Oryschak et al., 2010).

To our knowledge, no previous study has compared the feeding value of *B. juncea* and *B. napus* co-products generated by small-scale oil pressing compared with large-scale solvent-extraction for laying hens. Two experiments (Exp. 1 and Exp. 2) were therefore conducted to compare feeding relatively high dietary inclusions of *B. napus* and *B. juncea* extruded-expelled cakes and solvent-extracted meals on performance, egg quality, and nutrient digestibility in laying hens.

In Exp. 1, we sought to test the hypothesis that hen productivity and egg quality would not differ among hens fed diets containing 20% of either *B. napus* and *B. juncea* extruded-expelled cakes and solvent-extracted meals compared with a barley/wheat-based diet containing no *Brassica* co-products. In Exp. 2, we tested the hypothesis that nutrient digestibility would not differ for *B. napus* or *B. juncea* extruded-expelled cakes or solvent-extracted meals fed to laying hens.

MATERIALS AND METHODS

Animal use was approved and experiment procedures were reviewed by the University of Alberta Animal Care and Use Committee for Livestock (AUP00000149) and conformed to guidelines set forth by the Canadian Council on Animal Care (2009) for farm animals.

Layers Initial Management

Day-old chicks (Brown Nick, H & N International; Cuxhaven, Germany) were sourced from Pacific Pride Chicks Ltd. (Abbotsford, British Columbia) and delivered to the Poultry Research and Technology Centre (**PRTC**), University of Alberta South Campus, Edmonton, Alberta, Canada. Pullets were raised as groups in floor pens to 19 wk of age according to supplier recommendations (H & N International, 2011).

At 19 wk of age, pullets were relocated to a 3-tiered, commercial egg layer battery (Specht Ten Elsen & Co. GmbH; Sonsbeck, Germany) and were photo-stimulated according to the standard protocol at PRTC (15 to 20 lux, increasing gradually from 8 to 14 h/d during 16 to 23 wk of age). Following this phase, layers were exposed to 14 h light per day and maintained at 22.5° C. Cages had wire mesh floors and two nipple drinkers per cage.

Test Feedstuffs and Diets

Solvent-extracted *B. napus* (**NM**) and *B. juncea* (**JM**) meals (Table 1) were sourced from Bunge North America (Altona, Manitoba, Canada). Extruded-expelled *B. napus* (**NC**) and *B. juncea* (**JC**) cakes (Table 1) were sourced from Apex Nutri-Solutions Ltd. (Edberg, Alberta, Canada). For Exp. 1, test diets were fed over 2 production phases (weeks 1 to 24 and weeks 25 to 36 of lay, respectively) and were formulated to provide similar levels of AME, crude fat, CP and digestible Lys to AME ratio (Tables 2 and 3). Diets were fed in mash form and formulated to meet or exceed recommended levels of digestible nutrients as specified in the production guide for this strain (H & N International, Cuxhaven, Germany; and NRC, 1994).

For the digestibility experiment (Exp. 2), diets fed in mash form consisted of a basal and test diets comprising 30% NM, JM, NC, or JC blended with 70% basal diet for a total of 5 treatments (Table 4). Diets in Exp. 2 included titanium dioxide (3330 grade; Brenntag Specialties; Leduc, Alberta, Canada) as an indigestible marker.

Experiment 1

Beginning at 20 wk of age, layers were progressively transitioned from a common start-of-lay diet to their respective experimental diets over a 2-wk period. The 5 test diets were fed to 120 hens housed 4 per cage, 6 replicates per diet over a 36-wk production cycle from 23 to 59 wk of age. Laying hens were weighed on d 0 and at the conclusion of each of the nine 4-wk periods. Feed remaining in each feeder was subtracted from the weight of feed added over the 4 wk to calculate feed disappearance for each test cage. Environmental conditions (current, maximum and minimum temperature and humidity over the previous 24 h) and the number of eggs produced by each test cage were recorded at approximately the same time each day. Each week, eggs laid within a 24-h period were individually weighed for each test cage to calculate average egg weight.

Eggs collected during a 48 h period between days 68 and 70 were retained at room temperature and on day 72, each egg was weighed intact and then broken out. Wet weights of shell, albumen and yolk were recorded and the proportion of each relative to whole egg weight was calculated.

On day 150, all eggs produced were collected, individually numbered and retained overnight at room temperature. The following morning, the specific gravity of eggs was determined using 18 room-temperature saline solutions with specific gravities ranging from 1.065 to 1.095 (relative to fresh water), which were verified with a hydrometer. These same eggs were then weighed and broken out to determine albumen height to calculate Haugh Units. The pH of the albumen and yolk were measured using a model AB15 Accumet pH meter (Fisher Scientific Canada; Ottawa, Ontario, Canada).

Table 1. Analyzed nutrient composition (% as is, except gross energy) of *Brassica napus* and *Brassica juncea* solvent-extracted meals and extruded-expelled cakes fed in Experiments 1 and 2.

	Brassica napus		*Brassica juncea*	
	Solvent–extracted meal[1]	Extruded–expelled cake[2]	Solvent–extracted meal[1]	Extruded–expelled cake[2]
Moisture	10.57	6.58	8.99	5.02
Gross energy, Mcal/kg	4.377	4.915	4.338	4.906
Crude protein	37.69	34.60	38.40	35.87
Neutral detergent fiber	27.60	22.30	22.26	22.03
Acid detergent fiber	19.68	14.80	12.79	13.13
Crude fiber	7.75	6.82	7.24	6.57
Crude fat	2.52	11.94	2.56	9.93
Linoleic acid (18:2n6)	–	2.45	–	1.61
Ash	7.60	6.19	7.35	6.74
Phosphorus	0.98	0.90	1.09	0.99
Calcium	0.55	0.47	0.62	0.66
Indispensable amino acids				
Arginine	2.50	2.03	2.44	2.18
Histidine	1.07	0.87	0.94	0.88
Isoleucine	1.67	1.43	1.53	1.43
Leucine	2.92	2.56	2.70	2.55
Lysine, total	2.24	1.68	1.96	1.72
Lysine, reactive	2.02	1.48	1.70	1.43
Methionine	0.80	0.66	0.68	0.63
Methionine + Cysteine	1.77	1.44	1.44	1.33
Phenylalanine	1.66	1.54	1.50	1.49
Threonine	1.72	1.40	1.57	1.43
Tryptophan	0.46	0.44	0.45	0.48
Valine	2.26	1.93	2.00	1.87
Dispensable amino acids				
Alanine	1.81	1.57	1.67	1.54
Aspartic Acid	2.92	2.34	2.85	2.44
Cysteine	0.97	0.78	0.76	0.70
Glutamic Acid	6.95	6.45	5.78	6.10
Glycine	2.09	1.73	1.90	1.77
Proline	2.31	2.16	2.00	2.20
Serine	1.50	1.39	1.39	1.36
Tyrosine	1.12	1.01	1.06	1.06
Total amino acids	37.67	32.47	33.76	32.37

[1]Bunge North America (Altona, Manitoba, Canada).
[2]Apex Nutri-Solutions Ltd. (Egbert, Alberta, Canada).

All eggs produced over a 36 h period during week 13 of the experiment (37 wk of age) were broken out and the liquid contents pooled to produce a single specimen per test cage. Egg specimens were homogenized, frozen and freeze dried for subsequent fatty acid analysis.

