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Effects of feeding high protein or conventional canola meal on dry cured and conventionally cured bacon

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ABSTRACT

Objectives were to compare belly, bacon processing, bacon slice, and sensory characteristics from pigs fed high protein canola meal (CM-HP) or conventional canola meal (CM-CV). Soybean meal was replaced with 0 (control), 33, 66, or 100% of both types of canola meal. Left side bellies from 70 carcasses were randomly assigned to conventional or dry cure treatment and matching right side bellies were assigned the opposite treatment. Secondary objectives were to test the existence of bilateral symmetry on fresh belly characteristics and fatty acid profiles of right and left side bellies originating from the same carcass. Bellies from pigs fed CM-HP were slightly lighter and thinner than bellies from pigs fed CM-CV, yet bacon processing, bacon slice, and sensory characteristics were unaffected by dietary treatment and did not differ from the control. Furthermore, testing the existence of bilateral symmetry on fresh belly characteristics revealed that bellies originating from the right side of the carcasses were slightly ($P \leq 0.05$) wider, thicker, heavier and firmer than bellies from the left side of the carcass.

1. Introduction

Canola meal is an alternative to soybean meal (SBM) as a protein supplement for pigs (Baidoo, Aherne, Mitaru, & Blair, 1987; Bell, 1975; Maison, 2013). Conventional canola meal (CM-CV) has less crude protein (35–40%) than SBM (48.5%) and about 3 times as much fiber, limiting the availability of essential amino acids and lowering the digestible energy in pig diets (Thacker, 1992). A new hybridized variety of high protein canola meal (CM-HP) contains less fiber and is thought to have a greater concentration of digestible energy than CM-CV. Antinutritional factors including sinapine, tannins, and phytic acid can affect feed intake, digestibility of protein, and absorption of minerals, respectively, in pigs fed canola meal (Bell, 1993). Sinapine acts as a substrate for trimethylamine production, which caused a "fishy" taint in eggs produced by laying hens fed canola meal (Griffiths, Fenwick, Pearson, Greenwood, & Butler, 1980; Mawson, Heaney, Zdunczyk, & Kozlowska, 1994; Pearson, Butler, & Fenwick, 1980). Previous research reported no effects on sensory characteristics of fresh pork loins from pigs fed CM-CV (Dransfield, Nute, Mottram, Rowan, & Lawrence, 1985). Results of studies feeding pigs other ingredients high in polyunsaturated fatty acids (PUFA) indicated that pigs fed diets with high concentrations of PUFA had soft bellies, which present challenges in bacon processing (Leick et al., 2010; Person et al., 2005). To our knowledge, no research has been reported on the effects of canola meal on processed pork quality characteristics, particularly fresh belly quality, bacon processing, and bacon sensory characteristics. Therefore, primary objectives were to compare fresh belly, bacon processing, bacon slice, and bacon sensory characteristics from pigs fed high protein canola meal (CM-HP) or conventional canola meal (CM-CV).

Bilateral symmetry describes the assumption that data collected on one side of the carcass is equally representative of the other side of the carcass (Breidenstein, Kauffman, Laplant, & Norton, 1964). Breidenstein et al. (1964) reported the difference between left and right sides of a carcass was approximately 8%, and these differences were attributed to experimental error. Historically, bellies originating from the same carcass were assumed to be symmetrical in composition (Schroder & Rust, 1974). New techniques are currently being used to analyze fresh belly quality (Seman, Barron, & Matzinger, 2013); less is known about bilateral symmetry when using these techniques. Therefore, secondary objectives were to test the existence of bilateral symmetry (effect of carcass side) on fresh belly characteristics and fatty acid profiles of right and left side bellies originating from the same carcass.

2. Materials and methods

Experimental procedures for the live phase portion of the experiment were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois.

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2.1. Experimental design

One hundred forty bellies from 70 pork carcasses were obtained from the University of Illinois Meat Science Laboratory and sourced from a previous experiment (Little et al., 2014). A complete description of slaughter and fabrication procedures was provided in greater detail by Little et al. (2014). Briefly, a 3-phase feeding program (Tables 1, 2, and 3) was used with grower diets fed from d 0 to d 35, early finisher diets from d 35 to d 63, and late finisher diets from d 63 to d 91 of the growing-finishing period. There were 7 treatments within each phase consisting of a corn-SBM diet with no canola meal (control), 3 diets containing different levels of CM-HP (*Brassica napus* containing 45% CP), and 3 diets containing different levels of CM-CV (40% CP). Canola meal replaced 33, 66, or 100% of SBM with both sources of CM. All diets were formulated to meet current estimates for nutrient requirements for growing and finishing pigs (NRC, 2012).

Full details of diet composition were described in Little et al. (2014). There was greater crude protein in control diets (17.11%) compared with 33% CM-HP (15.15%), 66% CM-HP (15.72%), 100% CM-HP (16.13%), 33% CM-CV (15.74%), 66% CM-CV (15.65%), and 100% CM-CV

Table 1
Ingredient composition of experimental diets, phase 1 (d 0–35), as-fed basis.

Item	Diet						
	Control[a]	CM-HP[a]			CM-CV[a]		
	0%	33%	66%	100%	33%	66%	100%
Ingredients, %							
Corn	68.33	67.93	67.48	66.96	66.08	63.72	61.33
Canola meal, high protein	–	9.57	19.15	28.72	–	–	–
Canola meal, conventional	–	–	–	–	11.68	23.35	35.00
Soybean meal, 48% CP	27.00	18.00	9.00	–	18.00	9.00	–
Phytase premix[b]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.21	1.30	1.38	1.30	1.13	0.92	0.60
Dicalcium phosphate	0.52	0.25	–	–	0.15	–	–
L-Lysine HCl	0.18	0.21	0.25	0.28	0.23	0.28	0.34
DL-Methionine	0.02	–	–	–	–	–	–
L-Threonine	0.02	0.02	0.02	0.02	0.01	0.01	0.01
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin–mineral premix[c]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed composition,							
DM	88.98	88.78	89.33	88.52	87.66	89.64	89.34
CP	19.10	20.57	18.59	18.68	19.74	20.16	19.75
ADF	4.44	4.70	6.38	7.24	5.25	7.01	8.27
NDF	8.72	9.14	10.50	12.53	10.45	12.27	13.12
Ca	0.76	0.70	0.74	0.95	0.60	0.40	0.68
P	0.43	0.44	0.44	0.45	0.41	0.43	0.52
Indispensable AA							
Arg	1.17	1.13	1.00	0.95	1.15	1.12	1.03
His	0.49	0.49	0.45	0.45	0.49	0.51	0.49
Ile	0.80	0.77	0.70	0.66	0.78	0.78	0.71
Leu	1.74	1.64	1.53	1.50	1.63	1.67	1.55
Lys	1.06	1.08	0.95	0.98	1.12	1.05	1.08
Met	0.30	0.32	0.31	0.33	0.32	0.33	0.35
Phe	0.93	0.87	0.77	0.73	0.87	0.86	0.76
Thr	0.72	0.73	0.67	0.68	0.71	0.75	0.73
Trp	0.22	0.23	0.22	0.21	0.21	0.23	0.23
Val	0.89	0.90	0.85	0.86	0.91	0.95	0.92
Total	8.32	8.16	7.45	7.35	8.19	8.25	7.85
Dispensable AA							
Ala	1.00	0.96	0.91	0.91	0.96	1.00	0.95
Asp	1.81	1.63	1.34	1.15	1.64	1.49	1.24
Cys	0.29	0.33	0.36	0.39	0.32	0.38	0.43
Glu	3.42	3.38	3.08	3.05	3.33	3.41	3.26
Gly	0.77	0.80	0.76	0.79	0.80	0.86	0.86
Pro	1.16	1.18	1.15	1.22	1.15	1.25	1.27
Ser	0.83	0.78	0.70	0.66	0.78	0.77	0.71
Tyr	0.59	0.53	0.49	0.47	0.57	0.53	0.50
Total	9.87	9.59	8.79	8.64	9.55	9.69	9.22
All AA	18.19	17.75	16.24	15.99	17.74	17.94	17.07
Calculated composition							
NE, kcal/kg	2496	2471	2444	2414	2425	2350	2274
Glucosinolates, μmol/g	–	0.98	1.95	2.93	2.23	4.46	6.69

[a] Percentage of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) as a replacement for soybean meal.
[b] Optiphos 2000; Enzyvia, Sheridan, IN.
[c] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 2
Ingredient composition of experimental diets, phase 2 (d 35 to 63), as-fed basis.

