# Effects of high-protein or conventional canola meal on growth performance, organ weights, bone ash, and blood characteristics of weanling pigs

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**ABSTRACT:** An experiment was conducted to evaluate effects of 2 high-protein canola meals (canola meal A [CMA]: 45.69% CP and canola meal B [CMB]: 46.97% CP) and a conventional canola meal (CM-CV: 35.10% CP) on growth performance, organ weights, bone ash, and blood parameters of weanling pigs. Inclusion rates of canola meal (CM) in the diets were 10, 20, 30, or 40% for CMA and CM-CV, whereas inclusions were 10, 20, or 30% for CMB. A control diet containing no CM was also formulated. Therefore, 12 diets were used in this experiment. A total of 420 pigs (initial BW: 9.8 ± 1.1 kg) were divided into 3 blocks and randomly allotted to 1 of the 12 diets with 8 replicate pens per treatment and 4 or 5 pigs per pen. The ADG, ADFI, and G:F were calculated, and at the conclusion of the experiment, 1 pig in each pen was euthanized to allow measurements of organ weights, collection of blood, and collection of the third and fourth metacarpals from the left foot. Results indicate that ADFI was linearly ($P < 0.05$) decreased if inclusion of CMA, CMB, or CM-CV was increased. Average daily gain for pigs fed CMA tended to increase quadratically with the maximum response observed at 10 or 20% CM inclusion in the diet ($P = 0.06$). However, G:F was linearly ($P < 0.05$) increased by adding CMA or CM-CV to the diets. Liver weights were also linearly ($P < 0.05$) increased if pigs were fed diets containing CMB, but kidney weights were linearly ($P < 0.05$) decreased by the addition of CM-CV to the diets. Thyroid gland weights increased linearly ($P < 0.05$) for pigs fed diets containing CMA. No differences were observed in heart and bone weights if CM was added to the diets. Addition of any of the 3 CM linearly ($P < 0.05$) increased bone ash percentage in the metacarpals. Inclusion of CMA or CM-CV linearly ($P < 0.05$) decreased concentrations of serum triiodothyronine, and the inclusion of CMA also linearly ($P < 0.05$) decreased serum thyroxine concentrations. No differences were observed for complete blood counts or blood urea nitrogen if CM was added to the diets. In conclusion, up to 20% high-protein CM or CM-CV may be included in diets for weanling pigs from 2 wk postweaning without reducing growth performance or negatively affecting organ, bone, or blood parameters. In some instances, it may also be possible to use greater inclusion rates.

**Key words:** blood parameters, canola meal, growth performance, high-protein canola meal, organ weights, weanling pigs

## INTRODUCTION

Canola and rapeseed meals are the second most commonly used protein sources in the world in animal diets (Arntfield and Hickling, 2011). Rapeseed meal has been fed to livestock for decades, though inclusion in swine diets has been limited in the past due to antinutritional factors such as glucosinolates, erucic acid, and fiber. In response, Canadian plant breeders developed a low-glucosinolate and low erucic acid variety of rapeseed, known as canola. Past studies have not shown consistency in the amount of soybean meal (**SBM**) that can be replaced by canola meal (**CM**) in diets fed to weanling pigs, varying from less than 10% (Rundgren, 1983) to complete replacement (Bowland, 1975). Results of more recent studies indicate that 15 to 20% units of SBM in diets can be replaced by CM with no negative or positive effects on growth performance (Landero et al., 2011; Seneviratne et al., 2011).

**Table 1.** Analyzed nutrient composition of ingredients (as-fed basis)[1]

| Item | Canola meal A | Canola meal B | Conventional canola meal | Soybean meal |
|---|---|---|---|---|
| GE, kcal/kg | 4,450 | 4,403 | 4,172 | 4,222 |
| ME, kcal/kg[2] | 2,893 | 3,346 | 2,492 | 3,796 |
| DM, % | 91.24 | 91.13 | 89.90 | 88.15 |
| CP, % | 45.69 | 46.97 | 35.10 | 46.67 |
| Ash, % | 6.88 | 6.10 | 7.98 | 5.57 |
| Ether extract, acid hydrolyzed, % | 3.48 | 3.28 | 3.77 | 2.48 |
| NDF, % | 18.32 | 17.90 | 25.04 | 8.23 |
| ADF, % | 12.66 | 10.95 | 17.53 | 4.81 |
| Ca, % | 0.64 | 0.51 | 1.25 | 0.29 |
| P, % | 1.26 | 1.16 | 1.16 | 0.57 |
| Phytate, % | 3.57 | 3.20 | 2.69 | 1.43 |
| Phytate-bound P[3], % | 1.01 | 0.90 | 0.76 | 0.40 |
| Nonphytate-bound P[4], % | 0.25 | 0.26 | 0.40 | 0.17 |
| Indispensable AA, % | | | | |
| Arg | 2.79 | 2.87 | 2.09 | 3.43 |
| His | 1.23 | 1.23 | 0.91 | 1.24 |
| Ile | 1.77 | 1.89 | 1.35 | 2.32 |
| Leu | 3.18 | 3.31 | 2.53 | 3.73 |
| Lys | 2.61 | 2.67 | 2.02 | 3.07 |
| Met | 0.91 | 0.91 | 0.68 | 0.69 |
| Phe | 1.80 | 1.90 | 1.38 | 2.45 |
| Thr | 1.85 | 1.84 | 1.49 | 1.82 |
| Trp | 0.67 | 0.71 | 0.46 | 0.68 |
| Val | 2.23 | 2.48 | 1.72 | 2.50 |
| Dispensable AA, % | | | | |
| Ala | 1.88 | 1.92 | 1.50 | 2.02 |
| Asp | 3.00 | 3.35 | 2.44 | 5.34 |
| Cys | 1.21 | 1.19 | 0.82 | 0.68 |
| Glu | 7.36 | 7.45 | 5.41 | 7.86 |
| Gly | 2.18 | 2.20 | 1.69 | 1.98 |
| Pro | 2.81 | 2.84 | 2.08 | 2.29 |
| Ser | 1.74 | 1.67 | 1.32 | 2.03 |
| Tyr | 1.20 | 1.24 | 0.96 | 1.75 |

[1]Canola meal A and canola meal B were sourced from Canada; conventional canola meal and soybean meal were sourced from the University of Illinois, Urbana.