Experiment 2

Two weeks after the conclusion of the 36-wk production cycle (59 wk of age), hens from the Exp. 1 (n = 103) were combined with an additional 137 Brown Nick and were randomly redistributed among 60 cages in the battery for 4 hens per cage. Adjacent cages were paired, resulting in experimental units that consisted of 8 birds. All cages were then offered a standard layer ration *ad libitum* for an additional 7 d. On day 8, feeders were emptied and paired cages then had *ad libitum* access to one of the 5 digestibility test diets for a 7-d period. On the afternoon of day 13, labeled plastic trays were placed on the manure belt underneath each test cage to collect excreta for a 36-h period. On the morning of day 15, layers were humanely euthanized by cervical dislocation. The portion of the ileum spanning the vitelline diverticulum to approximately 3 cm cranial to the ileo-caecal junction was then excised from each bird and the digesta therein was gently expressed manually. Digesta and excreta were pooled to produce a single specimen of each per test cage.

Sample Preparation and Laboratory Analysis

Excreta samples were dried to constant weight in a forced air oven at 65°C whereas digesta samples were freeze-dried (EL-85 freeze drier, Virtis SP Scientific; Stone Ridge, NY). Feed, lyophilized digesta, and dry excreta samples were ground in a centrifugal mill (ZM200; Retsch GmBH; Haan, Germany) to pass through a 1 mm screen. Feed and ingredient samples from Exp. 1 and 2 were analyzed using AOAC (2006) methods for DM (method 930.15), CP (method 990.03), crude fiber (method 978.10), ether extract (method 920.39), ash (method 942.05), acid detergent fiber (ADF; method 973.18), selected minerals (method 985.01) and amino acids (**AA**; method 982.30) at the

Table 2. Ingredient composition and analyzed nutrient content of Phase 1 (weeks 1 to 24) diets fed in Experiment 1, % as fed.

		Brassica napus		*Brassica juncea*	
	Control	Meal	Cake	Meal	Cake
Barley	58.64	43.47	28.54	43.47	28.54
Wheat	–	12.71	27.34	12.71	27.34
B. napus solvent-extracted meal	–	20.00	–	–	–
B. napus extruded-expelled cake	–	–	20.00	–	–
B. juncea solvent-extracted meal	–	–	–	20.00	–
B. juncea extruded-expelled cake	–	–	–	–	20.00
Soybean meal	12.99	5.10	4.68	5.10	4.68
Wheat DDGS	10.00	1.05	4.07	1.05	4.07
Limestone[1]	9.28	9.07	9.15	9.07	9.15
Canola oil	6.70	6.50	4.20	6.50	4.20
Vitamin and trace mineral premix[2]	0.50	0.50	0.50	0.50	0.50
Choline premix[3]	0.50	0.50	0.50	0.50	0.50
Mono-dicalcium phosphate	0.49	0.45	0.40	0.45	0.40
Sodium bicarbonate	0.37	0.29	0.25	0.29	0.25
Salt	0.05	0.11	0.13	0.11	0.13
D,L—Methionine	0.18	0.13	0.10	0.13	0.10
L—Lysine-HCl	0.15	0.06	0.07	0.06	0.07
L—Threonine	0.10	0.00	0.02	0.01	0.02
CBS Superzyme® Plus[4]	0.05	0.05	0.05	0.05	0.05
Moisture	9.79	10.25	9.86	9.54	9.13
Crude protein	19.65	17.47	18.16	18.24	18.29
Neutral detergent fiber	16.48	18.25	15.29	14.87	15.71
Acid detergent fiber	4.93	7.07	5.64	5.96	5.48
Crude fiber	3.28	4.33	3.53	3.56	3.24
Ash	13.94	12.57	12.84	12.92	12.79
Calcium	3.86	3.82	3.92	3.97	3.89
Phosphorus	0.49	0.55	0.56	0.54	0.60
Crude fat	7.43	7.13	7.63	7.32	6.69
Linoleic acid (18:2n6)[5]	2.12	1.76	1.97	2.01	1.91
Indispensable amino acids					
Arginine	0.96	0.99	1.08	1.00	1.02
Histidine	0.39	0.41	0.43	0.43	0.44
Isoleucine	0.67	0.67	0.72	0.71	0.71
Leucine	1.28	1.27	1.35	1.33	1.33
Lysine	0.78	0.83	0.84	0.82	0.76
Methionine	0.48	0.41	0.40	0.40	0.37
Methionine + cystine	0.77	0.75	0.72	0.75	0.70
Phenylalanine	0.91	0.86	0.89	0.90	0.88
Threonine	0.67	0.66	0.70	0.65	0.66
Tryptophan	0.19	0.20	0.21	0.22	0.22
Valine	0.88	0.92	0.96	0.95	0.94
Dispensable amino acids					
Alanine	0.69	0.73	0.78	0.76	0.75
Aspartic acid	1.27	1.21	1.33	1.20	1.22
Cysteine	0.29	0.34	0.32	0.35	0.33
Glutamic acid	4.03	3.90	3.92	4.35	4.29
Glycine	0.69	0.79	0.83	0.81	0.81
Proline	1.45	1.45	1.45	1.40	1.54
Serine	0.74	0.73	0.75	0.76	0.75
Tyrosine	0.52	0.50	0.53	0.52	0.54
Total amino acids	17.07	17.14	17.76	17.77	17.75

[1]1:2 (w/w) blend of fine and coarse grit limestone, respectively.

[2]Hi-Pro Feeds LP; Edmonton, Alberta, Canada. Provided the following per kg of mixed feed: 80 mg/kg iron; 100 mg/kg zinc; 88 mg/kg manganese; 15 mg/kg copper; 1.65 mg/kg iodine; 0.3 mg/kg selenium; 12,500 IU/kg vitamin A; 3,125 IU/kg vitamin D3; 40 IU/kg vitamin E; 2.5 mg/kg vitamin K (menadione); 37.5 mg/kg niacin; 12.5 mg/kg pantothenic acid; 7.5 mg/kg riboflavin; 5 mg/kg pyridoxine; 2.55 mg/kg thiamin; 0.625 mg/kg folic acid; 0.15 mg/kg biotin; and, 0.01875 mg/kg vitamin B12.

[3]Hi-Pro Feeds LP; Edmonton, Alberta, Canada. Provided 400 mg/kg of choline per kg of mixed feed.

[4]Canadian Bio-Systems; Calgary, Alberta, Canada. Provided the following enzyme activities per kg of mixed feed: xylanase, 1,200 U; glucanase, 150 U; invertase, 700 U; protease, 1,200 U; cellulase, 500 U; amylase, 12,000; mannanase, 60; phytase, 1,000 U.

[5]Linoleic acid is reported for Phase 1 diets only, as eggs sampled for fatty acid composition were from hens fed Phase 1 diets.

Table 3. Ingredient composition and analyzed nutrient content of Phase 2 (weeks 25 to 36) diets fed in Experiment 1, % as fed.