Item	Diet						
	Control[a]	CM-HP[a]			CM-CV[a]		
	0%	33%	66%	100%	33%	66%	100%
Ingredients, %							
Corn	74.50	74.16	73.83	73.43	72.73	70.91	69.05
Canola meal, high protein	–	7.45	14.89	22.34	–	–	–
Canola meal, conventional	–	–	–	–	9.08	18.16	27.24
Soybean meal, 48% CP	21.00	14.00	7.00	–	14.00	7.00	–
Phytase premix [b]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.15	1.23	1.28	1.20	1.10	0.90	0.65
Dicalcium phosphate	0.40	0.18	–	–	0.10	–	–
L-Lysine HCl	0.20	0.23	0.25	0.28	0.24	0.28	0.32
L-Threonine	0.03	0.03	0.03	0.03	0.03	0.03	0.02
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin–mineral premix[c]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed composition, %							
DM	88.16	88.42	88.61	88.36	88.65	88.52	88.29
CP	15.55	15.78	15.26	17.36	16.57	16.80	15.98
ADF	3.59	4.38	4.69	5.41	5.06	6.17	7.28
NDF	9.03	10.21	9.84	10.47	11.23	12.23	12.60
Ca	0.62	0.76	0.70	0.86	0.70	0.55	0.39
P	0.39	0.43	0.42	0.43	0.38	0.39	0.42
Indispensable AA							
Arg	0.93	0.93	0.89	0.88	0.90	0.88	0.88
His	0.39	0.41	0.41	0.42	0.39	0.40	0.41
Ile	0.63	0.65	0.62	0.59	0.57	0.62	0.61
Leu	1.40	1.49	1.42	1.40	1.30	1.40	1.37
Lys	0.83	0.97	0.92	0.88	0.96	0.89	0.97
Met	0.25	0.26	0.30	0.31	0.25	0.31	0.32
Phe	0.73	0.74	0.70	0.66	0.66	0.69	0.66
Thr	0.57	0.62	0.60	0.63	0.58	0.61	0.64
Trp	0.20	0.18	0.20	0.19	0.18	0.19	0.19
Val	0.72	0.76	0.76	0.77	0.70	0.76	0.78
Total	6.65	7.01	6.82	6.73	6.49	6.75	6.83
Dispensable AA							
Ala	0.83	0.88	0.84	0.86	0.81	0.84	0.85
Asp	1.42	1.32	1.18	1.04	1.20	1.16	1.06
Cys	0.24	0.28	0.34	0.38	0.26	0.34	0.36
Glu	2.70	2.91	2.85	2.88	2.54	2.73	2.80
Gly	0.63	0.68	0.68	0.71	0.65	0.68	0.73
Pro	0.97	1.07	1.09	1.13	0.97	1.05	1.10
Ser	0.67	0.68	0.63	0.62	0.63	0.62	0.62
Tyr	0.50	0.49	0.46	0.44	0.44	0.46	0.44
Total	7.96	8.31	8.07	8.06	7.50	7.88	7.96
All AA	14.61	15.32	14.89	14.79	13.99	14.63	14.79
Calculated composition nutrcomposition							
NE, kcal/kg	2536	2515	2495	2472	2480	2422	2363
Glucosinolates, μmol/g	–	0.76	1.52	2.28	1.73	3.47	5.20

[a] Percentage of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) as a replacement for soybean meal.
[b] Optiphos 2000; Enzyvia, Sheridan, IN.
[c] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

(15.74%) diets in the third phase. There was greater net energy in control diets (2562 kcal/kg) compared with 33% CM-HP (2544 kcal/kg), 66% CM-HP (2525 kcal/kg), 100% CM-HP (2506 kcal/kg), 33% CM-CV (2513 kcal/kg), 66% CM-CV (2463 kcal/kg), and 100% CM-CV (2412 kcal/kg) diets in the third phase. Lysine levels were the following: control (0.83%), 33% CM-HP (0.82%), 66% CM-HP (0.92%), 100% CM-HP (0.74%), 33% CM-CV (0.87%), 66% CM-CV (0.77%), and 100% CM-CV (0.97%) diets in the third phase.

Each dietary treatment was replicated 10 times (10 single sex pens per treatment) for a total of 70 pens (fed in 2 blocks with 35 pens per block based on farrowing date) with 4 gilts or barrows per pen. One pig from each pen was randomly selected at the conclusion of the feeding period to determine carcass measurements outlined in Little et al. (2014) as well as, fresh belly, bacon processing, bacon slice, and bacon sensory characteristics. Bellies from selected pigs (1 pig per pen; 35 pigs per block) were processed in two blocks separated by a two week time period which were based on farrowing date.

2.2. Fresh belly characteristics

Left and right sides of each carcass were fabricated to comply with Institutional Meat Purchase Specifications (IMPS) as described by the

Table 3
Ingredient composition of experimental diets, phase 3 (d 63 to 91), as-fed basis.

Item	Diet						
	Control[a]	CM-HP[a]			CM-CV[a]		
	0%	33%	66%	100%	33%	66%	100%
Ingredients, %							
Corn	77.82	77.51	77.19	76.84	76.27	74.67	73.07
Canola meal, high protein	–	6.38	12.77	19.15	–	–	–
Canola meal, conventional	–	–	–	–	7.78	15.57	23.35
Soybean meal, 48% CP	18.00	12.00	6.00	–	12.00	6.00	–
Phytase premix[b]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.07	1.15	1.12	1.07	1.04	0.82	0.60
Dicalcium phosphate	0.24	0.06	–	–	–	–	–
L-Lysine HCl	0.14	0.17	0.19	0.21	0.18	0.21	0.25
L-Threonine	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin–mineral premix[c]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed composition, %							
DM, %	90.25	90.11	90.35	90.12	90.07	90.09	90.07
CP, %	17.11	15.15	15.72	16.13	15.74	15.65	15.74
ADF, %	3.47	3.94	4.82	5.13	5.03	5.59	6.47
NDF, %	9.09	9.25	9.33	10.91	10.33	11.22	12.82
Ca, %	0.53	0.55	0.57	0.68	0.45	0.44	0.42
P, %	0.35	0.35	0.37	0.40	0.33	0.35	0.41
Indispensable AA							
Arg	0.89	0.86	0.92	0.78	0.96	0.82	0.87
His	0.39	0.39	0.43	0.38	0.42	0.39	0.42
Ile	0.63	0.59	0.63	0.54	0.67	0.58	0.60
Leu	1.47	1.38	1.46	1.34	1.52	1.38	1.41
Lys	0.83	0.82	0.92	0.74	0.87	0.77	0.97
Met	0.26	0.24	0.28	0.27	0.29	0.29	0.30
Phe	0.74	0.69	0.72	0.62	0.77	0.66	0.67
Thr	0.55	0.55	0.61	0.54	0.62	0.56	0.64
Trp	0.17	0.19	0.20	0.18	0.19	0.19	0.19
Val	0.71	0.71	0.78	0.70	0.78	0.71	0.78
Total	6.64	6.42	6.95	6.09	7.09	6.35	6.85
Dispensable AA							
Ala	0.83	0.82	0.88	0.80	0.89	0.82	0.87
Asp	1.35	1.21	1.33	0.93	1.39	1.09	1.05
Cys	0.26	0.26	0.33	0.33	0.30	0.33	0.36
Glu	2.72	2.65	2.92	2.56	2.91	2.62	2.79
Gly	0.58	0.62	0.70	0.61	0.68	0.63	0.72
Pro	1.00	1.01	1.12	1.06	1.08	1.05	1.14
Ser	0.65	0.63	0.67	0.56	0.70	0.61	0.63
Tyr	0.50	0.46	0.46	0.42	0.51	0.44	0.45
Total	7.89	7.66	8.31	7.27	8.46	7.59	8.01
All AA	14.53	14.08	15.26	13.36	15.55	13.94	14.86
Calculated composition							
NE, kcal/kg	2562	2544	2525	2506	2513	2463	2412
Glucosinolates, μmol/g	–	0.65	1.30	1.95	1.49	2.97	4.46