[2]Values determined in a previous experiment (Berrocoso et al., 2015).

[3]Phytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[4]Nonphytate-bound P was calculated as the difference between total P and phytate-bound P.

Traditional CM contains approximately 37% CP (NRC, 2012), but newer varieties of canola with greater concentrations of CP have been developed, and the meal from these seeds may contain approximately 45% CP (Slominski et al., 2012). These high-protein varieties of canola usually have a larger seed size and thinner seed coat than the conventional varieties of *Brassica napus* (Rahman et al., 2001) and, therefore, contain less dietary fiber (Slominski et al., 2012).

There is, however, limited information about feeding CM produced from these varieties to weanling pigs.

Therefore, the objectives of this experiment were to determine growth performance, organ weights, bone ash, and blood characteristics of weanling pigs fed diets containing either high-protein CM or conventional CM (CM-CV) at increasing inclusion levels and to determine the optimum inclusion level of high-protein CM in diets for weanling pigs.

## MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Pigs used in the experiment were offspring of G-performer boars × F-25 females (Genetiporc, Alexandria, MN).

### Diets, Animals, and Experimental Design

Two sources of CM produced from new varieties of high-protein canola seeds (canola meal A [**CMA**] and canola meal B [**CMB**]) and a CM-CV were used (Tables 1 and 2). Canola meal A and the CM-CV were used at inclusion rates of 10, 20, 30, or 40% of diets fed to weanling pigs, whereas CMB was used only at 10, 20, or 30% inclusion. A control diet containing no CM was also included in the experiment, so a total of 12 diets were formulated (Tables 3 and 4). Canola meal primarily replaced SBM in the diets, and all diets were formulated based on the digestibility values for energy, AA, and P that had previously been determined in the same batches of the 3 sources of CM and the SBM that were used in this experiment.

A total of 420 pigs that had been weaned for 2 wk (initial BW: 9.8 ± 1.1 kg) were divided into 3 blocks based on date of birth, and blocks were started 2 wk apart. Within each block, pigs were randomly allotted via a randomized complete block design to the 12 dietary treatments based on initial BW. There were 3 replicate pens in block 1, 3 replicate pens in block 2, and 2 replicate pens in block 3. Therefore, there were a total of 8 replicates per dietary treatment. There were 5 replicates with 4 pigs per pen, and 3 replicates with 5 pigs per pen with an equal number of barrows and gilts on each treatment. Pens were 1.2 by 1.4 m with slatted or mesh floors, and each pen was equipped with a feeder and a nipple drinker.

Individual pig BW was recorded at the initiation of the experiment, and final BW was recorded at the conclusion. Feed was added as needed to assure free access at all times throughout the 3-wk experiment. Feed intake per pen was recorded. Water was available at all times.

### Sample Collection and Analysis

At the conclusion of the experiment, 1 pig of average BW in each pen was sacrificed, organ weights were recorded, and tissue and blood samples were collected. An equal number of barrows and gilts were sacrificed. Blood samples were collected from the jugular vein of each pig with or without EDTA to yield whole blood and serum, respectively. Tubes were stored on ice immediately after collection. The blood sample collected in EDTA from each pig was analyzed for total and differential blood cell counts using an automated hematology analyzer calibrated for porcine blood (Cell-Dyn 3700; Abbott Laboratories, Abbott Park, IL). Serum was collected to analyze triiodothyronine (**T3**), thyroxine (**T4**), and blood urea nitrogen (**BUN**). Thyroid hormones were analyzed using an ELISA kit according to the recommendation of the manufacturer (Abnova, Taipei, Taiwan), and BUN was analyzed on an Olympus AU680 chemistry analyzer (Olympus Life Science Research Europa GmbH, Munich, Germany). The minimal detectable concentrations of T3 and T4 by these assays were 0.5 and 1.0 ng/mL, respectively.

Following blood collection, pigs were killed via captive bolt penetration and exsanguination. The liver, heart, kidneys, and thyroid gland were removed, and the weight of each organ was recorded.

**Table 2.** Analyzed glucosinolate composition of ingredients (as-fed basis)[1]

| Item, μmol/g | Canola meal A | Canola meal B | Conventional canola meal |
|---|---|---|---|
| Progoitrin | 4.244 | 3.624 | 2.105 |
| Glucoalyssin | 0.909 | 0.582 | 0.423 |
| Gluconapoleiferin | 0.695 | 0.662 | 0.423 |
| Gluconapin | 1.952 | 2.276 | 1.393 |
| 4-hydroxyglucobrassicin | 4.784 | 4.121 | 1.845 |
| Glucobrassicanapin | 0.790 | 0.752 | 0.591 |
| Glucoerucin | 0.935 | 0.928 | 0.955 |
| Glucobrassicin | 0.368 | 0.521 | 0.256 |
| Gluconasturtiin | 0.336 | 0.295 | 0.437 |
| Neoglucobrassicin | 0.473 | 0.456 | 0.266 |
| Total Glucosinolates | 15.486 | 14.217 | 8.694 |

[1]Canola meal A and canola meal B were sourced from Canada; conventional canola meal was sourced from the University of Illinois, Urbana.

The third and fourth metacarpals were collected from the front left foot of each sacrificed pig. Bones were autoclaved for 40 min and cheesecloth was used to aid in the removal of soft tissue. Bones were defatted in ether for 3 d with ether being changed daily. Defatted bones were dried overnight at 130°C and then ashed in a muffle furnace at 600°C for 16 h for determination of total bone ash.

