ABSTRACT
This experiment was conducted to evaluate effects of replacing ‘part’ of soybean meal (SBM) with 4% rapeseed meal (RSM) or 4% canola meal (CM) on growth performance, nutrient digestibility, blood characteristics, faecal noxious gas emission, and meat quality in finishing pigs. A total of 120 crossbred finishing pigs [(Yorkshire × Landrace) × Duroc] with an average body weight of 50.71 ± 1.97 kg were randomly divided into one of three dietary treatments according to their sex and BW (10 replicate pens with 2 barrows and 2 gilts per pen). Dietary treatments were as follows: (1) CON, a corn-SBM-based diet; (2) CM4, diet containing 4% CM originated from Korea; (3) RSM4, diet containing 4% RSM originated from India. Replacing SBM with 4% RSM or 4% CM had no effects on average daily gain, average daily feed intake, gain to feed ratio, concentrations of blood urea nitrogen and creatinine, faecal ammonia, hydrogen sulphide, and total mercaptans emission, meat quality, and apparent total tract digestibility of dry matter, nitrogen, and gross energy. In conclusion, the inclusion of 4% of RSM or CM in finishing pig diets had no negative effects on growth performance, nutrients digestibility, faecal noxious gas emission, blood characteristics, and meat quality.

1. Introduction
There has been an increase in economic concern movement to explore feed ingredients for swine with respect to high growth performance at a lower feeding cost. Pigs feed uses cereal grain as a major ingredient. Corn (as a cereal grain) is the most fundamental feed ingredient for it provides high energy input due to its high level of total nutrients. The other main feed ingredient is soybean meal (SBM) that has been used as a major protein source (O’Doherty et al. 2001). However, because of the increasing cost of SBM, many researchers have been anxious to find other protein sources such as by-product of oilseed meal.

Canola was developed through conventional plant breeding from rapeseed to obtain low levels of erucic acid in the oil and low levels of glucosinolates in the coproducts produced from the plants (Bell 1993). Canola meal (CM) is a coproduct produced after oil extraction processing and is widely used as a protein ingredient in animal diets (Sanjayan et al. 2014). Compared with SBM, CM contains less crude protein and amino acids and relatively high levels of fibre, which may reduce feed intake and digestibility of nutrients (González-Vega and Stein 2012). Some rapeseeds, however, which are high in glucosinolates, are still grown in some parts of the world because of the need of some acids for the industry application. The glucosinolates, anti-nutritional factors, have been demonstrated to impair growth and feed intake (Agerbirk and Olsen 2012; Florou-Paneri et al. 2014; Hanczakowska and Swiatkiewicz 2014; Torres-Pitarch et al. 2014). Therefore, to reduce cost of ingredients, the objective of this experiment was to evaluate whether 4% rapeseed meal (RSM) or CM can replace part of SBM as a protein source in finishing pig diets.

2. Materials and methods
The experimental protocols were approved by Animal Care and Use Committee of Dankook University.

2.1. Experimental design, animals, housing, and diets
A total of 120 crossbred pigs [(Yorkshire × Landrace) × Duroc] with an average body weight (BW) of 50.71 ± 1.97 kg were used for a 12-week trial. The pigs were randomly sorted into 1 of 3 dietary treatments with 10 replicate pens per treatment and 4 pigs (2 barrows and 2 gilts) per pen according to initial BW and sex. Dietary treatments were as follows: (1) CON, a corn-SBM-based diet; (2) CM4, diet containing 4% CM originated from Korea; and (3) RSM4, diet containing 4% RSM originated from India. The analysed nutrient levels of SBM, CM, and RSM are presented in Table 1. All diets were formulated to meet or exceed the nutritional requirement (NRC 2012; Table 2). All pigs were housed in an environmentally controlled room with a slatted plastic floor. Each pen was equipped with a self-feeder and a nipple drinker to allow ad libitum access to feed and water throughout the experimental period.
### Table 1. Analysed value of SBM, CM, and RSM.