[a] Percentage of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) as a replacement for soybean meal.
[b] Optiphos 2000; Enzyvia, Sheridan, IN.
[c] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfa

North American Meat Processors Association (2010). Whole bellies had the spareribs and teat line removed, and flank end squared to meet the specifications of an IMPS #408 belly. Fresh skin-on bellies were allowed to equilibrate to approximately 2 °C for at least 24 h after fabrication. Bellies were laid flat and covered with butcher's paper to minimize evaporative loss during equilibration. Bellies were evaluated at the middle of the belly for length and width. Belly flop distances were collected by draping the middle of the belly vertically, skin side down, over a 2.54 cm wide stationary bar and measuring the distance between the two skin edges (Thiel-Cooper, Parrish, Sparks, Wiegand, & Ewan, 2001). A wider flop distance was indicative of a more firm belly, and a narrower flop distance was indicative of a less firm belly. Belly thickness was measured at 8 different locations by pushing a sharpened ruler through a belly laid skin-side down in a similar manner described by Stites et al. (1991). Measurements 1 through 4 were collected along the dorsal edge of the belly starting at the anterior end and working towards the posterior end. Measurements 5 through 8 were collected along the ventral edge of the belly starting at the anterior end and working towards the posterior end. Average belly thickness was calculated from the mean of the eight measurements. Belly fat firmness was evaluated on the fat side of the belly along the dorsal edge of the anterior end of each belly using a Check Line durometer (Electromatic

Equipment Co., Inc. Cedarhurts, NY) where a greater number was indicative of firmer fat. A fat tissue sample containing all three fat layers was collected from the dorsal edge of the anterior end of each belly and used to determine fatty acid profiles. Fresh belly characteristics were collected independently on both bellies of each carcass to determine bilateral symmetry between carcass sides and then averaged together to determine dietary effects.

2.3. Fatty acid profile determination

Fatty acid profile determination was conducted using a similar procedure to Tavárez et al. (2012). Samples were frozen in liquid nitrogen before being pulverized in a blender (Warin Products, Torrington, CT). The resulting powder was collected and used to obtain fatty acid methyl esters (FAME) according to methods described byAOCS (1997). Fatty acid methyl esters were analyzed using a gas chromatograph (Hewlett Packard 5890 series II) equipped with an auto-sampler and a DB-was capillary column (30 m × 0.25 mm × 0. 25 μm film coating, Agilent Technologies, Santa Clara, CA). The equipment was operated under a constant pressure at 1.30 kg/cm^2 using helium as the carrier gas and a 99:1 split ratio. Temperatures of the injector and flame-ionization detector were held constant at 250 °C and 260 °C, respectively. The oven was operated at 170 °C for 2 min (programmed temperature to increase 4 °C/min up to 240 °C and then held constant for 12.5 min). Chromatographs from FAME were integrated using Agilent Chemstation software for gas chromatograph systems (Version B.01.02, Agilent® Technologies, Inc.). Peaks were identified using a gas chromatograph reference standard (GLC 68 from Nu-check-prep, Elysian, Mn). Fatty acids were normalized so that the area of each peak was represented as a percentage of the total area. Iodine values (IV) were calculated using two different equations. The first equation was: IV = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723) (AOCS, 1998). This is the most used equation, however, it does not account for the long chain PUFA that are present in CM. Therefore, the second equation was: IV = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.795) + C20:2 (1.57) + C20:3 (2.38) + C20:4 (3.19) + C20:5 (4.01) + C22:4 (2.93) + C22:6 (4.64); Meadus et al., 2010). Fatty acid profile were collected independently on both bellies of each carcass to determine bilateral symmetry between carcass sides and then averaged together to determine dietary effects.

2.4. Cured belly manufacturing

Fresh bellies were skinned using a hand-held skinner (S-1011 Best and Donovan; Cincinnati, OH) and weighed to determine green weight. Bellies from the left side of the carcasses were randomly assigned to a conventional or a dry cure manufacturing process, and the matching right side was allotted to the opposite treatment. Bellies assigned to conventional curing were injected with a multi-needle injector (Schroder Injector/Marinator, Model N50; Wolf-Tec, Inc, Kingston, NY) with a cure solution to a target of 110% of original green weight, and were immediately weighed again to determine pump uptake. Cure solution was formulated to include 1.5% salt, 0.34% phosphate, 0.05% sodium erythorbate, 0.11% sugar, and 0.014% sodium nitrate in the finished product. Pump uptake was calculated using the following equation previously used by Boler et al. (2011): Pump uptake $= \frac{\text{Pumped weight}-\text{Green weight}}{\text{Green Weight}} \times 100$. Conventional cured bellies were allowed to equilibrate at 4 °C for 24 h following injection to allow for complete distribution of the cure solution. Conventional cured bellies were weighed to determine equilibrium belly weight, combed from the flank end, and cooked in a smokehouse (Alkar, Lodi, WI) to an internal end temperature of 52.2 °C. Conventional cured bellies were placed in a cooler for 24 h and allowed to cool to 2 °C. Bellies assigned to the dry curing treatment were placed in coolers, covered with ice packs, and transported to a USDA inspected bacon processing facility. Bellies were dry cured for 2 weeks (targeted 2.54 cm of sodium migration per week). Dry cured bellies were processed using proprietary techniques, packaged, and transported back to the University of Illinois Meat Science Laboratory for slicing and further evaluation.

2.5. Bacon slicing

Bellies were weighed just prior to slicing to determine cooked weight. Cooked yield was calculated from the following equation previously used by Boler et al. (2011): Cooked yield $= \frac{\text{Cooked weight}}{\text{Green weight}} \times 100$. Bellies were individually placed in the slicer (TREIF USA Inc., Shelton, CT) and sliced to an approximate slice thickness of 24 slices per kg. Bacon was removed to maintain anatomical orientation. Ends and incomplete pieces were sorted by trained University of Illinois personnel and sliced weight of each belly was recorded. Bellies were divided into 3 approximately equal zones. Zones were designated as blade end, middle, and flank end. Two slices were collected from the middle of each zone, packaged in Whirl-Pac bags, and stored at −4 °C for determination of proximate composition (moisture and extractible lipid percentage). One complete slice was collected from the middle of each of the 3 zones for image analysis. Slices were laid flat on a 30.48 cm x 40.64 cm piece of white parchment paper with appropriate identification, cure treatment, and anatomical location of each slice (blade, middle, or flank). The three slices were vacuum packaged as a set, frozen, and stored for image analysis. Six slices were collected from the middle zone and used for sensory analysis.

2.6. Bacon proximate composition

Proximate composition was determined by homogenizing 2 slices from each of the 3 zones (blade, middle, flank) in a food processor (Cuisinart model CUI DFP-7BC, Cuisinart, East Windsor, NJ). A 5 gram sample of the homogenate was oven dried in duplicate at 110 °C for approximately 24 h to determine percent moisture. The dried sample was washed multiple times in an azeotropic mixture of warm chloroform: methanol as described by Novakofski, Park, Bechtel, and McKeith (1989) and weighed to determine lipid content.

2.7. Bacon slice lean image analysis

Bacon slice image analysis was conducted with a similar procedure described in Boler et al. (2011). Slices were photographed as a set using a Canon Powershot SX20IS camera (Canon Inc., Melville, NY) at a standardized distance from the samples. A ruler was included in each image to allow for the establishment of a known distance. Images were converted to a black and white TIFF in Adobe Photoshop CS6, and total slice length, width, and area were calculated. The individual slice outlines were selected using the magic wand tool, and image analysis was conducted using Image-J image processing and analysis software in Java (Abramoff, Magalhaes, & Ram, 2004). Threshold values were adjusted as needed within each image to account for variations in lean and fat color. Secondary lean area [cutaneous trunci (Person et al., 2005)] was calculated by pixel density in Image-J. Percent lean area was calculated using the following equation: Percent lean $= \frac{\text{total lean area}}{\text{total slice area}} \times 100$. Lean to fat ratio was calculated using the following equation: Lean : fat $= \frac{\text{total lean area}}{\text{total slice area}-\text{total lean area}}$. Percent lean and lean to fat ratios were calculated for the blade, middle, flank slices, and the average of all three.