		Brassica napus		*Brassica juncea*	
	Control	Meal	Cake	Meal	Cake
Barley	57.76	50.25	37.22	50.25	37.22
Wheat	–	3.18	15.47	3.18	15.47
B. napus solvent-extracted meal	–	20.00	–	–	–
B. napus extruded-expelled cake	–	–	20.00	–	–
B. juncea solvent-extracted meal	–	–	–	20.00	–
B. juncea extruded-expelled cake	–	–	–	–	20.00
Soybean meal	13.13	5.00	4.27	5.00	4.27
Wheat DDGS	10.00	2.42	5.93	2.42	5.93
Limestone[1]	9.80	9.58	9.66	9.58	9.66
Canola oil	6.93	7.41	5.30	7.41	5.30
Vitamin and trace mineral premix[2]	0.50	0.50	0.50	0.50	0.50
Choline premix[3]	0.50	0.50	0.50	0.50	0.50
Mono-dicalcium phosphate	0.45	0.41	0.35	0.41	0.35
Sodium bicarbonate	0.37	0.33	0.31	0.33	0.31
Salt	0.04	0.09	0.11	0.09	0.11
D,L—Methionine	0.19	0.14	0.14	0.14	0.14
L—Lysine-HCl	0.17	0.11	0.13	0.11	0.13
L—Threonine	0.11	0.03	0.06	0.03	0.06
CBS Superzyme® Plus[4]	0.05	0.05	0.05	0.05	0.05
Moisture	7.45	7.96	8.06	6.43	7.14
Crude protein	18.39	18.67	19.15	19.07	19.62
Neutral detergent fiber	11.10	13.49	12.06	12.58	12.44
Acid detergent fiber	6.03	8.62	5.96	7.40	6.48
Crude fiber	4.33	5.45	4.42	4.07	4.06
Ash	13.40	13.66	13.61	13.49	13.56
Calcium	4.62	4.62	4.47	4.39	4.40
Phosphorus	0.47	0.56	0.58	0.53	0.57
Crude fat	7.70	8.21	8.16	8.31	7.15
Indispensable amino acids					
Arginine	0.93	0.97	1.07	0.97	0.97
Histidine	0.38	0.41	0.43	0.42	0.42
Isoleucine	0.70	0.70	0.74	0.73	0.71
Leucine	1.29	1.30	1.38	1.36	1.32
Lysine	0.87	0.92	0.92	0.92	0.87
Methionine	0.42	0.48	0.48	0.40	0.44
Methionine + cystine	0.71	0.86	0.86	0.78	0.79
Phenylalanine	0.94	0.90	0.94	0.95	0.92
Threonine	0.71	0.73	0.81	0.75	0.73
Tryptophan	0.18	0.20	0.17	0.21	0.21
Valine	0.82	0.88	0.92	0.89	0.87
Dispensable amino acids					
Alanine	0.71	0.72	0.77	0.77	0.75
Aspartic acid	1.29	1.23	1.34	1.22	1.18
Cysteine	0.30	0.38	0.38	0.37	0.35
Glutamic acid	4.00	3.78	3.91	4.39	4.26
Glycine	0.71	0.78	0.82	0.81	0.08
Proline	1.58	1.54	1.57	1.69	1.65
Serine	0.76	0.76	0.79	0.82	0.77
Tyrosine	0.55	0.53	0.56	0.57	0.57
Total amino acids	17.32	17.53	18.30	18.53	18.10

[1]1:2 (w/w) blend of fine and coarse grit limestone, respectively.

[2]Hi-Pro Feeds LP; Edmonton, Alberta, Canada. Provided the following per kg of mixed feed: 80 mg/kg iron; 100 mg/kg zinc; 88 mg/kg manganese; 15 mg/kg copper; 1.65 mg/kg iodine; 0.3 mg/kg selenium; 12,500 IU/kg vitamin A; 3,125 IU/kg vitamin D3; 40 IU/kg vitamin E; 2.5 mg/kg vitamin K (menadione); 37.5 mg/kg niacin; 12.5 mg/kg pantothenic acid; 7.5 mg/kg riboflavin; 5 mg/kg pyridoxine; 2.55 mg/kg thiamin; 0.625 mg/kg folic acid; 0.15 mg/kg biotin; and, 0.01875 mg/kg vitamin B12.

[3]Hi-Pro Feeds LP; Edmonton, Alberta, Canada. Provided 400 mg/kg of choline per kg of mixed feed.

[4]Canadian Bio-Systems; Calgary, Alberta, Canada. Provided the following enzyme activities per kg of mixed feed: xylanase, 1,200 U; glucanase, 150 U; invertase, 700 U; protease, 1,200 U; cellulase, 500 U; amylase, 12,000; mannanase, 60; phytase, 1,000 U.

Agricultural Experiment Station Chemical Laboratories (**AESCL**) of the University of Missouri (Columbia, Missouri, USA). Neutral detergent fiber (**NDF**) was determined according to Holst (1973). Digesta samples were also assayed for DM, CP, and AA at AESCL using the same methods. Test diets from Exp. 1 and lyophilized egg samples were also analyzed for fatty acid content (method Ce 1d-91; AOCS, 2013). Gross energy in test ingredients, Exp. 2 diets and excreta specimens was measured by isoperibol oxygen bomb calorimetry

Table 4. Ingredient composition and analyzed nutrient content of experimental diets fed to laying hens in Experiment 2, % as fed.

		Brassica napus		*Brassica juncea*	
	Basal	Meal	Cake	Meal	Cake
Corn	75.00	52.50	52.50	52.50	52.50
B. napus solvent-extracted meal	–	30.00	–	–	–
B. napus extruded-expelled cake	–	–	30.00	–	–
B. juncea solvent-extracted meal	–	–	–	30.00	–
B. juncea extruded-expelled cake	–	–	–	–	30.00
Dried egg white[1]	10.00	7.00	7.00	7.00	7.00
Limestone[2]	10.00	7.00	7.00	7.00	7.00
Mono-dicalcium phosphate	2.00	1.40	1.40	1.40	1.40
Layer vitamin and trace mineral premix[3]	0.70	0.49	0.49	0.49	0.49
Layer choline premix[4]	0.70	0.49	0.49	0.49	0.49
Titanium dioxide[6]	0.75	0.53	0.53	0.53	0.53
Sunflower oil[5]	0.60	0.42	0.42	0.42	0.42
Salt	0.25	0.18	0.18	0.18	0.18
Moisture	9.70	9.49	7.95	9.17	7.72
Gross energy, Mcal/kg	3.562	3.820	3.971	3.835	3.999
Crude protein	15.12	22.22	21.47	22.39	21.53
Ash	14.77	12.65	13.00	11.68	12.40
Crude fiber	4.50	9.41	7.34	6.63	5.43
Crude fat	3.26	3.42	6.05	3.37	6.34
Titanium, ppm	4,250	3,060	3,220	3,140	3,030
Indispensable amino acids					
Arginine	0.74	1.22	1.10	1.30	1.17
Histidine	0.36	0.55	0.50	0.56	0.53
Isoleucine	0.62	0.86	0.82	0.88	0.84
Leucine	1.42	1.82	1.76	1.89	1.79
Lysine	0.75	1.18	1.04	1.15	1.05
Methionine	0.43	0.55	0.53	0.55	0.51
Methionine + cystine	0.77	1.04	0.98	1.03	0.96
Phenylalanine	0.79	1.02	1.01	1.05	1.01
Threonine	0.58	0.92	0.85	0.96	0.86
Tryptophan	0.18	0.25	0.26	0.24	0.25
Valine	0.83	1.15	1.08	1.15	1.10
Dispensable amino acids					
Alanine	0.93	1.17	1.12	1.21	1.12
Aspartic acid	1.26	1.74	1.61	1.84	1.64
Cysteine	0.33	0.49	0.45	0.47	0.45
Glutamic acid	2.23	3.46	3.51	3.54	3.53
Glycine	0.52	0.93	0.85	0.97	0.88
Proline	0.85	1.29	1.30	1.28	1.29
Serine	0.82	1.10	1.07	1.14	1.06
Tyrosine	0.52	0.68	0.66	0.71	0.68
Total amino acid	14.26	20.58	19.68	21.10	19.89

[1]MFI Foods Canada, Winnipeg, Manitoba, Canada.
[2]1:2 (w/w) blend of fine and coarse grit limestone, respectively.
[3]Hi-Pro Feeds LP; Edmonton, Alberta, Canada. Provided the following per kg of mixed basal diet: 80 mg/kg iron; 100 mg/kg zinc; 88 mg/kg manganese; 15 mg/kg copper; 1.65 mg/kg iodine; 0.3 mg/kg selenium; 12,500 IU/kg vitamin A; 3,125 IU/kg vitamin D3; 40 IU/kg vitamin E; 2.5 mg/kg vitamin K (menadione); 37.5 mg/kg niacin; 12.5 mg/kg pantothenic acid; 7.5 mg/kg riboflavin; 5 mg/kg pyridoxine; 2.55 mg/kg thiamin; 0.625 mg/kg folic acid; 0.15 mg/kg biotin; and, 0.01875 mg/kg vitamin B12.
[4]Hi-Pro Feeds LP; Edmonton, Alberta, Canada. Provided 400 mg/kg of choline per kg of mixed basal diet.
[5]Sunflower oil was included as a source of linoleic acid to meet the requirement while minimizing crude fat content of the diet.
[6]Brenntag Specialties; Leduc, Alberta, Canada.