| Item                  | SBM  | CM   | RSM  |
|-----------------------|------|------|------|
| GE, kcal/kg           | 4423 | 5444 | 3391 |
| DM, %                 | 89.33| 89.76| 90.25|
| Crude protein, %      | 48.45| 38.57| 36.16|
| Crude ash, %          | 6.29 | 6.15 | 7.41 |
| Total phosphorus, %   | 0.67 | 1.12 | 1.07 |
| Calcium, %            | 0.42 | 0.84 | 0.72 |
| Crude fibre, %        | 3.87 | 11.14| 12.98|
| Total glucosinolate, µmol/g | – | 23.26| 75.45|
| Essential amino acids, % | | | |
| Arg                   | 3.43 | 2.76 | 2.45 |
| His                   | 1.31 | 1.01 | 0.92 |
| Iso                   | 2.17 | 1.55 | 1.47 |
| Leu                   | 3.65 | 2.50 | 2.38 |
| Lys                   | 3.03 | 2.15 | 2.11 |
| Met                   | 0.65 | 0.88 | 0.88 |
| Phe                   | 2.43 | 1.57 | 1.61 |
| Thr                   | 1.70 | 1.64 | 1.61 |
| Try                   | 0.67 | 0.49 | 0.47 |
| Val                   | 2.24 | 1.88 | 1.75 |
| Non-essential amino acids, % | | | |
| Ala                   | 2.07 | 1.66 | 1.62 |
| Asp                   | 5.57 | 2.91 | 2.77 |
| Cys                   | 0.73 | 0.89 | 0.85 |
| Glu                   | 8.72 | 6.11 | 5.79 |
| Gly                   | 1.91 | 1.83 | 1.76 |
| Pro                   | 2.26 | 1.97 | 1.83 |
| Ser                   | 1.95 | 1.64 | 1.61 |
| Tyr                   | 1.71 | 0.93 | 0.91 |

### Table 2. Diets’ compositions of control diet (as-fed basis).

| Item                  | CON   | CM4   | RSM4  |
|-----------------------|-------|-------|-------|
| Ingredient, %         |       |       |       |
| Corn                  | 72.29 | 61.90 | 63.91 |
| Corn gluten           | –     | 2.40  | 2.00  |
| Wheat bran            | –     | 2.30  | 2.00  |
| SBM                   | 22.00 | 18.00 | 18.00 |
| CM                    | –     | 4.00  | –     |
| RSM                   | –     | –     | –     |
| Rice bran             | –     | 2.30  | 1.40  |
| Soybean hull          | –     | 1.50  | 1.05  |
| Tallow (liquid)       | 3.00  | 5.17  | 5.13  |
| L-Lys·HCl (78%)       | 0.16  | 0.15  | 0.17  |
| DL-Met (99%)          | 0.01  | –     | –     |
| Limestone             | 0.77  | 1.00  | 0.88  |
| Dicalcium phosphate   | 1.26  | 0.77  | 0.95  |
| Salt                  | 0.20  | 0.20  | 0.20  |
| Vitamin premix        | 0.20  | 0.20  | 0.20  |
| Mineral premix        | 0.10  | 0.10  | 0.10  |
| Choline chloride      | 0.01  | 0.01  | 0.01  |
| Total                 | 100   | 100   | 100   |
| Calculated composition, % |       |       |       |
| Metabolizable energy, kcal/kg | 3410 | 3410 | 3410 |
| Crude protein         | 15.95 | 15.95 | 15.95 |
| Crude fibre           | 3.10  | 4.18  | 3.80  |
| Calcium               | 0.65  | 0.65  | 0.65  |
| Total phosphorus      | 0.55  | 0.55  | 0.55  |
| Available phosphorus  | 0.33  | 0.27  | 0.29  |
| Lys                   | 0.90  | 0.90  | 0.90  |
| Me + Cys              | 0.60  | 0.60  | 0.62  |
| Total Glucosinolate, µmol/g | 0   | 0.93  | 3.02  |

Notes: Abbreviation: MC: canola meal from Korea; RSM: rapeseed meal from India; SBM: soybean meal.