2.8. Sensory evaluation

Sensory evaluation was performed in a similar manner as described in previous studies performed at the University of Illinois Meat Science Laboratory Sensory Center (Bess et al., 2013; Lowe, Bohrer, Holmer, Boler, & Dilger, 2014). Sixteen panelists familiar with bacon evaluation were selected among departmental students and staff and were trained according to the American Meat Science Association Guidelines (AMSA, 1995). Panelists participated in training sessions for orientation to scale attributes prior to evaluation. Panelists rated attributes on a 15-cm line scale with anchors at 0, 7.5, and 15 cm, where 0 cm indicated no saltiness, no flavor intensity, no off-flavor, or no off-odor. Panelists were presented bacon with various attributes and assessed bacon for saltiness, flavor, off-flavor, and off-odor training prior to evaluation.

Six panelists were selected at random from the pool of 16 panelists for each panel. Conventional and dry cured bacon slices were evaluated separately by the 6-member trained panel. Panelists were separated in individual booths under ambient temperature, humidity, and under red light. Panelists were provided apple juice and unsalted crackers to serve as a palate cleanser between each sample. Six bacon slices were placed on baking sheets and cooked at 177 °C for 10 min in a convection oven (Southbend Model V-15, Fuquay-varina, NC). Cooked slices were allowed to cool for approximately 5 min and then cut into 2.54 cm pieces. Each panelist received 4 pieces in a plastic cup covered with a plastic lid. Samples were labeled with a session code and a sample code. There were 20 sensory sessions, which included 7 conventional or dry cured bacon samples. All 7 dietary treatments were represented in each sensory session.

2.9. Statistical analyses

Belly served as the experimental unit for data analysis, because pigs were fed in pens (4 pigs/pen) and one pig from each pen was used for this experiment. Fresh belly characteristics and fatty acid profile determination were collected on both bellies from each carcass independently to determine bilateral symmetry between carcass sides and then averaged to determine dietary effects. Fresh belly characteristics, fatty acid profile, bacon processing characteristics, bacon slice characteristics, and bacon sensory characteristics were analyzed with the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a general linear mixed model to compare dietary treatments. The fixed effects in the model were treatment (control, 33% CM-HP, 66% CM-HP, 100% CM-HP, 33% CM-CV, 66% CM-CV, and 100% CM-CV) and sex (barrow and gilt), and a random effect of block (farrowing group). Only a few interactions between sex and dietary treatments were observed so sex was omitted from the final model and only the main effects of diet were analyzed. Least square means were separated with the PDIFF option and were calculated for each independent variable. Orthogonal polynomial contrast statements were used to test linear and quadratic effects of increasing the level of CM-HP or CM-CV on each dependent variable. Normality of residuals was confirmed and outliers were tested using the UNIVARIATE procedure of SAS. No comparisons between cure treatments were conducted. Bilateral symmetry data between left and right bellies originating from the same carcass were compared using the paired option of the PROC T Test in SAS. Statistical significance and tendencies were accepted at $P \leq 0.05$ and $0.05 < P \leq 0.10$, respectively.

3. Results and discussion

Over the 91 d growing-finishing period, ADG and ADFI were decreased ($P \leq 0.01$) in pigs fed CM-HP compared with CM-CV, which resulted in similar feed efficiency. Furthermore, there was a linear increase ($P = 0.03$) in ADFI as CM-CV inclusion level increased. There were no differences among treatments for ending live weight, HCW, carcass yield, loin eye area, 10th rib backfat thickness, or estimated carcass lean (Little et al., 2014).

3.1. Fresh belly characteristics

Belly weight, length, width, flop distance, and durometer were not different ($P \geq 0.14$) among pigs fed any inclusion rate of CM-HP or CM-CV compared with pigs fed control (Table 4). All bellies were generally soft. Bellies from pigs fed CM-HP tended to be lighter ($P = 0.08$) and thinner ($P = 0.07$) than bellies from pigs fed CM-CV, which was likely because carcasses from pigs fed CM-HP (88.91 kg) were lighter than carcasses from pigs fed CM-CV (90.29 kg) and bellies from pigs fed CM-HP (12.11%) made up a lesser percentage of side weight compared to bellies from pigs fed CM-CM (12.45%; Little et al., 2014). Belly length, width, flop distance, and durometer were not different ($P \geq 0.40$) between bellies from pigs fed CM-HP or CM-CV. There was a tendency for a linear decrease ($P = 0.10$) in belly width as inclusion rate of CM-HP increased. There was a tendency for a quadratic decrease in belly weight ($P = 0.07$) and in belly thickness ($P = 0.03$) as inclusion rate of CM-CV increased. There were no linear or quadratic effects ($P \geq 0.25$) of CM-HP or CM-CV on flop distance or durometer.

Bellies are valued by not only the proportion of the carcass they constitute, but also the quality of the fat in the belly. Thin bellies result in economic losses due to the reduction in processing yield and the ratio of top grade bacon slices (Person et al., 2005). Decreased pork fat firmness and quality can make bellies more difficult to slice, thus reducing bacon slicing yields and the ratio of the grade one bacon slices produced per belly green weight (Apple, 2010; Kyle, Bohrer, Schroeder, Matulis, & Boler, 2014). Seman et al. (2013) evaluated multiple techniques used to measure pork fat quality and reported the durometer was one of the best predictors of bacon slicing yield among the current industry measurements, but still explained little variation with an R^2 value of

Table 4
Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on fresh belly characteristics of finishing pigs.

	Diet							SEM	*P*-values				CM-HP vs. CM-CV[c]
	Control[a]	CM-HP[a]			CM-CV[a]				CM-HP		CM-CV		
	0%	33%	66%	100%	33%	66%	100%		Linear	Quad[b]	Linear	Quad[b]	
Bellies[d], n	10	10	10	10	10	10	10						
Belly wt, kg	4.43	4.35	4.29	4.19	4.66	4.61	4.26	0.16	0.27	0.94	0.41	0.07	0.08
Length, cm	59.77	59.84	60.8	58.99	59.93	61.46	59.69	1.33	0.72	0.28	0.74	0.27	0.50
Width, cm	23.61	23.37	23.34	22.72	23.28	23.84	23.07	0.36	0.10	0.59	0.51	0.54	0.40
Thickness[e], cm	3.55	3.66	3.48	3.64	3.91	3.74	3.61	0.11	0.85	0.85	0.97	0.03	0.07
Flop distance, cm	15.16	13.91	13.13	15.42	17.01	15.38	13.13	3.90	1.00	0.32	0.33	0.25	0.48
Durometer[f]	59.42	61.67	58.68	57.83	61.26	60.56	58.40	2.30	0.45	0.50	0.72	0.39	0.72

[a] Percentage of canola meal as a replacement for soybean meal.
[b] Quadratic effects of increasing canola meal.
[c] Pooled effects of high protein canola meal versus pooled effects of canola meal.
[d] The average of left and right side bellies were used for this analysis.
[e] Thickness is the average of 8 locations of measurement: locations 1 to 4 are from anterior to posterior on the dorsal edge of the belly and locations 5 to 8 are from anterior to posterior on the ventral edge of the belly.
[f] Durometer (Electromatic Equipment Co., Inc., Cedarhurts, NY) measured belly firmness on the dorsal edge of the anterior end of the belly. Greater durometer values indicate greater firmness.

only 0.13. Furthermore, the durometer was better able to predict fat quality of heavy bellies (>5.5 kg) while bellies in the current study were relatively light (<5.5 kg) according to standards set by Seman et al. (2013). Overall, fresh belly characteristics, including weight and fat firmness, were unaffected in pigs fed CM-HP or CM-CV compared with pigs fed control.

