EVALUATION OF THE NUTRITIONAL VALUE OF CANOLA MEAL, 00-RAPESEED MEAL, AND 00-RAPESEED EXPELLERS FED TO PIGS

BY

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DISSERTATION

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ABSTRACT: To determine and to compare nutritional value in canola meal and 00-rapeseed products, four experiments were conducted by using canola meal, 00-rapeseed meal, and 00-rapeseed expellers from different sources in pig diets. The objectives of Exp. 1 were to determine and to compare the chemical composition of canola meal from crushing plants in North America with 00-rapeseed meal from crushing plants in Europe, and to compare 00-rapeseed meal from solvent extraction procedure with 00-rapeseed expellers from expeller extraction procedure. Results indicated that concentrations of sucrose, P, K, Zn, and glucosinolates are greater ($P <$ 0.05) in 00-rapeseed meal than in canola meal. Concentrations of GE and acid hydrolyzed ether extract (**AEE**) are greater ($P < 0.05$) in 00-rapeseed expellers than in 00-rapeseed meal, but concentrations of CP, Thr, ash, sucrose, crude fiber, NDF, ADL, hemicellulose, Ca, K, Mg, Mn, P, and S were greater ($P < 0.05$) in 00-rapeseed meal than in 00-rapeseed expellers. In Exp.2, the objective was to determine and to compare the apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of CP and AA in canola meal, 00-rapeseed meal, and 00-rapeseed expellers when used in growing pig diets. Results indicated that the SID of Lys, Met, Thr, and Trp in canola meal were 70.6, 84.5, 73.0, and 82.6%. Values for 00-rapeseed meal were 71.9, 84.6, 72.6 and 82.6%, and in 00-rapeseed expellers, values were 74.7, 87.1, 74.0, and 83.4%, respectively. The SID of CP and all AA except Thr, Trp, and Gly in 00-rapeseed expellers were greater ($P < 0.01$) than in 00-rapeseed meal. In Exp. 3, DE and ME in canola meal, 00-rapeseed meal, and 00-rapeseed expellers were determined. Average DE and ME values in canola meal were 3,378 and 3,127 kcal/kg DM, whereas DE and ME in 00-rapeseed meal were 3,461 and 3,168 kcal/kg DM, and in 00-rapeseed expellers, values were 4,005 and 3,691 kcal/kg DM, respectively. Results indicated that 00-rapeseed expellers have greater ($P < 0.01$) DE and ME than 00-rapeseed meal. In Exp. 4, the objectives were to determine apparent total tract digestibility (**ATTD**) and standardized total tract digestibility (**STTD**) of P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, and to determine the effect of using microbial phytase in diets containing canola meal, 00-rapeseed meal, and 00-rapeseed expellers. The ATTD and STTD of P were 44.99 and 48.82% in canola meal, 45.77 and 50.36% in 00-rapeseed meal, and 44.83 and 48.60% in 00-rapeseed expellers. The ATTD and STTD of P increased (P < 0.001) by 19.09 and 19.15 percentage units for canola meal, 16.76 and 16.90 percentage units for 00-rapeseed meal, and 24.45 and 24.39 percentage units for 00-rapeseed expellers if microbial phytase was used in the diets. In conclusion, with a few exceptions, the concentration of energy and nutrients in canola meal and 00-rapeseed meal is not different. However, the concentration of glucosinolates in canola meal is less than in 00-rapeseed meal. The concentrations of AEE and GE in 00-rapeseed expellers are greater than in 00-rapeseed meal, but the concentrations of most other nutrients in 00-rapeseed meal are greater than in 00-rapeseed expellers. The digestibility of energy, CP, and most AA is not different between canola meal and 00-rapeseed meal, but the values in 00-rapeseed expellers are greater than in 00-rapeseed meal. Phosphorus digestibility is not different between canola meal and 00-rapeseed products, but the ATTD and STTD of P will be improved if microbial phytase is used in the diets.

Key words: composition, digestibility, canola meal, 00-rapeseed meal, 00-rapeseed expellers, pigs

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LIST OF ABBREVIATIONS

AA	Amino acid
ADF	Acid detergent fiber
ADFI	Average daily feed intake
ADG	Average daily gain
ADL	Acid detergent lignin
AEE	Acid hydrolyzed ether extract
AID	Apparent ileal digestibility
Ala	Alanine
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
Arg	Arginine
Asp	Aspartate
ATTD	Apparent total tract digestibility
B	Brassica
BW	Body weight
°C	Degrees Celsius
Ca	Calcium
CF	Crude fiber
Co	Cobalt
CP	Crude protein
Cr	Chromium
Cu	Copper