(model 6400, Parr Instrument Company, IL; ISO Standard 9831:1998) using benzoic acid as standard at the Feeds Innovation Institute, University of Saskatchewan (Saskatoon, Saskatchewan, Canada). Titanium concentrations in diet, excreta and digesta samples from Exp. 2 were determined according to the procedure in Myers et al. (2004). Reactive lysine (method 975.44) content was determined in *Brassica* co-products at AESCL.

Calculations

In Exp. 1, feed disappearance was calculated for each experimental unit in each 4-wk phase of the experiment by dividing the amount of feed added, minus orts, divided by the number of bird-days.

Average egg mass production for each experimental unit in a given week was calculated as the average egg weight, multiplied by the number of eggs produced divided by the number of bird-days. Feed efficiency (egg mass: feed) was calculated for each experimental unit for each 4-wk phase by dividing egg mass production by feed disappearance.

Proportional weight of egg components was calculated by dividing the weight of the separated yolk, albumen and shell by the weight of the whole egg.

Haugh units for an individual egg were calculated as:

$$Haugh\ units\quad (HU) = 100 \times \log\left(h - 1.7w^{0.37} - 7.6\right)$$

Where h and w were the measured albumen height and intact egg weight (g), respectively.

In Exp. 2, apparent digestibility of gross energy and nutrients in digesta and excreta was calculated as:

$$Apparent\ Digestibility,\ \% = \left[1 - \left(\frac{\%\ marker_{test\ diet}}{\%\ marker_{digesta\ or\ excreta}} \times \frac{\%\ nutrient_{digesta\ or\ excreta}}{\%\ nutrient_{test\ diet}}\right)\right] \times 100$$

Where the % of nutrient and marker in test diets and digesta or excreta were expressed on dry matter basis. The apparent digestible nutrient content in the test ingredient was then calculated as:

$$D_{ingredient} = \frac{D_{diet} - P_{basal} \times D_{basal}}{P_{ingredient}}$$

where $D_{ingredient}$, D_{diet} and D_{basal} are the % digestibility of a nutrient in the test ingredient, test diet and basal diet, respectively; and P_{basal} and $P_{ingredient}$ are relative proportions of the total nutrient level in the test diet contributed by the basal diet and the test ingredient, respectively ($P_{basal} + P_{ingredient} = 1$).

Statistical Analyses

For Exp. 1, the effect of NM, NC, JM, and JC inclusion in diets fed to laying hens was compared to that of hens fed a control diet containing no *Brassica* co-products in a randomized complete block design with 6 replicate cages of 4 hens per treatment. This approach was favored over a factorial comparison of *Brassica* species and processing streams as both seed stock and processing plants were not the same. Each *Brassica* co-product was therefore treated as a distinct test article because one could not distinguish between variation due to seed source/quality and processing plant.

Test cage was the sampling unit for performance variables and nutrient digestibility, whereas individual layers were the sampling unit for body weight. Individual eggs and pooled liquid egg samples were the sampling units for egg quality/attributes and egg fatty acid concentrations.

For Exp. 2, energy and nutrient digestibility of NM, NC, JM, and JC were determined using the difference method feeding a basal diet in a randomized complete block design with 6 replicate test cages of 8 hens per test diet. Test cage also served as the sampling unit for this experiment.

Continuous variables were assessed for normality using the UNIVARIATE procedure. The TRANSREG procedure was then used to determine the optimal value of lambda (λ) to normalize (or approximate normality) nonconforming variable using a Box-Cox transformation:

$$X' = \frac{(X^{\lambda} - 1)}{\lambda}$$

Or,

$$X' = log\,(X)\ where \lambda = 0$$

Where X and X' are the native and transformed observations, respectively. When the TRANSREG procedure yielded an optimal λ of 1, data were assumed to be normally distributed and were therefore not transformed.

Continuous variables were then analyzed as general linear mixed models using the MIXED procedure of SAS (Version 9.3, 2011, SAS Institute Inc., Cary, NC). For Exp. 1, statistical models included the fixed effect of *Brassica* co-product (none, NM, NC, JM, and JC), whereas area block (location of test cage within battery) was included as a random term. For repeated measurements, data were analyzed both within sampling event (by day, week or phase) and for the overall experiment (across sampling events) to obtain the standard errors and treatment means for separation. For continuous variables, least-squares means derived from the MIXED procedure on untransformed data are reported. The significance levels (P-values) for model effects and least significant difference means separation tests were derived from the output of the MIXED procedure on transformed data (for variables where transformation was suggested by the outcome of the TRANSREG procedure).

Lay percentage and specific gravity from Exp. 1, which were treated as count and categorical data, respectively, were analyzed as generalized linear mixed models using the GLIMMIX procedure of SAS. Models for both variables included the fixed effect of canola co-product and included block as a random effect. A Poisson distribution and log link function were specified in the model for lay percentage, whereas a normal distribution and identity link function were specified in the model for specific gravity. As for other repeated measurements, lay percentage data were analyzed both within sampling event and for the overall experiment.

RESULTS

Nutrient content of solvent-extracted NM and JM meals and extruded-expelled NC and JC cakes is listed in Table 1. Cakes contained numerically lower moisture and CP compared with the respective meals whereas fat

Table 5. Effect of diet on lay percentage (eggs/100 hens housed/d) of hens in Experiment 1.[1]

		Brassica napus		*Brassica juncea*		Pooled	*P*-value
	Control	Meal	Cake	Meal	Cake	SEM	Diet
Weeks 1 to 4	97.03	96.28	96.13	97.32	97.62	2.01	0.981
Weeks 5 to 8	95.94	94.64	93.18	94.88	95.81	2.06	0.885
Weeks 9 to 12	96.87	98.22	97.02	98.17	98.42	2.04	0.972
Weeks 13 to 16	96.43	96.03	97.17	98.07	97.62	2.01	0.952
Weeks 17 to 20	97.22	95.14	96.58	96.78	97.92	2.01	0.902
Weeks 21 to 24	96.63	95.04	95.58	96.23	96.03	2.03	0.985
Weeks 25 to 28	94.41	94.67	94.88	95.88	97.37	2.02	0.833
Weeks 29 to 32	93.26	91.77	94.20	96.40	94.15	1.99	0.585
Weeks 33 to 36	92.66	92.56	93.20	94.99	92.91	2.01	0.906
Overall	95.59	94.92	95.32	96.52	96.42	0.67	0.368

[1]LSmeans based on 6 cages of 4 birds each per diet.