3.2. Fatty acid profiles

Full fatty acid profiles are presented in Table 5. Total SFA, total MUFA, total PUFA, UFA:SFA, and iodine value (calculated with two methods; AOCS, 1998; Meadus et al., 2010) were not different ($P \geq 0.24$) among pigs fed any inclusion rate of CM-HP or CM-CV compared with pigs fed control, nor were there differences ($P \geq 0.43$) between pigs fed CM-HP and CM-CV. There was a linear decrease ($P = 0.02$) in total PUFA and a tendency for a linear decrease ($P = 0.07$) in iodine value (Meadus et al., 2010) as inclusion of CM-HP increased. There was a tendency for a linear increase ($P = 0.10$) in total MUFA as inclusion of CM-CV increased. Decreased pork fat firmness has been associated with high levels of MUFA and PUFA in pork bellies (Apple et al., 2007; Eggert, Belury, Kempa-Steczko, Mills, & Schinckel, 2001). Pigs fed diets high in MUFA and PUFA have been shown to have bellies with high levels of unsaturated fatty acids (Apple et al., 2007 Leick et al., 2010). Yet, in the current population of pigs, feeding CM-HP or CM-CV, protein supplements with greater PUFA than the SBM diet, had minimal impacts on the fatty acid content of bellies.

Omega-6:omega-3 was not different ($P \geq 0.67$) among pigs fed any inclusion rate of CM-HP compared with pigs fed control. Yet, ω6:ω3 was 2.3% greater ($P < 0.0001$) in pigs fed 33% CM-CV, 7.0% greater ($P < 0.0001$) in pigs fed 66% CM-CV, and 10.0% greater ($P < 0.0001$) in pigs fed 100% CM-CV compared with pigs fed control. Omega-6: omega-3 was 6.9% greater ($P < 0.0001$) in pigs fed CM-HP compared with pigs fed CM-CV. Furthermore, there was a linear decrease ($P < 0.0001$) in ω6:ω3 as inclusion CM-CV increased. Typically,

Table 5
Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on fatty acid profile of finishing pigs.

	Diet							SEM	*P*-values				
	Control[1]	CM-HP[1]			CM-CV[1]				CM-HP		CM-CV		CM-HP vs. CM-CV[3]
	0%	33%	66%	100%	33%	66%	100%		Linear	Quad[2]	Linear	Quad[2]	
Bellies[4], n	10	10	10	10	10	10	10						
C14:0, %	1.22	1.23	1.22	1.26	1.23	1.19	1.19	0.05	0.59	0.66	0.35	0.91	0.25
C14:1, %	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.002	0.59	0.49	0.42	0.52	0.43
C15:0, %	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.003	0.46	0.81	0.93	0.77	0.26
C16:0, %	21.80	21.74	21.62	22.34	22.15	21.67	21.55	0.62	0.29	0.22	0.38	0.46	0.67
C16:1, %	2.42	2.39	2.39	2.43	2.35	2.36	2.39	0.09	0.96	0.72	0.86	0.58	0.64
C17:0, %	0.35	0.32	0.30	0.29	0.34	0.34	0.31	0.02	0.04	0.53	0.17	0.46	0.08
C17:1, %	0.36	0.32	0.31	0.30	0.35	0.35	0.32	0.02	0.02	0.52	0.13	0.63	0.07
C18:0, %	9.62	9.95	9.57	10.21	10.02	9.78	9.58	0.39	0.29	0.59	0.79	0.31	0.63
C18:1n − 9, %	41.72	41.56	42.54	42.26	42.02	42.51	42.66	0.41	0.14	0.87	0.06	0.85	0.40
C18:2n − 6, %	18.47	18.49	18.10	17.15	17.64	17.76	17.96	1.05	0.03	0.26	0.46	0.23	0.72
C18:3n − 6, %	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.003	0.16	0.74	0.33	0.91	0.60
C18:3n − 3, %	1.20^{bc}	1.21^{b}	1.18^{bc}	1.13^{c}	1.19^{bc}	1.25^{ab}	1.31^{a}	0.08	0.06	0.23	<0.01	0.19	<0.01
C20:0, %	0.19	0.20	0.20	0.20	0.21	0.21	0.20	0.01	0.22	0.98	0.43	0.11	0.43
C20:1n − 9, %	0.80	0.80	0.82	0.79	0.80	0.83	0.82	0.03	0.99	0.56	0.48	0.79	0.62
C20:2n − 6, %	0.79^{a}	0.77^{ab}	0.75^{ab}	0.66^{c}	0.71^{bc}	0.73^{ab}	0.71^{bc}	0.04	<0.0001	0.11	0.02	0.22	0.61
C20:3n − 6, %	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.01	0.26	0.69	0.38	0.29	0.47
C20:4n − 6, %	0.29	0.27	0.27	0.25	0.27	0.27	0.25	0.02	0.06	0.96	0.06	0.87	1.00
C20:3n − 3, %	0.16^{a}	0.16^{a}	0.16^{a}	0.14^{b}	0.15^{a}	0.16^{a}	0.16^{a}	0.01	<0.01	0.06	0.53	0.32	0.07
C20:5n − 3, %	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.004	0.07	0.19	0.39	0.02	0.95
C22:0, %	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.46	0.31	0.61	0.94	0.41
C22:1n − 9, %	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.004	0.31	0.31	0.77	0.67	0.37
C22:2n − 6, %	0.04	0.03	0.03	0.05	0.03	0.03	0.04	0.01	0.46	0.16	0.66	0.25	0.86
C23:0, %	0.04	0.04	0.03	0.04	0.03	0.04	0.04	0.004	0.54	0.49	0.85	0.79	0.67
C22:4n − 6, %	0.10	0.09	0.09	0.08	0.10	0.09	0.09	0.005	<0.01	1.00	0.04	0.51	0.28
C22:5n − 3, %	0.0749^{ab}	0.0700^{abc}	0.0695^{bc}	0.0632^{c}	0.0711^{ab}	0.0766^{a}	0.0749^{ab}	0.003	<0.01	0.78	0.62	0.68	<0.01
C24:0, %	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.004	0.33	0.69	0.49	0.74	0.25
C22:6n − 3, %	0.04	0.04	0.04	0.03	0.03	0.04	0.04	0.005	0.37	0.66	0.71	0.53	0.89
Total SFA[5], %	33.33	33.58	33.04	34.47	34.09	33.34	32.97	1.04	0.28	0.32	0.49	0.34	0.63
Total MUFA[6], %	45.34	45.13	46.11	45.82	45.56	46.10	46.24	0.45	0.21	0.93	0.10	0.93	0.43
Total PUFA[7], %	21.33	21.29	20.84	19.71	20.35	20.56	20.80	1.19	0.02	0.26	0.52	0.21	0.91
UFA:SFA ratio[8]	2.01	2.00	2.03	1.91	1.94	2.01	2.04	0.09	0.25	0.29	0.50	0.36	0.64
IV[9] (AOCS, 1998)	74.04	73.94	74.04	72.02	72.75	73.58	74.24	1.85	0.11	0.25	0.70	0.24	0.78
IV[10] (Meadus et al., 2010)	77.63	77.39	77.44	75.13	76.07	76.98	77.55	1.99	0.07	0.25	0.87	0.24	0.77
ω6:ω3[11]	13.14^{a}	13.08^{ab}	13.16^{a}	13.18^{a}	12.84^{b}	12.22^{c}	11.83^{d}	0.10	0.65	0.66	<0.0001	0.69	<0.0001

a,b,c,d Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$).
[1] Percentage of canola meal as a replacement for soybean meal.
[2] Quadratic effects of increasing canola meal.
[3] Pooled effects of high protein canola meal versus pooled effects of canola meal.
[4] The average of left and right side bellies were used for this analysis.
[5] Total SFA = (C14:0) + (C15:0) + (C16:0) + (C17:0) + (C18:0) + (C20:0) + (C22:0) + (C23:0) + (C24:0).
[6] Total MUFA = (C14:1) + (C16:1) + (C17:1) + (C18:1n − 9) + (C20:1n − 9) + (C22:1n − 9).
[7] Total PUFA = (C18:2n − 6) + (C18:3n − 6) + (C18:3n − 3) + (C20:2n − 6) + (C20:3n − 6) + (C20:4n − 6) + (C20:3n − 3) + (C20:5n3) + (C22:2n − 6) + (C22:4n − 6) + (C22:5n − 3) + (C22:6n − 3).
[8] UFA:SFA = (total MFUA + total PUFA) / total SFA.
[9] Iodine value = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723).
[10] Iodine value = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.795) + C20:2 (1.57) + C20:3 (2.38) + C20:4 (3.19) + C20:5 (4.01) + C22:4 (2.93) + C22:6 (4.64).
[11] ω6:ω3 = [(C18:2n − 6) + (C18:3n − 6) + (C20:2n − 6) + (C20:3n − 6) + (C20:4n − 6) + (C22:2n − 6) + (C22:4n − 6)] / [(C18:3n − 3) + (C20:3n − 3) + (C20:5n − 3) + (C22:5n − 3) + (C22:6n − 3)].