CV	Coefficient of variation
Cys	Cysteine
d	Days
DE	Digestible energy
DM	Dry matter
DMI	Dry matter intake
et al.	And others
EU	Europe
Exp.	Experiment
Fe	Iron
FEDNA	Fundacion Española para el Desarrollo de la Nutricion Animal
g	Grams
GE	Gross energy
G:F	Gain to feed ratio
Glu	Glutamate
Gly	Glycine
h	Hour
HCl	Hydrochloric acid
His	Histidine
HPLC	High-performance liquid chromatography
I	Iodine
i.e.	That is
IL	Illinois

Ile	Isoleucine
Int.	International
ISO	International Standards Organization
K	Potassium
kcal	Kilocalories
kg	Kilograms
Lys	Lysine
Leu	Leucine
ME	Metabolizable energy
Met	Methionine
mg	Milligrams
mm	Millimeters
μg	Micrograms
μmol	Micromoles
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
N	Normal (concentration)
Na	Sodium
NC	North Carolina
NDF	Neutral detergent fiber
NE	Net energy

NFE	Nitrogen free extract
NRC	National Research Council
P	Phosphorus
P	Probability
Phe	Phenylalanine
PHILSAN	Philippine Society of Animal Nutritionists
Pro	Proline
PUN	Plasma urea nitrogen
R^2	Coefficient of determination
RMSE	Root mean square error
S	Sulfur
SAS	Statistical Analysis System
Se	Selenium
SE	Standard error
SEM	Standard error of mean
Ser	Serine
SID	Standardized ileal digestibility
STTD	Standardized total tract digestibility
TMA	Trimethylamine
Trp	Tryptophan
Tyr	Tyrosine
USDA	United States Department of Agriculture
Val	Valine

vs.	Versus
wk	Week
Zn	Zinc

CHAPTER 1

INTRODUCTION

Canola seeds and 00-rapeseeds are oilseeds that contribute approximately 13% of the total oilseed and protein meals production in the world (USDA, 2013a). The production and crushing industry for canola and 00-rapeseed is increasing because of the increased demand for vegetable oil in China and India and biodiesel use in the EU (USDA, 2013b). Canola meal, 00-rapeseed meal, and 00-rapeseed expellers are products from oil crushing plants, and they may be used as ingredients in animal diets because canola and 00-rapeseed have been selected for improved AA profile and low levels of erucic acid and glucosinolates (Thomas, 2005; Newkirk, 2009; Diederichsen and McVetty, 2011).

Canola seeds have been genetically modified from traditional varieties of rapeseeds by plant breeders to obtain plants with low levels of erucic acid in the oil and low levels of glucosinolates in the non-oil part of the plants (Thomas, 2005; Newkirk, 2009). Therefore, by the definition, rapeseeds that contain low levels of erucic acid (< 2%) in oil and glucosinolates (< 30 μmol/g) in defatted meal are called canola in North America, but they are called "double-zero" or "double-low" rapeseeds or 00-rapeseeds in Europe (Shahidi, 1990; Spragg and Mailer, 2007; Newkirk, 2009). However, variations among varieties in climatic conditions and in harvesting conditions may affect the concentration of fat, protein, AA, and carbohydrates in canola seeds and meals (Barthet and Duan, 2011, Newkirk, 2011). Differences in oil crushing and extraction procedures may also influence the concentration of fat and protein and availability of nutrients in the meals (Bell, 1993; Newkirk et al., 2003). For animal diets, the nutritional value of feed ingredients is a function of nutrient composition, specifically digestible protein and AA levels, and in energy and mineral concentrations (Arntfield and Hickling, 2011). Therefore, it is important to determine effects of different varieties, growing and harvesting conditions, and oil extraction methods on nutrient composition and availability in canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

The objective of this dissertation is to determine and to compare the chemical composition of canola meal, 00-rapeseed meal, and 00-rapeseed expellers from different sources and different oil extraction methods. The second objective is to determine and to compare the variability in apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of CP and AA, apparent total tract digestibility (**ATTD**) and standardized total tract digestibility (**STTD**) of phosphorus, and ATTD of GE and concentration of DE and ME in canola meal, 00-rapeseed meal, and 00-rapeseed expellers fed to growing pigs.

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CHAPTER 2

CANOLA MEAL, 00-RAPESEED MEAL, AND 00-RAPESEED EXPELLERS FED TO PIGS: REVIEW OF LITERATURE

INTRODUCTION

Canola was developed from rapeseed by plant breeders to obtain plants with low levels of erucic acid in the oil and low levels of glucosinolates in the non-oil part of the plants (Thomas, 2005; Newkirk, 2009). Rapeseed with low levels of erucic acid (< 2%) and glucosinolates (< 30 μmol/g) are called “double-zero” or “double-low” rapeseeds or 00-rapeseeds in Europe, but in North America, such varieties are called canola (Shahidi, 1990; Spragg and Mailer, 2007; Newkirk, 2009). New varieties of canola and 00-rapeseeds have been developed to improve yield, disease and insect resistance, oil quality, and canola meal quality (Thomas, 2005; Diederichsen and McVetty, 2011). For canola meal and 00-rapeseed meal, the products remaining after extraction of oil from canola seeds or 00-rapeseeds, efforts have been directed towards increasing the concentration of CP, AA, vitamins, and minerals, and reducing the concentration of fiber and antinutrients (fiber and glucosinolates; Newkirk, 2011). At the same time, the digestibility of AA, energy, and carbohydrates has been improved (Newkirk, 2009). Therefore, canola meal or 00-rapeseed meal can be used in animal feed formulations.