Dietary treatments were as follows: (1) CON, a corn-SBM-based diet; (2) CM4, diet containing 4% CM originated from Korea; (3) RSM4, diet containing 4% RSM originated from India. Vitamin premix provided per kg of complete diet: vitamin A, 11,025 IU; vitamin D3, 1,103 IU; vitamin E, 44 IU; vitamin K, 4.4 mg; riboflavin, 8.3 mg; niacin, 50 mg; thiamine, 4 mg; pantothenic acid, 29 mg; choline, 166 mg; and vitamin B12, 33 µg. Mineral premix provided per kg of complete diet: Cu, 12 mg; Zn, 85 mg; Mn, 8 mg; I, 0.28 mg; and Se, 0.15 mg.

### 2.2. Sampling and measurements

SBM, CM, and RSM, in addition to the experimental diets were analysed for dry matter (DM) (method 930.15; AOAC, 2012), crude protein (method 984.13; AOAC, 2012), ash (method 942.05; AOAC, 2012), calcium (method 927.02; AOAC, 2012), phosphorus (method 984.27; AOAC 2012), and crude fibre (method 978.10; AOAC, 2012). Gross energy (GE) was measured using an oxygen bomb calorimeter (Parr 6100, Parr instrument Co., Moline, IL, USA). Total glucosinolates content of CM and RSM was determined according to the method described by Daun and McGregor (1981).

SBM, CM, and RSM were also analysed for concentration of amino acids. With the exception of Met, Cys, and Try, the amino acid content was determined after hydrolysis with 6 N HCl at 110°C for 24 h using an amino acid analyser (Hitachi L-8900, Tokyo, Japan). Met and Cys were determined as methionine sulphone and cysteic acid after cold performic acid oxidation overnight and hydrolysing with 7.5 N HCl at 110°C for 24 h using an amino acid analyser. Try was determined after LiOH hydrolysis for 22 h at 110°C using high-performance liquid chromatography (Agilent 1200 Series, Santa Clara, CA, USA).

Individual pig BW and feed consumption on a pen basis were recorded at the beginning and end of 12 week to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio (G:F). During the experimental period, pigs were fed diets mixed with 0.2% chromic oxide (Cr2O3) as an indigestible marker for the determination of apparent total tract digestibility (ATTD) for DM, GE, and nitrogen. At 12 week, faecal samples were collected from 8 pigs in each treatment group via rectal massage. All feed and faecal samples were stored at −20°C until analysis. Faeces were thawed at 57°C for 72 h, ground to pass through a 1-mm screen, after which the feed and faecal samples were analysed for DM and N according to the AOAC (2012). Chromium was analysed via UV absorption spectrophotometry (Shimadzu UV-1111mm1201, Shimadzu, Kyoto, Japan) following the method described by Williams et al. (1962). Energy was determined by using an oxygen bomb calorimeter (Parr 6100, Parr instrument Co., Moline, IL, USA). Nitrogen was determined (Kjetc 2300 Nitrogen Analyzer; Foss Tecator AB, Hoegeanaes, Sweden). The digestibility was calculated using the following formula:

\[
\text{Digestibility (％) = } \frac{1 - \left[ (N_f \times \text{Cd}) / (Nd \times \text{Cf}) \right]}{100}
\]

where Nf is the nutrient concentration in faeces (% DM), Nd the nutrient concentration in diet (% DM), Cd the chromium concentration in feed and faecal samples were analysed for DM and N according to the AOAC (2012). Chromium was analysed via UV absorption spectrophotometry (Shimadzu UV-1111mm1201, Shimadzu, Kyoto, Japan) following the method described by Williams et al. (1962). Energy was determined by using an oxygen bomb calorimeter (Parr 6100, Parr instrument Co., Moline, IL, USA). Nitrogen was determined (Kjelt 2300 Nitrogen Analyzer; Foss Tecator AB, Hoegeanaes, Sweden). The digestibility was calculated using the following formula:

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\]
Faeces were collected by rectum massage, and urine was collected on per pen basis using a steel plate at 12 week to determine faecal ammonia, total mercaptans, and hydrogen sulphide emission. Amounts of 150 g fresh faeces and 150 g urine mixture samples were stored in 2.6 L plastic boxes for replicates (Yan, Lim et al. 2012; Yan, Wang et al. 2012). The samples were fermented for seven days at room temperature (28°C). During the fermentation period, a gas sampling pump (Gastec, GV-100, Japan) was utilized for gas detection. The adhesive plasters were punctured, and 100 ML of headspace air was sampled approximately 2.0 cm above the faeces surface in 1 min.

At the end of the experiment, all pigs were transferred to the slaughter house and treated with conventional procedures. Carcasses were chilled at 2°C for 24 h and a piece of the right loin was taken through a perpendicular cut between the 10th and 11th ribs. Before evaluation of meat quality, meat samples were thawed at ambient temperature. The colour measurement (L*, a*, b*) was taken through a perpendicular cut between the 10th and 11th ribs, which also used the above-mentioned digitizing area-line sensor. Drip loss was measured using approximately 4.5 g of meat sample according to the plastic bag method described by Honikel (1998). Cooking loss was determined as described previously by Sullivan et al. (2007).

2.3. Statistical analysis

All experimental data were analysed as a randomized complete block design using the general linear models procedure of SAS (1996). The pen was used as the experimental unit. Orthogonal contrasts were used to the effect of treatments: CON vs. RSM4 + CM4 and RSM4 vs. CM4. Variability in the data was expressed as the pooled standard error of the mean (SEM), and \( P \leq 0.05 \) was considered statistically significant.

3. Results

Effects of dietary supplementation with 4% RSM or CM on growth performance, nutrient digestibility, blood characteristics, and faecal noxious emission are shown in Table 3. Compared with CON dietary treatment, inclusion of 4% RSM or CM did not influence ADF, ADFI, G:F, blood characteristics (BUN and serum creatinine), faecal noxious gas emission (ammonia, total mercaptans, and hydrogen sulphide), and the ATTD of DM, GE, and N. Additionally, meat quality was not affected by replacing part of SBM with 4% CM or RSM (Table 4).

4. Discussion

In several previous experiments, it has been demonstrated that between 15% and 30% CM can be included in diets fed to growing-finishing pigs without impairing growth performance (King et al. 2001; Seneveratne et al. 2011). Additionally, it has

### Table 3. The effects of replacing part of SBM with 4% RSM or CM on growth performance, digestibility, blood characteristics, and faecal noxious gas emission in finishing pigs.

| Items                      | Dietary treatment | P-value | SEM | CON     | CM4    | RSM4   | SBM vs. CM + RSM | CM vs. RSM |
|----------------------------|-------------------|---------|-----|---------|--------|--------|------------------|------------|
| Growth performance         |                   |         |     |         |        |        |                  |            |
| ADG, g                     | 789.3             | 771.8   | 750.7 | 17.43   | NS     | NS     |                  |            |
| ADFI, g                    | 2249              | 2210    | 2212 | 19.05   | NS     | NS     |                  |            |
| G:F                        | 0.35              | 0.35    | 0.34 | 0.01    | NS     | NS     |                  |            |
| Apparent total tract digestibility |         |         |     |         |        |        |                  |            |
| DM                          | 70.88             | 70.33   | 70.65 | 0.92    | NS     | NS     |                  |            |
| Nitrogen                    | 70.03             | 69.97   | 70.53 | 1.07    | NS     | NS     |                  |            |
| GE                          | 71.45             | 70.93   | 70.85 | 1.14    | NS     | NS     |                  |            |
| Blood characteristics       |                   |         |     |         |        |        |                  |            |
| Blood area                 | 14.60             | 13.75   | 13.55 | 0.55    | NS     | NS     |                  |            |
| Creatinine                 | 1.63              | 1.68    | 1.61 | 0.06    | NS     | NS     |                  |            |
| Faecal noxious gas emission |                   |         |     |         |        |        |                  |            |
| Ammonia                    | 14.05             | 13.50   | 14.50 | 1.20    | NS     | NS     |                  |            |
| Total mercaptans           | 25.20             | 24.94   | 25.33 | 0.48    | NS     | NS     |                  |            |
| Hydrogen sulphide          | 14.51             | 15.04   | 14.62 | 0.71    | NS     | NS     |                  |            |