Americans consume diets that contain ω6:ω3 of around 15:1 or 16:1 (Simopoulos, 2008). A ratio of 4:1 to 1:1 is advised for human diets, as consuming greater levels of ω6 PUFA can lead to cardiovascular disease, cancer, and inflammatory diseases (Simopoulos, 2008). When comparing ω6:ω3 of pork fat with fat from ruminants, pork fat will generally have greater ω6:ω3 regardless of diet (Wood et al., 2004). Therefore, while feeding pigs CM-CV is a viable option to lower ω6:ω3 of pork fat; pork fat may still be relatively high in ω6:ω3.

3.3. Processing characteristics

3.3.1. Conventional cure

Belly weights (green, pumped, cooked, and sliced) and yields (pump uptake and cooked yield) were not different ($P \geq 0.36$) among pigs fed any inclusion rate of CM-HP or CM-CV compared with pigs fed control, nor were there differences ($P \geq 0.17$) between pigs fed CM-HP and CM-CV (Table 6). There were no linear or quadratic effects ($P \geq 0.22$) in pigs fed increased levels of CM-HP for belly weights or yields. There was a tendency for a quadratic decrease ($P = 0.09$) in pigs fed increased levels of CM-CV for cooked yield. Similarly, Shackelford et al. (1990) reported belly pump and cooked yields were unaffected in pigs fed elevated levels of unsaturated fats, yet slicing yields were reduced in pigs fed canola oil compared with pigs fed corn-SBM. Overall, processing characteristics of conventional cured bacon were unaffected by feeding pigs CM-HP or CM-CV.

3.3.2. Dry cure

Belly weights (green, cooked, and sliced) and cooked yield were not different ($P \geq 0.15$) among pigs fed any inclusion rate of CM-HP or CM-CV compared with pigs fed control. Green weights were lighter ($P = 0.05$) and cooked and sliced weights tended to be lighter ($P \geq 0.09$) in bellies from pigs fed CM-HP compared with CM-CV. Cooked yield was not different ($P = 0.73$) between pigs fed CM-HP and CM-CV. Limited research has been conducted analyzing the effects of diet on processing yields of dry cured bacon. Overall, cooked yield of dry cured bacon was unaffected by feeding pigs CM-HP or CM-CV.

3.4. Bacon slice characteristics

3.4.1. Conventional cure

Conventional cured bacon slice composition analyzed with image and chemical analysis was not different ($P \geq 0.25$) among pigs fed any inclusion rate of CM-HP or CM-CV compared with pigs fed control (Table 7). Conventional cured bacon slice percent lean was greater ($P = 0.02$), lean:fat tended to be greater ($P = 0.07$), moisture percentage tended to be greater ($P = 0.06$), and lipid percentage was reduced ($P = 0.04$) in pigs fed CM-HP compared with CM-CV. There were no linear or quadratic effects ($P \geq 0.22$) in pigs fed increased levels of CM-HP for conventional cured bacon slice characteristics measured. There was a tendency for a quadratic increase ($P = 0.10$) in moisture percentage and a tendency for a quadratic decrease ($P = 0.06$) in lipid percentage in pigs fed increased levels of CM-CV.

3.4.2. Dry cure

Dry cured bacon slice composition analyzed with image and chemical analysis was not different ($P \geq 0.18$) among pigs fed any inclusion rate of CM-HP or CM-CV compared with pigs fed control. Dry cured bacon total slice area tended to be reduced ($P = 0.06$) in pigs fed CM-HP compared with pigs fed CM-CV. This was likely a result of differences in belly weights. There were no linear or quadratic effects ($P \geq 0.22$) in pigs fed increased levels of CM-HP for dry cured bacon slice characteristics. There was a tendency for a quadratic increase ($P = 0.09$) in dry cured bacon percent lean as CM-CV inclusion increased.

3.4.3. Bacon slice characteristics discussion

Smith, West, and Carpenter (1975) reported fat bacon slices were inferior to lean bacon slices in consumer acceptability, more specifically cooked appearance and percentage of slice defects. Person et al. (2005) reported bacon from thin bellies (47.9% moisture; 36.2% lipid) had greater consumer palatability attributes, namely bacon flavor, fattiness, and crispiness, compared with bacon from thick bellies (40.4% moisture; 46.3% lipid). Composition of bacon for all treatment groups in the current study was more similar to thin bellies; however, some treatment groups had even a lesser proportion of lipids. More research is warranted to develop relationships between thin bellies (high moisture and low lipid) and sensory attributes.

3.5. Sensory characteristics

3.5.1. Conventional cure

Saltiness, flavor intensity, off flavor, and off odor of conventional cured bacon were not different ($P \geq 0.26$) among pigs fed any inclusion rate of CM-HP or CM-CV compared with pigs fed control (Table 8). Saltiness, flavor intensity, and off odor were not different ($P \geq 0.27$) between pigs fed CM-HP and CM-CV. However, off flavor scores of conventionally cured bacon were greater ($P = 0.04$) in pigs fed CM-

Table 6
Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on bacon processing characteristics of finishing pigs.

	Diet							SEM	*P*-values				
	Control[a]	CM-HP[a]			CM-CV[a]				CM-HP		CM-CV		CM-HP vs. CM-CV[c]
	0%	33%	66%	100%	33%	66%	100%		Linear	Quad[b]	Linear	Quad[b]	
Conventional Cure													
Bellies, n	10	10	10	10	10	10	10						
Green wt, kg	4.41	4.45	4.24	4.20	4.59	4.62	4.28	0.18	0.31	0.82	0.66	0.16	0.19
Pumped wt, kg	4.88	4.92	4.71	4.66	5.07	5.08	4.74	0.22	0.32	0.80	0.65	0.18	0.21
Pump uptake, %	10.67	10.42	11.13	10.8	10.37	10.1	10.83	1.49	0.53	0.91	0.90	0.19	0.28
Cooked wt, kg	4.30	4.39	4.14	4.11	4.54	4.55	4.21	0.21	0.36	0.76	0.76	0.13	0.17
Cook yield, %	97.37	98.5	97.71	97.63	98.69	98.53	98.15	1.11	1.00	0.22	0.32	0.09	0.20
Sliced wt, kg	3.52	3.74	3.21	3.43	3.82	3.67	3.43	0.21	0.41	1.00	0.66	0.20	0.29
Dry Cure													
Bellies, n	10	10	10	10	10	10	10						
Green wt, kg	4.45	4.25	4.34	4.17	4.74	4.59	4.23	0.17	0.31	0.92	0.27	0.05	0.05
Cooked wt, kg	4.12	3.95	4.02	3.89	4.4	4.27	3.92	0.18	0.39	0.92	0.32	0.05	0.07
Cook yield, %	92.26	92.95	92.60	93.04	92.81	92.84	92.59	0.83	0.28	0.75	0.57	0.33	0.73
Sliced wt, kg	3.64	3.41	3.48	3.44	3.82	3.84	3.41	0.17	0.51	0.59	0.40	0.09	0.09

[a] Percentage of canola meal as a replacement for soybean meal.
[b] Quadratic effects of increasing canola meal.
[c] Pooled effects of high protein canola meal versus pooled effects of canola meal.