Table 6. Effect of diet on average daily feed disappearance (ADFI), egg-to-feed ratio (Egg: Feed), and body weight (BW) of hens in Experiment 1.[1]

		Brassica napus		*Brassica juncea*		Pooled	*P*-value
	Control	Meal	Cake	Meal	Cake	SEM	Diet
ADFI, g							
Weeks 1 to 4	94.3[b]	102.8[a]	102.5[a]	101.3[a]	103.4[a]	2.0	0.005
Weeks 5 to 8	100.1[b]	111.8[a]	108.3[a]	106.6[a]	109.1[a]	2.7	0.018
Weeks 9 to 12	110.5	109.5	111.2	108.1	114.2	3.4	0.786
Weeks 13 to 16	111.3	101.8	105.3	104.0	105.3	2.8	0.245
Weeks 17 to 20	111.8	103.9	106.9	103.2	108.2	3.5	0.348
Weeks 21 to 24	117.5	121.3	112.6	109.8	115.4	3.9	0.316
Weeks 25 to 28	109.8	118.0	109.7	107.9	116.8	3.8	0.164
Weeks 29 to 32	111.6	111.1	102.3	100.9	109.6	4.3	0.153
Weeks 33 to 36	117.8	121.7	111.2	111.5	114.5	3.4	0.176
Overall	109.4[a,b]	111.4[a]	107.8[b,c]	105.9[c]	110.8[a,b]	1.8	0.006
Egg:Feed, g:g							
Weeks 1 to 4	0.603[a]	0.560[b]	0.545[b]	0.565[b]	0.556[b]	0.012	0.023
Weeks 5 to 8	0.569[a]	0.520[b]	0.506[b]	0.525[b]	0.519[b]	0.014	0.044
Weeks 9 to 12	0.551	0.552	0.546	0.562	0.549	0.015	0.947
Weeks 13 to 16	0.555	0.589	0.580	0.586	0.584	0.012	0.243
Weeks 17 to 20	0.564	0.604	0.575	0.592	0.572	0.016	0.460
Weeks 21 to 24	0.545	0.523	0.524	0.559	0.529	0.016	0.463
Weeks 25 to 28	0.559	0.533	0.545	0.561	0.535	0.013	0.248
Weeks 29 to 32	0.550[b,c]	0.547[c]	0.592[a,b]	0.610[a]	0.556[b,c]	0.015	0.025
Weeks 33 to 36	0.525	0.515	0.525	0.544	0.500	0.017	0.450
Overall	0.558[a,b]	0.548[b,c]	0.549[b,c]	0.567[a]	0.544[c]	0.006	0.006
BW, g							
Week 0	1,852	1,940	1,898	1,897	1,912	33	0.246
Week 4	1,945	2,039	1,982	1,965	2,005	36	0.241
Week 8	2,011	2,095	2,032	2,016	2,051	41	0.397
Week 12	2,073	2,129	2,065	2,042	2,095	43	0.487
Week 16	2,151	2,172	2,097	2,094	2,140	46	0.511
Week 20	2,140	2,164	2,093	2,108	2,175	48	0.473
Week 24	2,177	2,179	2,102	2,111	2,163	45	0.473
Week 28	2,158	2,182	2,111	2,111	2,156	48	0.639
Week 32	2,164	2,159	2,092	2,097	2,158	43	0.560
Week 36	2,193	2,169	2,093	2,103	2,174	41	0.325

[1]LSmeans based on 6 cages of 4 birds each per diet.
[a–c]Means within a row lacking a common superscript differ ($P < 0.05$).

content was greater. Cakes and JM had similar fiber content but lower than NM. Cakes and JM also had lower AA content than NM.

Experiment 1

There was no effect of diet on rate of lay for the overall trial or any 4 wk period of Exp. 1 (Table 5). Hen BW was not affected by diet either (Table 6). Hens fed the control diet consumed less ($P < 0.05$) feed compared with hens fed *Brassica*-containing diets in the first 8 wk of the experiment, but not thereafter. There was an effect of diet ($P < 0.01$) on overall ADFI with the greatest difference being reduced feed consumption in hens fed JM compared with controls. Overall egg: feed efficiency was also affected by diet ($P < 0.01$). Layers

Table 7. Effect of diet on egg weight in Experiment 1.[1]

		Brassica napus		*Brassica juncea*		Pooled	*P*-value
	Control	Meal	Cake	Meal	Cake	SEM	Diet
Weeks 1 to 4	58.51	58.74	58.26	58.48	58.56	0.51	0.971
Weeks 5 to 8	61.60[a]	60.94[a,b]	59.78[b,c]	59.41[c]	59.59[c]	0.71	0.004
Weeks 9 to 12	62.56[b]	64.34[a]	62.44[b]	61.85[b]	62.13[b]	0.63	0.003
Weeks 13 to 16	63.99[a,b]	64.98[a]	62.82[b,c]	62.04[c]	62.90[b,c]	0.57	<0.001
Weeks 17 to 20	64.63[a,b]	65.75[a]	63.54[b,c]	62.95[c]	63.09[c]	0.63	<0.001
Weeks 21 to 24	65.95[a]	66.12[a]	63.85[b]	63.42[b]	63.48[b]	0.61	<0.001
Weeks 25 to 28	65.23[a,b]	66.09[a]	63.89[b,c]	63.04[c]	63.75[c]	0.59	<0.001
Weeks 29 to 32	65.36[a,b]	66.70[a]	64.38[b,c]	63.72[c]	64.24[b,c]	0.56	<0.001
Weeks 33 to 36	66.13[a]	66.53[a]	64.07[b]	63.50[b]	63.98[b]	0.60	<0.001
Overall	63.75[b]	64.46[a]	62.55[c]	62.05[c]	62.41[c]	0.41	<0.001

[1]LSmeans based on 6 cages of 4 birds each per diet.
[a–c]Means within a row lacking a common superscript differ ($P < 0.05$).

Table 8. Effect of diet on egg quality, component weights and yolk colorimeter measurements for Experiment 1.[1]

		Brassica napus		*Brassica juncea*		Pooled	*P*-value
	Control	Meal	Cake	Meal	Cake	SEM	Diet
Egg quality							
Albumen height, mm	9.6	9.2	9.1	9.0	9.0	0.3	0.559
Haugh units	95.93	94.17	93.95	93.49	94.63	1.29	0.751
Albumen pH	8.42	8.27	8.39	8.23	8.25	0.06	0.142
Yolk pH	6.53[a]	6.26[b]	6.31[b]	6.26[b]	6.26[b]	0.03	<0.001
Specific gravity	1.090	1.091	1.093	1.090	1.093	0.001	0.338
Egg component weights							
Intact egg weight, g	66.18	65.55	63.71	63.84	63.02	0.96	0.075
Albumen, g	39.98[a,b]	40.62[a]	38.35[b,c]	38.06[b,c]	37.49[c]	0.71	0.009
Albumen, % of egg	60.41	60.63	60.55	60.03	59.80	0.35	0.397
Shell, g	8.84	8.67	8.51	8.56	8.61	0.15	0.610
Shell, % of egg	13.37	13.33	13.43	13.51	13.66	0.23	0.851
Yolk, g	17.30	16.98	16.81	16.78	16.67	0.26	0.492
Yolk, % of egg	26.14	26.13	26.21	26.31	26.45	0.28	0.931
Yolk color[2]							
L*	58.63[a]	55.69[b]	55.68[b]	54.80[b]	55.01[b]	0.43	<0.001
a*	−4.86[a]	−6.05[b]	−6.20[b]	−6.01[b]	−6.06[b]	0.15	<0.001
b*	22.98[d]	28.47[b]	27.68[b,c]	30.87[a]	26.05[c]	0.72	<0.001

[1]LSmeans based on 6 cages of 4 birds each per diet.
[2]Yolk color measured using a model CR-400 Chroma Meter (Konica Minolta; Ramsey, NJ, USA). Yolk color is expressed using the CIELAB color space system, where L* is the lightness variable and a*, b* specify the color within a 2 dimensional coordinate system.
[a–c]Means within a row lacking a common superscript differ ($P < 0.05$).

fed JC were less efficient compared with controls. For the first 8 wk of the experiment, layers fed *Brassica*-containing diets were less efficient than controls ($P < 0.05$).

The effect of diet on egg weight is presented in Table 7. Overall, eggs from hens fed the NM diet were heavier than those from controls ($P < 0.01$). Feeding of NC, JM, or JC resulted in lighter eggs than those from layers fed the control diet ($P < 0.01$). The same pattern was seen for the effect of diet expressed as egg mass production (g of egg/hen/day; data not shown).