**Table 3.** Ingredient composition of experimental diets (as-fed basis)[1]

| | Diet | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | Canola meal A | | | | Canola meal B | | | Conventional canola meal | | | |
| Ingredient, % | – | 10% | 20% | 30% | 40% | 10% | 20% | 30% | 10% | 20% | 30% | 40% |
| Ground corn | 55.61 | 51.54 | 47.42 | 43.33 | 39.11 | 52.01 | 48.35 | 44.62 | 49.55 | 43.36 | 37.19 | 31.05 |
| Canola meal A | – | 10.00 | 20.00 | 30.00 | 40.00 | – | – | – | – | – | – | – |
| Canola meal B | – | – | – | – | – | 10.00 | 20.00 | 30.00 | – | – | – | – |
| Conventional canola meal | – | – | – | – | – | – | – | – | 10.00 | 20.00 | 30.00 | 40.00 |
| Soybean meal, 47% CP | 28.00 | 21.00 | 14.00 | 7.00 | – | 21.00 | 14.00 | 7.00 | 22.50 | 17.00 | 11.50 | 6.00 |
| Whey powder, dried | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Fish meal | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Phytase premix[2] | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Choice white grease | – | 1.25 | 2.55 | 3.80 | 5.15 | 0.75 | 1.55 | 2.40 | 1.90 | 3.90 | 5.90 | 7.85 |
| Limestone | 1.30 | 1.20 | 1.08 | 0.95 | 0.83 | 1.22 | 1.14 | 1.05 | 1.00 | 0.70 | 0.40 | 0.10 |
| Lysine HCl | 0.25 | 0.23 | 0.22 | 0.2 | 0.19 | 0.24 | 0.22 | 0.21 | 0.25 | 0.26 | 0.27 | 0.28 |
| DL-Met | 0.07 | 0.03 | – | – | – | 0.03 | – | – | 0.04 | 0.03 | 0.01 | – |
| L-Thr | 0.05 | 0.03 | 0.01 | – | – | 0.03 | 0.02 | – | 0.04 | 0.03 | 0.01 | – |
| Salt | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Mecadox premix[3] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Vitamin-mineral premix[4] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |

[1]Canola meal A and canola meal B were sourced from Canada; conventional canola meal and soybean meal were sourced from the University of Illinois, Urbana.

[2]Phytase premix (OptiPhos 2000, Enzyvia LLC, Sheridan, IN) at 0.02% inclusion provided 400 units of phytase per kilogram of complete diet.

[3]The Mecadox premix (Phibro Animal Nutrition, Teaneck, NJ) provided 50 mg/kg complete diet of Carbadox.

[4]Provided the following quantities of vitamins and microminerals 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 as copper sulfate and copper chloride, 20 mg; Fe as ferrous sulfate, 126 mg; I as ethylenediamine dihydriodide, 1.26 mg; Mn as manganese sulfate, 60.2 mg; Se as sodium selenite and selenium yeast, 0.3 mg; and Zn as zinc sulfate, 125.1 mg.