Table 7
Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on bacon slice characteristics of finishing pigs.

	Diet							SEM	*P*-values				
	Control[a]	CM-HP[a]			CM-CV[a]				CM-HP		CM-CV		CM-HP vs. CM-CV[c]
	0%	33%	66%	100%	33%	66%	100%		Linear	Quad[b]	Linear	Quad[b]	
Conventional cure													
Bellies, n	10	10	10	10	10	10	10						
Average slice image analysis[d]													
Total slice area, cm[b]	74.02	73.01	67.32	69.67	75.44	74.94	69.48	3.97	0.22	0.62	0.35	0.31	0.23
Secondary lean, cm[b]	11.82	11.77	11.35	11.63	10.11	11.19	11.43	0.65	0.74	0.80	0.98	0.14	0.21
Total lean area, cm[b]	40.99	42.56	37.52	40.04	38.28	37.97	37.75	2.03	0.39	0.81	0.27	0.54	0.22
Percentage of lean[e], %	54.76	58.34	55.63	58.00	51.70	51.04	54.58	3.22	0.52	0.80	0.91	0.18	0.02
Lean:Fat[f]	1.39	1.53	1.35	1.84	1.20	1.11	1.27	0.28	0.30	0.49	0.70	0.49	0.07
Bacon composition													
Moisture, %	49.35	49.54	50.07	49.08	46.85	47.05	48.85	1.75	0.96	0.65	0.82	0.10	0.06
Lipid, %	34.61	34.52	33.67	34.96	38.54	38.33	35.45	2.48	0.98	0.70	0.77	0.06	0.04
Dry cure													
Bellies, n	10	10	10	10		10	10	10					
Average slice image analysis[d]													
Total slice area, cm[b]	73.49	70.31	68.7	69.81	79.19	72.94	70.05	5.03	0.33	0.46	0.20	0.14	0.06
Secondary lean, cm[b]	11.80	10.64	11.15	10.96	11.04	10.23	10.15	0.76	0.48	0.44	0.04	0.58	0.38
Total lean area, cm[b]	39.79	37.57	36.49	37.11	38.86	36.05	37.66	1.77	0.25	0.43	0.25	0.48	0.75
Percentage of lean[e], %	55.10	53.48	52.96	53.77	49.85	50.10	54.25	4.15	0.71	0.66	0.85	0.09	0.37
Lean:Fat[f]	1.42	1.29	1.18	1.57	1.10	1.10	1.30	0.31	0.77	0.30	0.73	0.30	0.37
Bacon composition													
Moisture, %	44.42	44.45	44.59	44.44	43.08	43.06	43.87	1.63	0.98	0.94	0.77	0.40	0.27
Lipid, %	38.09	38.29	37.73	37.99	40.32	40.35	38.81	2.61	0.92	0.99	0.79	0.32	0.23

[a] Percentage of canola meal as a replacement for soybean meal.
[b] Quadratic effects of increasing canola meal.
[c] Pooled effects of high protein canola meal versus pooled effects of canola meal.
[d] Average slice image analysis was the average of image analysis of a slice from the blade, middle, and flank portion of the belly.
[e] Percent lean = (total lean area / total slice area) × 100.
[f] Lean:fat = [total lean area / (total slice area − total area)].

HP compared with pigs fed CM-CV. This was primarily driven by pigs fed 100% CM-HP, which had the greatest scores for off flavor (0.31 on a 0–15 scale). Albeit, the magnitude of difference between pigs fed CM-HP and CM-CV was only 0.19 units on a 0–15 scale, a value very unlikely to affect overall product acceptability (Hayes, 2009). There were no linear or quadratic effects ($P \geq 0.11$) for saltiness, flavor intensity, off flavor, and off odor of conventional cured bacon in pigs fed increased levels of CM-HP or CM-CV. Overall, there were no industry relevant differences in sensory characteristics of conventional cured bacon from pigs fed CM-HP or CM-CV compared with bacon from pigs fed control. More importantly, there were no differences in sensory characteristics between pigs fed canola meal and control.

3.5.2. Dry cure

Saltiness, flavor intensity, off flavor, and off odor of dry cured bacon were not different ($P \geq 0.47$) among pigs fed any inclusion rate of CM-HP or CM-CV compared with pigs fed control. Saltiness tended to be greater ($P = 0.08$) in pigs fed CM-HP compared with CM-CV. Differences in the composition of bacon slices may have contributed to the saltiness, as bacon from pigs fed CM-HP had greater moisture percentage and less lipid percentage compared with bacon from pigs fed CM-CV. Flavor intensity, off flavor, and off odor of dry cured bacon were not different ($P \geq 0.15$) between pigs fed CM-HP and CM-CV. There were no linear or quadratic effects ($P \geq 0.17$) for saltiness, flavor intensity, off flavor, and off odor of dry cured bacon in pigs fed increased

Table 8
Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on bacon sensory characteristics of finishing pigs.[a]

	Diet							SEM	*P*-values				
	Control[b]	CM-HP[b]			CM-CV[b]				CM-HP		CM-CV		CM-HP vs. CM-CV[d]
	0%	33%	66%	100%	33%	66%	100%		Linear	Quad[c]	Linear	Quad[c]	
Conventional cure													
Bellies, n	10	10	10	10	10	10	10						
Saltiness	6.32	6.01	6.03	6.07	6.23	5.98	6.20	0.32	0.59	0.57	0.66	0.60	0.69
Flavor intensity	6.46	6.49	6.51	6.92	6.69	6.31	6.60	0.35	0.37	0.59	0.98	0.94	0.71
Off flavor	0.16	0.19	0.18	0.31	0.16	0.13	0.10	0.08	0.11	0.41	0.42	0.77	0.04
Off odor	0.10	0.13	0.22	0.19	0.13	0.11	0.14	0.09	0.19	0.62	0.72	0.93	0.27
Dry cure													
Bellies, n	10	10	10	10	10	10	10						
Saltiness	8.90	9.18	9.41	9.20	8.95	8.65	8.53	0.47	0.51	0.52	0.41	0.83	0.08
Flavor intensity	9.17	9.10	9.43	9.06	8.88	8.92	8.67	0.36	1.00	0.64	0.30	0.95	0.15
Off flavor	0.18	0.31	0.15	0.25	0.15	0.18	0.35	0.10	0.93	0.85	0.21	0.30	0.92
Off odor	0.11	0.07	0.06	0.15	0.05	0.14	0.17	0.05	0.61	0.17	0.25	0.34	0.52

[a] Sensory panelists rated attributes on a 15-cm line scale with anchors at 0, 7.5, and 15 cm, where 0 cm indicated no saltiness, no flavor intensity, no off-flavor, or no off-odor.
[b] Percentage of canola meal as a replacement for soybean meal.
[c] Quadratic effects of increasing canola meal.
[d] Pooled effects of high protein canola meal versus pooled effects of canola meal.

levels of CM-HP or CM-CV. Limited research has been conducted analyzing the effects of diet on sensory characteristics of dry cured bacon. Overall, flavor intensity, off flavor, and off odor were unaffected in dry cured bacon by feeding pigs either CM-HP or CM-CV.

3.6. Bilateral symmetry

3.6.1. Effect on fresh belly characteristics

Fresh belly characteristics were evaluated to determine bilateral symmetry of left and right side bellies originating from the same carcasses (Table 9). Belly width was 7.0% less ($P < 0.0001$), average thickness was 6.5% less ($P < 0.0001$), flop distance was 13.9% less ($P < 0.0001$), durometer (greater durometer scores indicate greater fat firmness) scores were 5.1% less ($P = 0.05$), belly weight (skin on) was 7.4% less ($P < 0.0001$), and belly green weight was 7.3% less ($P \geq 0.0001$) in left side bellies compared with right side bellies. Breidenstein et al. (1964) reported a non-significant difference of approximately 8% between left and right side pork carcasses (n = 20), which was attributed to experimental error. Breidenstein et al. (1964) also reported left side carcass weights were numerically heavier than right side carcass weights, further implying that results can be explained by experimental error, as right side bellies in the current study were heavier than left side bellies. However, Schroder and Rust (1974) reported there were no significant differences between paired bellies (n = 22), yet composition differed in different locations within a single belly. In the current study, sample size was greater than in previous research on bilateral symmetry, and the current data indicated bilateral symmetry of left and right side bellies originating from the same carcass may not be the same for dimensional characteristics and firmness tests.