The effect of diet on egg quality, egg components and yolk color is summarized in Table 8. Yolk pH was reduced in eggs from layers fed *Brassica* diets compared with controls ($P < 0.01$). Layers fed NM had the greatest egg albumen weight whereas layers fed JC had the lowest ($P < 0.01$). Yolk color measurements in eggs from hens fed *Brassica* diets all differed from controls ($P < 0.01$) with the exception of hue. Other egg quality measurements and egg component weights were not affected by diet.

Egg fat and relative fatty acid content are presented in Table 9. Eggs from hens fed NC and JM contained less fat than eggs from controls ($P < 0.05$). Eggs from controls had greater ($P < 0.05$) proportions of both saturated and polyunsaturated fatty acids compared with eggs from layers fed *Brassica* diets. This difference was largely because of increased proportions of C14:0 and C18:2 (n6), respectively, in eggs from layers fed control diets. Eggs from layers fed *Brassica* diets contained a greater proportion ($P < 0.01$) of monounsaturated fatty acids compared with controls, especially C17:1 and C9c18:1. Eggs from hens fed diets including *B. juncea* had relatively greater proportions of C18:3

Table 9. Effect of diet on whole egg fat content and fatty acid profile for Experiment 1.[1]

		Brassica napus		*Brassica juncea*		Pooled	*P*-value
	Control	Meal	Cake	Meal	Cake	SEM	Diet
Fat, % of egg dry matter	35.77[a]	35.30[a,b]	34.59[b]	34.63[b]	35.72[a]	0.33	0.037
Fat, mg/g of liquid egg	88.18[a]	86.62[a]	83.11[b]	85.69[a,b]	87.66[a]	1.16	0.037
Fatty acids, % of total fat							
Total saturated	27.82[a]	27.37[a,b]	27.00[b]	27.09[b]	27.44[a,b]	0.19	0.040
C14:0	0.25[a]	0.22[b,c]	0.21[c]	0.23[b,c]	0.23[b]	0.01	0.002
C16:0	20.31	19.79	19.79	19.71	20.33	0.21	0.069
C18:0	6.89[a,b]	7.00[a]	6.64[b,c]	6.79[a–c]	6.53[c]	0.14	0.044
C15:0	0.06	0.06	0.06	0.06	0.06	0.00	0.529
C17:0	0.19	0.20	0.19	0.19	0.19	0.00	0.349
C20:0	0.01	0.00	0.00	0.00	0.00	0.00	0.428
C22:0	0.12	0.11	0.12	0.11	0.11	0.00	0.696
Total monounsaturated	52.19[b]	54.00[a]	53.94[a]	53.33[a]	53.91[a]	0.25	<0.001
C16:1	1.89	1.78	1.82	1.85	1.99	0.06	0.131
C17:1	0.19[c]	0.20[b,c]	0.21[a]	0.21[a,b]	0.21[a]	0.00	0.004
C9t_18:1	0.13[a,b]	0.13[a,b]	0.14[a]	0.12[b]	0.12[b]	0.00	0.029
C9c-18:1	49.49[b]	51.33[a]	51.21[a]	50.72[a,b]	51.04[a]	0.26	<0.001
C20:1 (n9)	0.37	0.39	0.39	0.37	0.39	0.01	0.320
C24:1 (n9)	0.15	0.17	0.17	0.16	0.16	0.01	0.202
Total polyunsaturated	17.82[a]	16.44[b]	16.87[b]	17.07[a,b]	16.70[b]	0.28	0.021
C18:2 (n6)	12.67[a]	11.42[c]	11.85[b,c]	12.29[a,b]	11.74[b,c]	0.23	0.008
C18:3 (n3)	1.40[a,b]	1.22[c]	1.28[b,c]	1.43[a]	1.44[a]	0.05	0.005
C20:4 (n6)	1.67[a,b]	1.74[a]	1.69[a]	1.68[a,b]	1.59[b]	0.03	0.043
C20:4 (n3)	0.11	0.06	0.06	0.07	0.02	0.03	0.374
C20:5 (n3)	0.02	0.01	0.00	0.01	0.00	0.01	0.206
C22:5 (n3)	0.18	0.19	0.19	0.17	0.17	0.01	0.420
C22:6 (n3)	1.77	1.81	1.80	1.73	1.74	0.04	0.509
Total n3	3.48	3.28	3.33	3.38	3.37	0.06	0.281
Total long-chain n3	2.08	2.07	2.05	1.95	1.93	0.04	0.052
Total n6	14.34[a]	13.16[b]	13.54[b]	13.69[a,b]	13.33[b]	0.23	0.014
n6:n3	4.13	4.02	4.07	4.06	3.96	0.06	0.287

[1]LSmeans based on 6 cages of 4 birds each per diet.
[a–c]Means within a row lacking a common superscript differ ($P < 0.05$).

(n3) compared with those of layers fed diets including *B. napus* ($P < 0.01$).

Experiment 2

The apparent total tract digestibility (**ATTD**) of dry matter and gross energy and the apparent ileal digestibility (**AID**) of crude protein and AA of layers fed test diets containing high levels of *Brassica* meals and cakes is summarized in Table 10. Feeding *Brassica* diets depressed ATTD of dry matter ($P < 0.01$), gross energy ($P < 0.01$) and AID of CP ($P < 0.01$) compared with controls. The AID of most essential AA, with the exception of tryptophan, was reduced feeding *Brassica* diets compared with controls ($P < 0.01$). The AID of tryptophan was increased feeding *Brassica* diets compared with controls ($P < 0.05$).

The calculated ATTD of DM and gross energy, AME value and AID of CP and AA in *B. napus* or *B. juncea* solvent-extracted meal or extruded-expelled cake fed to laying hens are presented in Table 11. *Brassica* cakes had greater ($P < 0.05$) ATTD of both DM and gross energy than NM, but NM had greater ($P < 0.05$) AID of arginine, histidine, lysine, methionine, and sulfur AA than NC. *Brassica* cakes averaged 32% greater AME values than meals.

DISCUSSION

To our knowledge, this is the first study to report on the effects of feeding high dietary inclusion (20%) of *Brassica* oilseed cakes vs. meal to brown-shelled egg laying hens with regards to lay performance and egg quality, as well as to describe their respective digestible nutrient content.

Until recent revisions (Canola Council of Canada, 2015), recommended maximum canola meal inclusion in commercial poultry diets was constrained to 10% (Newkirk, 2009). Previous recommendations were largely based on older studies feeding rapeseed meal causing liver damage (Butler et al., 1982) and a single more recent report (Knezacek et al., 2009) of numerical, but no significant increase in mortality among hens fed diets with high dietary inclusions (16.7%) of canola meal compared with controls. More aggressive constraints (3 to 5%) were advocated for diets fed to brown-shelled egg layers because of alleged concerns over “fishy taint” in eggs from hens fed canola meal, which was instead attributable to a recessive trait that resulted in the deposition of trimethylamine in eggs (Ward et al., 2009).