**Table 4.** Analyzed nutrient composition of experimental diets (as-fed basis)[1,2]

| Item | Control | Canola meal A | | | | Canola meal B | | | Conventional canola meal | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | - | 10% | 20% | 30% | 40% | 10% | 20% | 30% | 10% | 20% | 30% | 40% |
| GE, kcal/kg | 3,875 | 3,981 | 4,062 | 4,140 | 4,274 | 3,869 | 4,085 | 4,056 | 3,989 | 4,142 | 4,376 | 4,436 |
| DM, % | 88.74 | 89.16 | 89.51 | 90.15 | 90.64 | 89.40 | 89.99 | 87.78 | 89.50 | 89.98 | 90.28 | 90.66 |
| CP, % | 22.64 | 21.22 | 22.68 | 24.98 | 25.81 | 21.82 | 22.19 | 25.32 | 22.46 | 23.48 | 22.44 | 22.37 |
| Ash, % | 5.20 | 5.50 | 5.77 | 6.01 | 5.66 | 5.93 | 6.07 | 5.88 | 5.39 | 5.77 | 5.53 | 5.68 |
| AEE[3], % | 2.59 | 3.01 | 5.85 | 6.18 | 7.20 | 3.07 | 4.56 | 4.73 | 2.93 | 3.72 | 8.27 | 9.71 |
| NDF, % | 6.00 | 7.50 | 8.36 | 9.85 | 11.05 | 7.20 | 8.43 | 9.39 | 7.38 | 9.11 | 10.66 | 13.04 |
| ADF, % | 2.87 | 3.53 | 3.93 | 4.67 | 5.52 | 3.03 | 3.62 | 4.37 | 3.55 | 5.25 | 6.12 | 8.00 |
| Ca, % | 1.13 | 1.01 | 1.02 | 1.03 | 0.96 | 1.06 | 0.98 | 0.97 | 1.02 | 0.84 | 0.79 | 0.75 |
| P, % | 0.48 | 0.53 | 0.58 | 0.64 | 0.73 | 0.51 | 0.58 | 0.63 | 0.54 | 0.56 | 0.62 | 0.66 |
| Total glucosinolates[4], μmol/g | 0 | 1.55 | 3.10 | 4.65 | 6.19 | 1.42 | 2.84 | 4.27 | 0.87 | 1.74 | 2.61 | 3.48 |
| Indispensable AA, % | | | | | | | | | | | | |
| Arg | 1.29 | 1.19 | 1.33 | 1.35 | 1.30 | 1.29 | 1.37 | 1.42 | 1.36 | 1.34 | 1.34 | 1.29 |
| His | 0.52 | 0.50 | 0.57 | 0.61 | 0.59 | 0.54 | 0.59 | 0.62 | 0.56 | 0.56 | 0.57 | 0.57 |
| Ile | 0.86 | 0.81 | 0.89 | 0.94 | 0.89 | 0.89 | 0.92 | 0.96 | 0.92 | 0.89 | 0.92 | 0.88 |
| Leu | 1.80 | 1.64 | 1.80 | 1.87 | 1.73 | 1.82 | 1.88 | 1.93 | 1.83 | 1.80 | 1.83 | 1.73 |
| Lys | 1.31 | 1.27 | 1.49 | 1.47 | 1.40 | 1.42 | 1.51 | 1.54 | 1.62 | 1.49 | 1.48 | 1.53 |
| Met | 0.42 | 0.36 | 0.43 | 0.46 | 0.45 | 0.39 | 0.42 | 0.47 | 0.45 | 0.42 | 0.46 | 0.44 |
| Phe | 0.98 | 0.89 | 0.97 | 0.98 | 0.90 | 0.98 | 1.01 | 1.02 | 1.01 | 0.98 | 0.99 | 0.93 |
| Thr | 0.88 | 0.81 | 0.91 | 0.93 | 0.90 | 0.86 | 0.92 | 0.98 | 0.92 | 0.94 | 0.93 | 0.93 |
| Trp | 0.27 | 0.28 | 0.30 | 0.30 | 0.28 | 0.27 | 0.28 | 0.30 | 0.25 | 0.24 | 0.28 | 0.30 |
| Val | 0.98 | 0.95 | 1.07 | 1.16 | 1.13 | 1.04 | 1.11 | 1.20 | 1.05 | 1.06 | 1.10 | 1.09 |
| Dispensable AA, % | | | | | | | | | | | | |
| Ala | 1.06 | 0.98 | 1.11 | 1.14 | 1.07 | 1.09 | 1.14 | 1.18 | 1.10 | 1.10 | 1.11 | 1.08 |
| Asp | 2.09 | 1.80 | 1.88 | 1.80 | 1.58 | 1.95 | 1.97 | 1.94 | 2.08 | 1.97 | 1.89 | 1.74 |
| Cys | 0.30 | 0.33 | 0.42 | 0.49 | 0.51 | 0.36 | 0.43 | 0.49 | 0.36 | 0.38 | 0.39 | 0.43 |
| Glu | 3.50 | 3.33 | 3.72 | 3.92 | 3.80 | 3.59 | 3.86 | 4.05 | 3.64 | 3.64 | 3.67 | 3.57 |
| Gly | 0.87 | 0.88 | 1.05 | 1.12 | 1.13 | 0.96 | 1.06 | 1.16 | 0.97 | 1.04 | 1.06 | 1.08 |
| Pro | 1.18 | 1.15 | 1.33 | 1.47 | 1.47 | 1.26 | 1.42 | 1.49 | 1.29 | 1.32 | 1.34 | 1.36 |
| Ser | 0.95 | 0.83 | 0.91 | 0.88 | 0.82 | 0.90 | 0.94 | 0.95 | 0.97 | 0.94 | 0.92 | 0.88 |
| Tyr | 0.68 | 0.59 | 0.65 | 0.64 | 0.60 | 0.67 | 0.68 | 0.68 | 0.69 | 0.68 | 0.68 | 0.65 |
| Total AA | 20.10 | 18.75 | 21.06 | 21.82 | 20.85 | 20.47 | 21.74 | 22.67 | 21.27 | 21.01 | 21.21 | 20.76 |

[1]Canola meal A and canola meal B were sourced from Canada; conventional canola meal and soybean meal were sourced from the University of Illinois, Urbana.

[2]Diets were formulated to contain similar quantities of NE (2,475 kcal/kg), standardized ileal digestible AA (1.29% Lys; 0.38% Met; 0.76% Thr; and 0.21% Trp), and standardized total tract digestible P (0.36%). Values for the NE, standardized ileal digestible AA, and standardized total tract digestible P were determined in previous experiments using the same batches of the ingredients used in this experiment (Parr et al., 2014; Berrocoso et al., 2015).

[3]Acid hydrolyzed ether extract.

[4]Values for total glucosinolates were calculated rather than analyzed by multiplying the analyzed value in each source of canola meal by the inclusion of that canola meal in the diet. It was assumed corn and soybean meal contained no glucosinolates.

Diets and ingredients were analyzed for GE using bomb calorimetry (Model 6300; Parr Instruments, Moline, IL), DM in a forced air oven after drying for 2 h at 135°C (Method 930.15; AOAC, 2007), and CP by combustion (Method 990.03; AOAC, 2007) using a Rapid N Cube (Elementar Americas Inc., Mt. Laurel, NJ) with Asp as the standard (Tables 1 and 4). Diets and ingredients were also analyzed for acid hydrolyzed ether extract (Method 2003.06; AOAC, 2007) on an automated analyzer (Soxtec 2050; FOSS North America, Eden Prairie, MN), ADF (Method 973.18; AOAC, 2007), NDF (Holst, 1973), and AA (Method 982.30 E [a, b, and c]; AOAC, 2007). Diet and ingredient samples were also analyzed for Ca and P using inductively coupled plasma spectroscopy (Method 985.01 A, B, and C; AOAC, 2007) after wet ashing (Method 975.03 B [b]; AOAC, 2007). Diets, ingredients, and bones were analyzed for ash (Method 942.05; AOAC, 2007). Ingredients were also analyzed for phytate concentration (Ellis et al., 1977) and glucosinolates (Method MGLUC-01; SunWest Food Laboratory Ltd., Saskatoon, SK).