3.6.2. Effect on fatty acid profile

Full fatty acid profiles are presented in Table 10. Total MUFA tended to be greater ($P = 0.08$) in left side bellies compared with right side bellies. Total SFA, total PUFA, UFA:SFA, and iodine value (calculated with two methods; AOCS, 1998; Meadus et al., 2010) were not different ($P \geq 0.36$) in left and right side bellies. Trusell et al. (2011) reported there were obvious differences in fatty acid composition and fat firmness within individual bellies depending on location of the belly the sample was collected from. However, we do not have an explanation for the differences in fatty acid profile between left and right side bellies that were observed in the current study, and additional research is warranted to investigate this further. The current data indicated that left and right side bellies originating from the same carcasses may differ in some individual fatty acids, but overall iodine value was unaffected by bilateral symmetry.

4. Conclusions

Primary objectives were to compare fresh belly, bacon processing, bacon slice, and bacon sensory characteristics from pigs fed CM-HP or CM-CV. Results indicated that bellies from pigs fed CM-HP were slightly lighter and thinner than bellies from pigs fed CM-CV, yet bacon processing, bacon slice, and sensory characteristics were unaffected by dietary treatment. Canola meal can be fed to growing-finishing pigs without

Table 9
Effects of bilateral symmetry on fresh belly characteristics of finishing pigs fed high protein canola meal (CM-HP) or conventional canola meal (CM-CV).

Item	Left side bellies	Right side bellies	Difference	SED[a]	*P*-value
Bellies, n	70	70			
Length, cm	60.42	59.72	0.70	0.49	0.15
Width, cm	22.53	24.10	−1.57	0.24	<0.0001
Thickness[b], cm					
Location 1	4.83	5.18	−0.35	0.07	<0.0001
Location 2	4.01	4.32	−0.31	0.07	<0.0001
Location 3	3.28	3.46	−0.17	0.05	<0.01
Location 4	3.14	3.64	−0.50	0.09	<0.0001
Location 5	3.28	3.42	−0.14	0.07	0.07
Location 6	3.17	3.38	−0.20	0.05	<0.01
Location 7	2.98	3.25	−0.28	0.06	<0.0001
Location 8	3.60	3.52	0.08	0.08	0.30
Average thickness, cm	3.54	3.77	−0.23	0.03	<0.0001
Flop distance, cm	13.78	15.69	−1.91	0.40	<0.0001
Durometer[c]	58.19	61.18	−2.99	1.51	0.05
Belly wt (skin on), kg	4.99	5.36	−0.37	0.04	<0.0001
Belly green wt, kg	4.24	4.55	−0.31	0.04	<0.0001

[a] Standard error of the difference of the mean.
[b] Locations 1 to 4 are from anterior to posterior on the dorsal edge of the belly and location 5 to 8 are from anterior to posterior on the ventral edge of the belly.
[c] Durometer (Electromatic Equipment Co., Inc., Cedarhurts, NY) measured belly firmness on the dorsal edge of the anterior end of the belly. Greater durometer values indicate greater firmness.

Table 10
Effects of bilateral symmetry on fatty acid profile of finishing pigs fed high protein canola meal (CM-HP) or conventional canola meal (CM-CV).

Item	Left side bellies	Right side bellies	Difference	SED[a]	*P*-value
Bellies, n	70	70			
C14:0, %	1.23	1.21	0.02	0.00	<0.001
C14:1, %	0.02	0.02	0.00	0.00	0.62
C15:0, %	0.05	0.06	0.00	0.00	<0.01
C16:0, %	21.86	21.81	0.05	0.07	0.47
C16:1, %	2.42	2.36	0.06	0.02	<0.001
C17:0, %	0.32	0.32	0.00	0.00	0.07
C17:1, %	0.33	0.33	0.00	0.00	0.62
C18:0, %	9.75	9.89	−0.15	0.07	0.04
C18:1n − 9, %	42.25	42.11	0.14	0.10	0.17
C18:2n − 6, %	17.89	17.98	−0.09	0.10	0.41
C18:3n − 6, %	0.03	0.03	0.00	0.00	0.87
C18:3n − 3, %	1.21	1.21	0.00	0.01	0.75
C20:0, %	0.20	0.20	−0.01	0.00	<0.0001
C20:1n − 9, %	0.80	0.82	−0.01	0.00	<0.01
C20:2n − 6, %	0.72	0.74	−0.02	0.01	0.01
C20:3n − 6, %	0.10	0.10	0.00	0.00	0.58
C20:4n − 6, %	0.27	0.26	0.01	0.00	<0.0001
C20:3n − 3, %	0.16	0.16	0.00	0.00	0.06
C20:5n − 3, %	0.03	0.03	0.00	0.00	0.12
C22:0, %	0.03	0.03	0.00	0.00	0.57
C22:1n − 9, %	0.03	0.03	0.00	0.00	0.31
C22:2n − 6, %	0.03	0.04	0.00	0.01	0.62
C23:0, %	0.04	0.04	0.00	0.00	0.35
C22:4n − 6, %	0.09	0.09	0.00	0.00	1.00
C22:5n − 3, %	0.07	0.07	0.00	0.00	0.19
C24:0, %	0.03	0.03	0.00	0.00	0.89
C22:6n − 3, %	0.04	0.04	0.00	0.00	0.84
Total SFA[b], %	33.49	33.61	−0.12	0.13	0.36
Total MUFA[c], %	45.86	45.65	0.21	0.12	0.08
Total PUFA[d], %	20.65	20.74	−0.09	0.12	0.43
UFA:SFA ratio[e]	2.00	1.99	0.01	0.01	0.37
IV[f] (AOCS, 1998)	73.53	73.50	0.03	0.18	0.87
IV[g] (Meadus et al., 2010)	76.95	76.90	0.05	0.19	0.80
ω6:ω3[h]	12.75	12.81	−0.07	0.04	0.12

[a] Standard error of the difference of the mean.
[b] Total SFA = (C14:0) + (C15:0) + (C16:0) + (C17:0) + (C18:0) + (C20:0) + (C22:0) + (C23:0) + (C24:0).
[c] Total MUFA = (C14:1) + (C16:1) + (C17:1) + (C18:1n − 9) + (C20:1n − 9) + (C22:1n − 9).
[d] Total PUFA = (C18:2n − 6) + (C18:3n − 6) + (C18:3n − 3) + (C20:2n − 6) + (C20:3n − 6) + (C20:4n − 6) + (C20:3n − 3) + (C20:5n3) + (C22:2n − 6) + (C22:4n − 6) + (C22:5n − 3) + (C22:6n − 3).
[e] UFA:SFA = (total MFUA + total PUFA) / total SFA.
[f] Iodine value = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723).
[g] Iodine value = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.795) + C20:2 (1.57) + C20:3 (2.38) + C20:4 (3.19) + C20:5 (4.01) + C22:4 (2.93) + C22:6 (4.64).
[h] ω6:ω3 = [(C18:2n − 6) + (C18:3n − 6) + (C20:2n − 6) + (C20:3n − 6) + (C20:4n − 6) + (C22:2n − 6) + (C22:4n − 6)] / [(C18:3n − 3) + (C20:3n − 3) + (C20:5n − 3) + (C22:5n − 3) + (C22:6n − 3)].

affecting processing characteristics and sensory attributes of bacon in relation to a SBM diet.

Secondary objectives were to test the existence of bilateral symmetry on fresh belly characteristics and fatty acid profiles of right and left side bellies originating from the same carcass. These data indicated that bellies originating from the same carcasses differed in weight, width, flop distance, and thickness, but had similar fatty acid profiles. When conducting research on fresh belly characteristics, differences in bilateral symmetry of left and right side bellies originating from the same carcass should be considered.

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