Notes: Abbreviation: ADFI: average daily feed intake; ADG: average daily gain; G:F: gain:feed ratio; NS: not significant; SEM: pooled standard error of the mean. Dietary treatments were as follows: (1) CON, a corn-SBM-based diet; (2) CM4, diet containing 4% CM originated from Korea; (3) RSM4, diet containing 4% RSM originated from India.
previously been reported that inclusion of RSM at the levels of 7%, 14%, or 21% in growing-finishing pigs’ diets had no negative effect on ADG, ADFI, and feed conversion ratio (McDonnell et al. 2010). However, effect of RSM or CM in pig diets has been reported to be inconsistent in many reports (Corino et al. 1991; Siljander-Rasi et al. 1996; McDonnell et al. 2010; Seneveratne et al. 2010). Seneveratne et al. (2010) reported that increasing dietary CM (0%, 7.5%, 15%, and 22.5%, respectively) linearly decreased ADG and ADFI but linearly increased G:F in growing-finishing pigs. In the present study, 4% CM or RSM fed in diet to pigs had no negative effects on ADG, ADFI, and G:F, suggesting that inclusion of 4% RSM or CM was not sufficient to impair growth performance of finishing pigs.

It is well known that RSM or CM has high fibre content that affects nutrient digestibility (Fernández and Jørgensen 1986; Landero et al. 2011). Many researchers have attempted to enhance the nutrient digestibility of RSM through decreasing fibre content and anti-nutritional factors such as glucosinolates by improving processing methods and supplementation of enzymes including carbohydride (Liu et al. 2014; Sanjayan et al. 2014). Low-temperature processing of RSM or CM and supplementation of multi-carbohydrase improved nutrient digestibility, as compared with conventional RSM or non-supplemented multi-carbohydrase (Liu et al. 2014; Sanjayan et al. 2014). In addition, it has been reported that RSM with multi-carbohydrase can be included to up to 25% without any negative growth performance and nutrient digestibility in weaned pig diets (Sanjayan et al. 2014). However, in the present study, inclusion of 4% RSM or CM without enzymes such as carbohydride did not affect nutrient digestibility.

In the present study, pigs fed with RSM or CM had no negative effects on BUN and creatinine, as compared with SBM. In agreement with the present study, it has previously been reported that replacing SBM with RSM had no detrimental effect on the blood characteristics in pigs (McDonnell et al. 2010; Landero et al. 2011; Jo et al. 2012; Xie et al. 2012). Replacing SBM with 11% CM decreased the concentration of IgG in blood plasma and supplementation with multienzyme significantly decreased malondialdehyde content in blood plasma (Xie et al. 2012). However, in the present study, replacing SBM with 4% RSM or CM had no negative effect on blood characteristics in finishing pigs. Faecal noxious gas emission and meat quality were regarded as one of the most important criteria of feed formulation in pig diets (Apple et al. 2002; Aarnink and Verstegen 2007; Cerisuelo et al. 2012). In the present study, pigs fed with RSM had no negative effects on faecal noxious gas emission (ammonia, total mercaptans, and hydrogen sulphide) and on meat quality such as meat colour, sensory evaluation, drip loss, pH, LMA, and WHC as compared with those fed with SBM. In inclusion, CM or RSM can be included in finishing pigs’ diets at the level of 4% without negative effects on growth performance, nutrient digestibility, blood characteristics, faecal noxious gas emission, and meat quality.

Disclosure statement
No potential conflict of interest was reported by the authors.

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