### Calculations and Statistical Analysis

At the conclusion of the experiment, pig weights were recorded and data were summarized to calculate

**Table 5.** Growth performance of weanling pigs fed diets containing graded inclusion levels of 3 different canola meals[1,2]

| | Diet | | | | | | | | | | | | | P-value | | | | | |
| | Control | Canola meal A | | | | Canola meal B | | | Conventional canola meal | | | | | Canola meal A | | Canola meal B | | Conventional canola meal | |
| Item | – | 10% | 20% | 30% | 40% | 10% | 20% | 30% | 10% | 20% | 30% | 40% | SEM | Lin.[3] | Q[4] | Lin. | Q | Lin. | Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial BW, kg | 9.9 | 9.9 | 10 | 9.9 | 9.9 | 10.1 | 10.0 | 9.8 | 10.0 | 9.8 | 9.8 | 9.9 | 0.56 | 0.983 | 0.886 | 0.853 | 0.703 | 0.926 | 0.930 |
| ADFI, kg | 0.96 | 1.00 | 0.94 | 0.87 | 0.84 | 1.00 | 0.94 | 0.88 | 0.98 | 0.94 | 0.90 | 0.84 | 0.04 | <0.001 | 0.170 | 0.02 | 0.072 | 0.012 | 0.218 |
| ADG, kg | 0.56 | 0.60 | 0.60 | 0.55 | 0.54 | 0.59 | 0.57 | 0.54 | 0.59 | 0.61 | 0.58 | 0.57 | 0.02 | 0.136 | 0.056 | 0.254 | 0.173 | 0.951 | 0.108 |
| G:F | 0.59 | 0.60 | 0.64 | 0.64 | 0.64 | 0.59 | 0.60 | 0.62 | 0.60 | 0.65 | 0.65 | 0.68 | 0.02 | 0.031 | 0.599 | 0.133 | 0.430 | 0.001 | 0.960 |
| Final BW, kg | 21.8 | 22.4 | 22.6 | 21.5 | 21.2 | 22.4 | 21.9 | 21.3 | 22.3 | 22.6 | 22.1 | 21.8 | 0.90 | 0.417 | 0.304 | 0.466 | 0.388 | 0.965 | 0.404 |

[1]Canola meal A and canola meal B were sourced from Canada; conventional canola meal and soybean meal were sourced from the University of Illinois, Urbana.

[2]Data are least squares means of 8 observations for all diets.

[3]Linear effect of each canola meal.

[4]Quadratic effect of each canola meal.

ADG, ADFI, and G:F. Percent bone ash was calculated by dividing ashed bone weight by dried defatted bone weight. Concentrations of nonphytate- and phytate-bound P in CM and SBM were calculated as previously described (Rojas and Stein, 2012). Glucosinolate concentration in the diets was calculated by multiplying the total analyzed glucosinolate concentration of the CM used by the inclusion level of that CM in the diet. Data for ADG, ADFI, G:F, organ weights, bone ash, total and differential blood counts, T3 and T4 levels, and BUN were analyzed using the PROC MIXED of SAS (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. The model included treatment as the fixed effect and block as the random effect. Least squares means were calculated for each independent variable. Linear and quadratic effects of inclusion level of CM were determined using orthogonal contrasts, and the control diet was included in all contrasts. Significance was assessed at $P \leq 0.05$ and tendencies were determined at $0.05 < P \leq 0.10$.

## RESULTS

### Composition of Ingredients

The 2 high-protein CM contained more GE, more CP, and more indispensable AA than the CM-CV, but AA concentrations in all CM were less than in SBM. Concentrations of ADF and NDF were also reduced in CMA and CMB compared with CM-CV, whereas the concentration of P was similar among all sources of CM, but greater than in SBM. The differences in ADF and NDF among ingredients were also reflected in the concentrations of ADF and NDF in the diets, with increasing ADF and NDF as CM replaced SBM and greater levels of ADF and NDF in diets containing CM-CV than in diets containing CMA or CMB. All diets were formulated to contain similar quantities of NE, standardized ileal digestible indispensable AA,

and standardized total tract digestible P, and because of differences among ingredients in concentration and digestibility of energy and nutrients, differences among diets in concentrations of total AA were expected and are assumed not to have influenced the results. The relatively high concentrations of total and digestible P in all sources of CM resulted in the concentration of total and digestible P to increase as CM increased in the diets.

### Growth Performance

All pigs readily consumed their assigned diets; however, a total of 10 pigs were removed from the experiment because they became sick or lame. One pig was on the control diet, 2 pigs were on the 20% diet, 3 were on the 30% diet, and 4 were on the 40% diet. None of the pig removals appeared to be treatment related. There were no differences in initial BW among pigs assigned to the 12 dietary treatments (Table 5). Average daily feed intake was linearly reduced ($P < 0.05$) with increased inclusion of CM, regardless of variety. Graded inclusion of CMA tended to increase (quadratic, $P = 0.06$) ADG, but adding CMB or CM-CV to the diets did not affect ADG. The G:F was improved (linear, $P < 0.05$) with increasing inclusion of CMA or CM-CV in the diets, but inclusion of CMB in the diets had no impact on G:F. Final BW was not affected by dietary treatments.

### Organ, Bone, and Blood Characteristics

Liver weight tended to increase (linear, $P = 0.06$) for pigs fed diets containing CMA and also increased (linear, $P < 0.05$) for pigs fed CMB, but inclusion of the CM-CV in the diets did not influence liver weight (Table 6). Thyroid gland weight was increased (linear, $P < 0.05$) for pigs fed diets containing CMA, but inclusion of CMB or the CM-CV did not influence thyroid gland weight. Feeding CM did not affect heart or kidney weights with