With regards to mortality, no birds participating in this 36-wk experiment were found dead whereas 2 were

Table 10. Apparent total tract retention (ATTR, %) of dry matter, gross energy, and apparent ileal digestibility (AID, %) of crude protein and amino acids (AA) for the basal and test diets containing 30% inclusion of *B. napus* or *B. juncea* extruded-expelled cake or solvent-extracted meal fed to laying hens in Experiment 2.[1]

		Brassica napus		*Brassica juncea*		Pooled	*P*-value
	Basal	Meal	Cake	Meal	Cake	SEM	Diet
ATTR, %							
Dry matter	68.88[a]	61.61[b]	64.87[b]	63.07[b]	64.87[b]	1.23	0.009
Gross energy	77.43[a]	68.30[b]	71.49[b]	70.37[b]	71.92[b]	1.58	0.005
AID, %							
Crude protein	80.55[a]	77.28[b]	75.65[b]	76.79[b]	76.91[b]	0.70	<0.001
Indispensable AA							
Arginine	87.52[a]	88.19[a]	85.90[b]	88.26[a]	88.63[a]	0.42	<0.001
Histidine	85.02[a]	83.90[a]	80.21[b]	84.26[a]	83.92[a]	0.61	<0.001
Isoleucine	86.02[a]	81.99[b]	80.16[c]	81.33[b,c]	81.09[b,c]	0.59	<0.001
Leucine	89.94[a]	86.00[b]	84.60[b]	85.19[b]	85.68[b]	0.61	<0.001
Lysine	84.13[a]	81.80[b]	79.96[c]	80.11[b,c]	81.47[b,c]	0.58	<0.001
Methionine	91.92[a]	90.73[a,b]	88.94[c]	89.80[b,c]	89.36[c]	0.44	<0.001
Methionine + Cysteine	87.69[a]	84.92[b]	82.70[c]	83.59[b,c]	83.37[b,c]	0.62	<0.001
Phenylalanine	89.46[a]	86.64[b]	86.01[b]	86.53[b]	87.14[b]	0.51	<0.001
Threonine	75.39[a]	73.89[a–c]	71.97[c]	74.17[a,b]	73.20[b,c]	0.79	0.031
Tryptophan	86.27[c]	89.57[a]	87.49[b,c]	88.74[a,b]	89.27[a,b]	0.67	0.013
Valine	86.31[a]	81.71[b]	80.55[b]	81.22[b]	81.63[b]	0.68	<0.001
Dispensable AA							
Alanine	87.63[a]	84.86[b]	83.25[c]	84.27[b,c]	84.04[b,c]	0.55	<0.001
Aspartic acid	81.48[a]	80.07[a,b]	76.96[c]	80.56[a]	78.82[b]	0.60	<0.001
Cysteine	82.21[a]	78.36[b]	75.31[c]	76.31[b,c]	76.65[b,c]	0.92	<0.001
Glutamic acid	88.48[a]	87.44[a,b]	85.38[c]	86.95[b]	86.72[b,c]	0.50	0.004
Glycine	76.85[a,b]	77.16[a]	73.63[c]	76.45[a,b]	75.11[b,c]	0.69	0.010
Proline	85.87[a]	79.12[b]	79.32[b]	78.94[b]	80.91[b]	0.80	<0.001
Serine	83.03[a]	79.99[b]	77.85[c]	80.15[b]	78.71[b,c]	0.67	<0.001
Tyrosine	86.42[a]	83.16[b,c]	81.67[c]	83.11[b,c]	83.52[b]	0.57	<0.001
Total amino acids	84.37[a]	81.49[b]	79.79[c]	80.97[b,c]	81.17[b,c]	0.58	<0.001

[1]LSmeans based on 6 replicate test cages of 8 hens per test diet.
[a–c]Means within a row lacking a common superscript letter differ ($P < 0.05$).

culled for physical injuries (data not shown). Also, while no detailed sensory evaluations were conducted on eggs, hundreds of eggs were broken out during this study and at no point did personnel working on this study note "fishy" odor emanating from eggs. The present observations indicate that high dietary inclusion of co-products from modern *Brassica* cultivars do not pose a heightened risk of morbidity or mortality. Our observations also confirm that suppliers of brown-shelled egg laying hen genetics have successfully eliminated the recessive trait responsible for "fishy taint" from modern strains.

Test Feedstuffs

As we expected, extruded-expelled cakes had greater fat content than corresponding solvent-extracted *B. napus* and *B. juncea* meals. Solvent (typically hexane) solubilizes most of the remaining lipids in cake resulting in a more efficient oil extraction processes. The remaining oil (~10%) in extruded-expelled cakes accounts for the dilution in protein and partially moisture content compared with meals. The remaining oil in cakes vs. meals is where the greatest relative nutritional value lies; 32% greater AME value. It allows cakes to be fed as energy source for poultry compared with meals without a major loss of protein content. Cost per Mcal AME from remaining oil in cake can be one-quarter to one-third of the cost of equivalent energy provided by adding liquid oil (Beltranena and Zijlstra, 2011). *Brassica juncea* cake and meal had lower fiber content than *B. napus* given that the hull constitutes a smaller proportion of the seed (Zhou et al., 2014), hence the greater ATTD of dry matter and gross energy. The difference in AA content between NM and NC, JM, and JC does not indicate that the latter were of lesser quality. It instead highlights that the NM sample fed was of unexpectedly greater AA quality. Indeed, that was reflected in NM having greater AID of lysine, methionine and sulfur AA than NC whereas JM and JC were intermediate.

Egg Production

Rate of lay and body weight were unaffected by dietary treatment whereas small differences were observed for overall feed disappearance (105.9 to 111.4 g/hen/d), egg mass: feed ratio (0.544 to 0.567) and average egg wt (62.05 to 64.46 g) among treatments. Our results are similar to those reported by Savary et al. (2017) where diets containing 20% *B. juncea* or *B. napus* solvent extracted meal did not affect feed consumption, egg production, feed efficiency

Table 11. Apparent total tract retention (ATTR, %) of dry matter, gross energy, apparent metabolizable energy (AME); and, apparent ileal digestibility (AID, %) of crude protein and amino acids in *B. napus* or *B. juncea* solvent-extracted meal or extruded-expelled cake fed to laying hens.

	Brassica napus		*Brassica juncea*		Pooled	*P*-value
	Meal	Cake	Meal	Cake	SEM	Ingredient
ATTR, %						
Dry matter	44.63[b]	55.90[a]	49.76[a,b]	56.03[a]	3.05	0.045
Gross energy	45.08[c]	55.55[a,b]	50.34[b]	56.31[a]	1.94	0.002
AME, Mcal/kg as fed	1.973[b]	2.730[a]	2.184[b]	2.763[a]	0.087	<0.001
AID, %						
Crude protein	74.16	70.15	73.01	72.83	1.37	0.268
Indispensable AA						
Arginine	88.73[a]	84.37[b]	88.80[a]	89.63[a]	0.65	<0.001
Histidine	82.92[a]	75.28[b]	83.56[a]	82.79[a]	1.20	<0.001
Isoleucine	78.09	74.20	76.78	75.19	1.21	0.144
Leucine	80.94	76.91	78.97	79.43	1.48	0.314
Lysine	79.76[a]	75.35[b]	76.18[b]	78.39[a,b]	1.13	0.046
Methionine	89.04[a]	83.71[b]	86.46[a,b]	84.92[b]	1.08	0.014
Methionine + Cysteine	81.79[a]	75.74[b]	78.22[a,b]	76.99[b]	1.43	0.040
Phenylalanine	83.05	81.34	82.66	83.95	1.13	0.449
Threonine	72.50	68.01	72.99	70.93	1.56	0.136
Tryptophan	91.87	88.81	91.37	92.02	1.28	0.281
Valine	77.13	74.61	76.05	75.99	1.38	0.646
Dispensable AA						
Alanine	81.02	76.41	79.57	78.51	1.35	0.136
Aspartic acid	78.41[a,b]	70.44[c]	79.53a	75.25[b]	1.33	<0.001
Cysteine	74.99	67.93	70.05	69.77	1.95	0.098
Glutamic acid	86.54[a]	82.55[b]	85.50[a]	85.11[a,b]	0.91	0.035
Glycine	77.37[a]	71.08[b]	76.16[a]	73.76[a,b]	1.26	0.011
Proline	73.00	73.45	74.03	75.89	1.26	0.384
Serine	75.72[a]	69.40[b]	76.03[a]	72.67[a,b]	1.65	0.034
Tyrosine	79.22	75.13	79.01	79.69	1.26	0.067
Total amino acids	78.59	74.58	77.36	77.51	1.16	0.124

[1]LSmeans based on 6 replicate test cages of 8 hens per test diet.
[a–c]Means within a row lacking a common superscript letter differ ($P < 0.05$).

or mortality compared with diets where soybean meal was the primary supplemental protein source.