**Table 6.** Organ, bone, and blood characteristics of weanling pigs fed diets containing graded inclusion levels of 3 different canola meals[1,2]

| Item | Control | Canola meal A | | | | Canola meal B | | | Conventional canola meal | | | | SEM | Canola meal A | | Canola meal B | | Conventional canola meal | |
| | | | | | | | | | | | | | | Lin.[3] | Q[4] | Lin. | Q | Lin. | Q |
| | - | 10% | 20% | 30% | 40% | 10% | 20% | 30% | 10% | 20% | 30% | 40% | | | | | | | |
| Organs wt, % of BW | | | | | | | | | | | | | | | | | | | |
| Liver | 2.84 | 2.83 | 2.90 | 2.98 | 3.05 | 3.17 | 3.05 | 3.34 | 2.89 | 2.96 | 2.85 | 2.86 | 0.10 | 0.057 | 0.600 | 0.024 | 0.861 | 0.975 | 0.500 |
| Heart | 0.52 | 0.52 | 0.53 | 0.53 | 0.53 | 0.55 | 0.54 | 0.52 | 0.55 | 0.53 | 0.53 | 0.52 | 0.02 | 0.484 | 0.648 | 0.917 | 0.106 | 0.570 | 0.259 |
| Kidneys | 0.59 | 0.58 | 0.57 | 0.51 | 0.57 | 0.57 | 0.58 | 0.58 | 0.61 | 0.56 | 0.51 | 0.48 | 0.03 | 0.248 | 0.415 | 0.811 | 0.649 | <0.001 | 0.423 |
| T. Gl.[5,6] | 12.1 | 11.3 | 13.1 | 13.4 | 15.0 | 12.7 | 12.0 | 15.7 | 12.6 | 14.0 | 14.4 | 12.4 | 0.001 | 0.040 | 0.445 | 0.106 | 0.259 | 0.556 | 0.189 |
| Bones | | | | | | | | | | | | | | | | | | | |
| Bone wt, g | 3.73 | 3.63 | 3.59 | 3.79 | 3.93 | 3.28 | 3.51 | 3.70 | 3.64 | 3.39 | 4.13 | 3.19 | 0.37 | 0.460 | 0.427 | 0.890 | 0.144 | 0.362 | 0.409 |
| Ash wt, g | 1.72 | 1.71 | 1.71 | 1.86 | 1.91 | 1.58 | 1.72 | 1.81 | 1.77 | 1.68 | 1.96 | 1.59 | 0.16 | 0.099 | 0.506 | 0.286 | 0.211 | 0.831 | 0.231 |
| Ash, % | 46.1 | 47.7 | 48.3 | 49.3 | 48.8 | 48.5 | 49.5 | 49.2 | 48.5 | 49.9 | 47.5 | 50.2 | 0.86 | 0.017 | 0.251 | 0.003 | 0.069 | <0.001 | 0.143 |
| Blood | | | | | | | | | | | | | | | | | | | |
| T3[7], ng/mL | 1.22 | 0.96 | 0.92 | 0.91 | 0.88 | 0.99 | 0.98 | 0.94 | 1.00 | 1.03 | 1.05 | 0.83 | 0.11 | 0.009 | 0.153 | 0.148 | 0.477 | 0.021 | 0.996 |
| T4[8], ng/mL | 38.0 | 36.5 | 33.7 | 33.4 | 31.2 | 36.3 | 36.4 | 33.3 | 37.3 | 36.1 | 36.0 | 35.4 | 2.82 | <0.001 | 0.850 | 0.069 | 0.721 | 0.125 | 0.770 |
| BUN[9], mg/dL | 11.5 | 10.1 | 10.2 | 11.2 | 11.6 | 11.4 | 10.2 | 10.9 | 9.6 | 10.6 | 8.9 | 9.3 | 1.01 | 0.676 | 0.152 | 0.375 | 0.577 | 0.115 | 0.651 |

[1]Canola meal A and canola meal B were sourced from Canada; conventional canola meal and soybean meal were sourced from the University of Illinois, Urbana.

[2]Data are least squares means of 8 observations for all diets.

[3]Linear effect of each canola meal.

[4]Quadratic effect of each canola meal.

[5]Thyroid gland.

[6]Weight of thyroid glands multiplied by 1,000.

[7]Triiodothyronine.

[8]Thyroxine.

[9]Blood urea nitrogen.

the exception that kidney weights from pigs fed diets containing CM-CV decreased (linear, $P < 0.05$) with increasing inclusion of CM in the diets.

No difference was observed in bone weight when CM was added to the diets. Adding CMA to the diets tended to increase (linear, $P = 0.10$) ashed bone weight, but no effects on ashed bone weight were observed for pigs fed diets containing CMB or the CM-CV. Bone ash percentage was increased (linear, $P < 0.05$) for pigs fed diets containing CM, regardless of the variety.

The concentration of T3 was decreased (linear, $P < 0.05$) for pigs fed diets containing CMA or CM-CV, but no difference was observed in T3 concentration if pigs were fed CMB diets. Inclusion of CMA linearly decreased ($P < 0.01$) and inclusion of CMB tended ($P = 0.07$) to decrease serum concentration of T4, but this was not the case for CM-CV. Adding CM to the diets did not affect the concentration of BUN.

Increasing the inclusion level of CM-CV tended ($P = 0.08$) to quadratically affect the number of lymphocytes, the concentration of hemoglobin ($P = 0.07$), and packed cell volume ($P = 0.07$) in pigs and increased (quadratic, $P < 0.05$) red blood cell concentration (Table 7). Inclusion of CMB linearly decreased ($P < 0.05$) red blood cell distribution width, but no other differences were observed in the total and differential blood cell counts among dietary treatments.

## DISCUSSION

### Composition of Ingredients

The CM-CV had lower concentrations of DM, CP, GE, and most AA compared with published values for solvent-extracted CM. Likewise, concentrations of NDF and ADF were less than values in the literature (NRC, 2012).

Canola meals A and B were produced from high-protein varieties of canola and, therefore, had greater CP and AA concentrations than CM-CV. Simbaya et al. (1995) reported that the protein concentration of high-protein CM was 3.8 percentage units greater than in CM-CV, but Slominski et al. (2012) reported a 6 percentage unit difference between the meals produced from conventional canola and high-protein canola. The reason that the difference observed in this study was more than 10 percentage units between high-protein CM and CM-CV may be that the CP in CM-CV was less than in the CM-CV used by others. Values analyzed for the high-protein CM were in agreement with or slightly less than previously published values (Simbaya et al., 1995; Slominski et al., 2012; Sanjayan, 2013; Liu et al., 2014).

In addition to greater protein concentration, high-protein canola varieties contain less fiber. This is partly due to the thinner hull, which, in addition to the larger

**Table 7.** Total and differential blood counts for weaning pigs fed diets containing graded inclusion level of 3 different canola meals[1,2]

| | Diet | | | | | | | | | | | | | P-value | | | | | |
| | Control | Canola meal A | | | | Canola meal B | | | Conventional canola meal | | | | | Canola meal A | | Canola meal B | | Conventional canola meal | |
| Item[3] | - | 10% | 20% | 30% | 40% | 10% | 20% | 30% | 10% | 20% | 30% | 40% | SEM | Lin.[4] | Q[5] | Lin. | Q | Lin. | Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WBC, $10^3$/µL | 24.3 | 15.1 | 17.8 | 17.7 | 17.2 | 19.2 | 17.8 | 21.9 | 17.4 | 17.9 | 20.4 | 19.3 | 2.74 | 0.21 | 0.18 | 0.54 | 0.15 | 0.37 | 0.17 |
| NEU, $10^3$/µL | 7.08 | 6.54 | 6.90 | 6.15 | 6.59 | 5.50 | 6.80 | 7.07 | 6.50 | 7.56 | 6.81 | 6.09 | 1.25 | 0.84 | 0.96 | 0.76 | 0.30 | 0.58 | 0.63 |
| LYM, $10^3$/µL | 16.6 | 7.65 | 9.75 | 10.8 | 9.64 | 12.9 | 10.1 | 13.5 | 9.85 | 9.28 | 12.1 | 11.6 | 2.15 | 0.17 | 0.12 | 0.34 | 0.21 | 0.39 | 0.08 |
| MONO, $10^3$/µL | 0.62 | 0.69 | 0.76 | 0.59 | 0.60 | 0.66 | 0.78 | 1.14 | 0.81 | 0.85 | 1.05 | 1.08 | 0.25 | 0.81 | 0.62 | 0.10 | 0.45 | 0.27 | 0.85 |
| RBC, $10^6$/µL | 6.80 | 6.45 | 6.57 | 6.58 | 6.62 | 6.47 | 6.76 | 6.57 | 6.53 | 6.48 | 6.64 | 6.84 | 0.20 | 0.80 | 0.27 | 0.64 | 0.69 | 0.70 | 0.03 |
| HGB, g/dL | 12.1 | 11.9 | 12.2 | 12.0 | 11.9 | 11.7 | 11.7 | 11.8 | 11.7 | 11.8 | 12.0 | 12.4 | 0.29 | 0.63 | 0.76 | 0.39 | 0.26 | 0.28 | 0.07 |
| HCT, % | 37.2 | 37.2 | 37.2 | 36.7 | 36.6 | 36.9 | 36.2 | 36.6 | 36.1 | 36.4 | 37.0 | 38.6 | 0.82 | 0.45 | 0.84 | 0.42 | 0.61 | 0.16 | 0.07 |
| MCV, fL | 55.4 | 57.6 | 56.7 | 55.9 | 55.3 | 57.3 | 53.8 | 56.0 | 55.5 | 56.2 | 55.8 | 56.7 | 1.19 | 0.51 | 0.13 | 0.64 | 0.84 | 0.12 | 0.80 |
| MCH, pg | 18.1 | 18.4 | 18.6 | 18.2 | 17.9 | 18.1 | 17.3 | 18.0 | 18.0 | 18.2 | 18.0 | 18.3 | 0.39 | 0.72 | 0.13 | 0.60 | 0.36 | 0.30 | 0.76 |
| MCHC, g/dL | 32.6 | 31.9 | 32.8 | 32.6 | 32.5 | 31.7 | 32.3 | 32.2 | 32.5 | 32.5 | 32.4 | 32.2 | 0.27 | 0.40 | 0.85 | 0.78 | 0.12 | 0.18 | 0.77 |
| RDW, % | 25.0 | 22.0 | 24.3 | 22.8 | 23.4 | 23.1 | 23.7 | 21.6 | 23.7 | 23.3 | 23.3 | 22.9 | 0.80 | 0.33 | 0.23 | 0.02 | 0.90 | 0.08 | 0.43 |

[1]Canola meal A and canola meal B were sourced from Canada; conventional canola meal and soybean meal were sourced from the University of Illinois, Urbana.

[2]Data are least squares means of 7 to 8 observations for all diets.

[3]WBC = white blood cell; NEU = neutrophil; LYM = lymphocyte; MONO = monocyte; RBC = red blood cell; HGB = hemoglobin; HCT = packed cell volume; MCV = mean corpuscular volume; MCH = mean corpuscular hemoglobin; MCHC = mean corpuscular hemoglobin concentration; RDW = red blood cell distribution width; fL = femtolitre ($10^{-15}$ L).

[4]Linear effect of each canola meal.

[5]Quadratic effect of each canola meal.

seed, results in the hull fraction accounting for less of the total seed mass (Liu et al., 2014). Analyzed values for NDF were in agreement with values reported by Slominski et al. (1994) and were approximately 7 percentage units less than the NDF of CM-CV. This is in accordance with previous research indicating that dietary fiber concentration in high-protein CM is 6 to 10 percentage units less than in CM-CV (Simbaya et al., 1995; Trindade Neto et al., 2012; Liu et al., 2014).

One of the main reasons for limited use of CM in swine diets is the high level of glucosinolates (Schöne et al., 2001). The high-protein CM used in this study contained almost twice the levels of glucosinolates compared with the CM-CV. However, all CM used in the present study contained much less glucosinolates than traditional rapeseed meal containing 120 to 150 µmol/g of total glucosinolates (Canola Council of Canada, 2009).