We anticipated that hens might consume less of the diets containing *B. juncea* co-products owing to the presence of gluconapin, a bitter tasting glucosinolate which constitutes >80% of total glucosinolates in *B. juncea* (Zhou et al., 2014). Instead, feed disappearance observed for hens fed JC was the same as the control, whereas those fed JM consumed approximately 3.5 g/d less. Our data therefore do not support the hypothesis that glucosinolates in *B. juncea* adversely affect feed consumption of laying hens.

Egg Quality

There was a ∼2 g reduction in egg weight observed when diets including *Brassica* cakes and JM were fed to hens. However, eggs from all treatments exceeded 60 g and largely fell into the same weight class. Egg producers in the US and Canada are generally paid the same farm gate price per dozen eggs within a weight class range, therefore the revenue per hen would be similar feeding soybean meal or *Brassica* coproduct diets. Given this context, the differences in egg weight among treatments was likely of greater statistical rather than practical relevance.

With the exception of yolk pH and color, egg quality parameters were not affected by dietary inclusion of 20% *Brassica* cakes or meals in diets fed to egg layers. The mechanism underlying and the functional significance of the slight increase in egg yolk acidity (∼0.25) from hens fed *Brassica* diets is unclear. It is conceivable, however, that shelf life of eggs could be positively affected through pH-mediated reduction in lipid peroxidation (Kim et al., 2016). The ∼2 g reduction in albumen weight matches the ∼2 g reduction in egg weight feeding diets including JM, JC, NC compared with NM. This reduction in whole egg and albumen weight may correspond to the unexpected superior AA composition of the NM fed in the current study and (or) its greater AID of lysine, methionine and sulfur AA vs. NC.

Darkening of egg yolk and chicken skin has been reported previously (Fenwick and Curtis, 1980) and therefore was expected feeding *Brassica* co-products. Darker egg yolk and broiler skin is preferred in countries such as Mexico where pigments are intentionally added to feed to achieve that result (Grčević et al., 2018). Feeding *Brassica* cake and meal could spare the additional cost associated with including pigments in poultry diets for this purpose (Ponsano et al., 2004). Yolk color differences were identified by objective measurements in the current study; however, it is unclear whether the changes observed would necessarily be apparent to retail consumers until breaking eggs for cooking.

Egg Fatty Acids

The remaining oil in *Brassica* cakes, in particular JC, could have resulted in a divergent fatty acid profile in eggs, owing to reported differences in fatty acid profiles between *B. juncea* and *B. napus* (Sharafi et al., 2015). There is evidence in the literature demonstrating the relationship between dietary fatty acid profiles in feed and table eggs (Gakhar et al., 2012; Shi et al., 2012; Aziza et al., 2013). Relative to the striking differences reported by Sharafi et al. (2015), there was comparatively little difference in relative proportions (% of total fatty acids) of C18:2 (20.51 vs. 16.17) and of C18:3 (9.45 vs. 9.01) between the NC and JC fed in the present experiment. The result showed generally few differences in fatty acid composition among eggs yielded by the dietary treatments compared in the present experiment. The differences in fatty acid profiles in eggs that were observed, however, did not appear to correspond well to the respective intakes of the same calculated for each dietary treatment (data not shown). In the present experiment, diets were formulated in such a way to attain a similar crude fat content across dietary treatments, which was achieved through feeding canola oil as the source of supplemental fat. This oil inclusion, in addition to the aforementioned lack of major differences in fatty acid profiles between JC and NC fed in this experiment, are likely responsible for the lack of substantive differences in egg fatty acid profiles. Our results therefore are in keeping with line with the body of literature describing a direct relationship between fatty acids in hen diets and the resultant eggs. Feeding of expeller-pressed *B. juncea* cake to pigs has also been shown to alter pork fatty acid profiles (Zhou et al., 2014). It should be emphasized that the egg n6: n3 fatty acid ratio of 0.25 was achieved with the feeding of all the experimental diets. This ratio matches current nutritional recommendations for humans which consider a 4:1 n6: n3 fatty acid ratio as ideal (Gómez-Candela et al., 2011).

Nutrient Digestibility

The observed pattern of ATTD digestibility of DM and GE between the *Brassica* cakes and meals was anticipated given the difference in remaining oil content. This finding is indicative of the important role of remaining oil in contributing to the dietary energy value of these co-products for poultry, irrespective of *Brassica* species fed. With regards to the comparison between solvent-extracted meals, we anticipated that the lower ADF and NDF in JM compared with NM might result in differences in ATTD of DM, GE, and AME between test ingredients. Instead, only trends towards greater ATTD of GE ($P = 0.065$) and AME ($P = 0.107$) for JM compared with NM were observed. Radfar et al. (2017) reported AMEn values using a cecaectomized rooster model of a similar magnitude and ranking for JM and NM (2055 vs. 1870 kcal/kg, respectively). In contrast to our study, however, the difference between the 2 *Brassica* species was highly significant. Jayaraman et al. (2016) in contrast, reported no difference in ATTD of GE or AME between JM and NM measured in 21-day-old broilers, though the magnitude of the AMEn values reported were at least 500 kcal/kg greater than those observed in the present experiment. Of these 2 previous reports, Radfar et al. (2017) is likely the most relevant comparison as the source of the JM and NM used in their study was similar to that fed in ours.

Few significant differences in AID for AA were observed among the *Brassica* co-products. Generally, AA digestibility coefficients were greatest for NM and lowest for NC, with comparatively little difference between JM and JC. Solvent-extracted canola meal is generally produced from high quality, food-grade seed, whereas lower quality (i.e., some green seed, frost damaged, or heated) seed is generally directed into alternative product streams, including bio-industrial or animal feed applications. In Western Canada, there has been a recent trend toward an increase in farm-level pressing activity so as to add value to lower quality seed. The variability in nutritional quality of the resultant cake therefore is likely to reflect the variability in the seed and pressing. The absence of tangible differences in AID of AA between JC and JM is perhaps the result of less variation due to the regional concentration of *B. juncea* production. Whereas *B. napus* is grown extensively throughout most of the Canadian Prairie Provinces and Western Ontario, most Canadian *B. juncea* is grown in the Southeastern region of the province of Saskatchewan where dryer agronomic conditions growing on Brown and Light Brown soils prevail (Oram et al., 2005; Government of Saskatchewan, 2017). Differences notwithstanding, the current study demonstrates a moderately high AA digestibility in all four co-products for laying hens. Further work with these co-products should be targeted to identifying seed quality factors that affect nutrient digestibility in the resultant cakes or meals.

Conclusions

The present study demonstrated that *Brassica* cakes and meals can be fed to laying hens at dietary inclusions up to 20% without adverse effects on hen productivity or egg quality. It was further demonstrated that while the AID of AA in all co-products was moderately high (>70%), further investigation is required to relate pre-press quality indicators in the seed to nutrient digestibility of the post-press co-products that result.

ACKNOWLEDGEMENTS

The authors would like to thank Breanne Chmilar, Dharma Shrestha and the staff of the Poultry Research

Centre, University of Alberta for animal care and technical assistance. We gratefully recognize the donation of feed enzymes by Canadian Bio-Systems Inc. (Calgary, Alberta, Canada). We acknowledge the financial support from Agriculture and Agri-Food Canada (Ottawa, Ontario, Canada) through the Canola Science Cluster and the Canola Council of Canada (Winnipeg, Manitoba, Canada).

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