### Growth Performance

The lack of a difference in ADG between the CM diets and the control diet is not consistent with data from Castell (1977), who concluded that pigs fed rapeseed meal had poorer ADG compared with pigs fed SBM, but the present observations are in agreement with more recent reports in which it was indicated that feeding up to 25% CM did not affect growth performance (King et al., 2001; Landero et al., 2011). The decrease in ADFI observed in this experiment is consistent with Baidoo et al. (1987), who conducted 4 experiments feeding graded inclusion levels of CM

to pigs and reported that increased CM inclusion rate decreased the ADFI of pigs. The observation that feed efficiency was improved for pigs fed CMA and CM-CV diets compared with pigs fed the control diet is in agreement with previous results (Castell, 1977). The increased G:F is mainly due to the decreased ADFI, as the inclusion rate of CM was increased in the diets. A potential explanation for this observation is that although the pigs gained the same, body composition may have been changed. It is unlikely that ME in the CM was underestimated because values that had been determined in the same batches of CM and SBM were used in diet formulations. The decrease in ADFI for pigs fed diets containing CM may be explained by the increase in glucosinolates in the diets, which cause a bitter taste. Schöne et al. (1997) recommended that the concentration of glucosinolates in diets should not exceed 2 µmol/g. The high-protein CM used in the present experiment are only under that recommended value at 10% inclusion, whereas the CM-CV is within that limitation up to 20% inclusion. Nevertheless, data from the current experiment indicating that between 20 and 40% high-protein or CM-CV may be included in diets for weanling pigs without negatively impacting growth performance is in agreement with recent data indicating that at least 20 or 25% CM-CV may be included in diets fed to weanling pigs (Sanjayan et al., 2014). Based on these observations, it appears that CM produced from currently grown varieties of canola may be included in greater quantities in diets fed to weanling pigs than previously concluded.

### Organs

The increase in liver weights is consistent with observations by Corino et al. (1991) and Castell and Cliplef (1993). These observations are in contrast to reports from previous studies indicating no change in the liver weights of pigs fed diets containing CM (Slinger, 1977; Thomke et al., 1983; Busato et al., 1991).

The increased weight of the thyroid gland with increasing inclusion of CM-CV is in agreement with studies published by Thomke et al. (1983) and Mullan et al. (2000). On the contrary, Busato et al. (1991) and King et al. (2001) reported that CM had no effect on thyroid gland weight. Diets containing CM also produced greater thyroid gland weights than the control diet, which is in agreement with Slinger (1977), who reported an increase in thyroid gland weights of pigs fed CM compared with pigs fed a corn-SBM diet. The increased thyroid gland weights for pigs fed CMA may be due to the higher level of glucosinolates in those diets. It has been reported that glucosinolates can reduce iodine absorption and incorporation in the thyroid gland and, therefore, induce hyperthyroidism and suppress T4 secretion (Tripathi and Mishra, 2007). The lack of a significant difference observed for pigs fed CMB compared with pigs fed the control diet is likely because the inclusion level of CMB in this study was less than 40%.

Increased thyroid gland weight may be due to a lack of iodine in the thyroid gland, which is possibly caused by goitrogens in CM (Underwood, 1977). Sihombing et al. (1974) conducted 4 experiments to investigate the effect of iodine supplementation on thyroid gland weight in pigs with induced hypothyroidism. Results of all 4 experiments indicated that thyroid gland weights were reduced with increasing iodine supplementation. However, iodine was included in the vitamin-micromineral premix that was used in this experiment, which may have ameliorated the effects of glucosinolates on weight of the thyroid glands. The decrease in kidney weights observed for pigs fed diets containing the CM-CV is contradictory to previous research by Thomke et al. (1983), but the lack of an effect of treatment on heart weight agrees with data reported by Slinger (1977).

### Bones

Although the thyroid gland data indicate a potential shortage of iodine, the lack of a difference in bone weights indicates that feeding up to 40% CM for 3 wk to weanling pigs does not affect bone growth. If the iodine deficiency had been severe, a reduction in bone growth would have been expected. The increase in bone ash percent with increasing inclusion of all 3 CM is likely a result of increased P concentration in the CM diets. Because of the high concentrations of

digestible P in the 3 sources of CM, concentrations of standardized total tract digestible P increased as the concentration of CM increased in the diets.

### Blood

The reduced serum concentrations of T3 and T4 in pigs fed CM compared with pigs fed the control diet are in agreement with results of previous research (Bowland, 1975; Busato et al., 1991). Reduced thyroid hormone levels in combination with increased thyroid gland weight may be indicative of impairment of thyroid function due to glucosinolates in the diets. The thyroid hormones are responsible for normal muscle function, including growth and development, and a deficiency may result in growth depression (Hocquette et al., 1998). The thyroid hormone concentrations that were observed in this experiment for pigs fed the CM diets, however, appear not to have been low enough to reduce growth performance of pigs.

There was no difference in BUN among treatments, indicating that all diets were balanced for AA to the same degree. Crystalline AA were used in diet formulation to obtain this balance. Data for complete blood counts can be used as indicators for the health status of animals. Reduced red blood cell number, hemoglobin concentration, and packed cell volume have been reported in pigs fed a rapeseed meal diet due to the high concentration of glucosinolates in this diet (Schöne et al., 1990). Feeding a diet containing a high level of glucosinolates also decreased white blood cell concentration, hemoglobin, and packed cell volume in growing rabbits (Tripathi et al., 2008). However, in the present experiment, only a few differences were observed in the total and differential blood counts and all values were within the normal range, indicating that inclusion of up to 40% of high-protein or CM-CV does not have negative effects on pig health.

In conclusion, high-protein CM or CM-CV can be included in diets for weanling pigs from 2 wk postweaning by up to 20% without reducing growth performance or negatively affecting organ, bone, or blood characteristics. However, results of this experiment indicate that even greater inclusion rates may be used, and it is possible that up to 40% high-protein CM or CM-CV may be included in diets fed to weanling pigs.

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