PRODUCTION OF CANOLA AND RAPESEED PRODUCTS

Canola seeds and rapeseeds are second in the world production in terms of oilseeds and protein meals that contribute approximately 13% of the total oilseed and protein meal production in the world (Lennox and Beckman, 2011; USDA, 2013; Table 2.1; Table 2.2). Currently, global production of canola seeds and rapeseeds exceed 60 million metric tons (USDA, 2013), and the major producers of canola seeds and rapeseeds and the resulting meals in the world are Europe, China, Canada, and India (USDA, 2013; Table 2.3; Table 2.4).

CANOLA SEEDS AND RAPESEEDS

The diameter of canola seeds and rapeseeds are between 1.5 and 2.5 mm, and the color may vary from black to reddish-brown or yellow. Canola seeds contain 42 to 43% fat and 20 to 30% CP (Spragg and Mailer, 2007, Newkirk, 2009; Barthet and Daun, 2011), and rapeseeds contain 40.7% fat and 19.0% CP (FEDNA, 2010). The concentration of oil in canola and rapeseeds has been improved by plant breeders, and the CP concentration tends to decrease as oil concentration is increased (Barthet and Daun, 2011). However, the factor that affects the composition of canola seeds and rapeseeds the most, is differences in the growing environment such as soil moisture, hot or cool weather, and harvest times (Newkirk, 2009; Barthet and Daun, 2011). Harvest in cool and wet weather results in canola seeds and rapeseeds having greater concentration of oil and chlorophyll than if seeds are harvested in hot and dry weather (Barthet and Daun, 2011). The chemical composition of canola seeds and rapeseeds is also affected by variety. The concentration of oil and CP is greater, and CF is less, in yellow-seeded canola and rapeseeds than in black-seeded varieties (Bell and Shires, 1982) because yellow seeded varieties have larger seeds than black seeded varieties. Therefore, the proportion of the fiber, which is mainly located in the seed coat, is less and the proportion of oil and CP is greater in yellow-seeded varieties, which results in production of meals that contain more CP and less fiber (Slominski et al., 2012)

CANOLA OIL AND CANOLA MEAL PROCESSING

The process of oil extraction from canola seeds includes drying and handling, seed cleaning and preparation, extraction, and processing of oil (Salunkhe et al, 1992; Unger, 2011). Oil extraction from canola seeds can be categorized by 2 processes: without or with solvent extraction (Adams et al., 2006). If solvent extraction is not used, oil may be expelled from the seeds using cold-pressing or double pressing (Adams et al., 2006; Spragg and Mailer, 2007, Newkirk, 2009).

If the solvent extraction process is used, canola seeds are cooked at a temperature between 80 and 90℃ and then pressed by expellers to remove 50 to 60% of the oil. The remaining oil is extracted by a solvent which is usually hexane (Salunkhe et al., 1992; Newkirk, 2009). After extraction, the solvent is removed from the meal in a desolventizer-toaster with a temperature between 80 and 115℃, and moisture is added during the process (Salunkhe et al., 1992; Newkirk, 2009). This procedure is called prepress solvent extraction, and results in production of canola meal that usually contains less than 3% oil (Sauvant et al., 2004; Newkirk, 2009). The double pressing process is similar to the prepress solvent extraction process, but solvent extraction, desolventization, drying, and cooling is not used. Instead, the pre-pressed seeds go through a second press to remove additional oil. The oil concentration in canola expellers from this process is between 8 and 10% (Newkirk, 2009).

In the cold-pressing process, canola seeds are not pre-conditioned before pressing by expellers, and the temperature is maintained at 60℃ throughout the mechanical process (Adams et al., 2006). Canola oil from cold-pressed processing is called virgin oil and is in demand by consumers of organic and natural foods, and usually the price of cold pressed oil is greater than that of conventional canola oil (Przybylski and Eskin, 2011). Oil concentration in the resulting canola expellers is 11 to 13% (Spragg and Mailer, 2007; Seneviratne et al., 2010; Woyengo et al., 2010).

The effect of processing on canola meal and canola expeller quality was reviewed by Newkirk (2009) who considered 3 factors: temperature, moisture, and additives (gum and soap). During seed cooking, the temperature is 80 to 90℃, and the moisture ranges between 6 and 10%. This step is needed to deactivate the myrosinase enzyme, and to prevent hydrolysis of glucosinolates into toxic metabolites (aglucones). However, excessive heating may result in Maillard reactions that can cause protein damage and reduced digestibility of AA in animals (Bell, 1993; Newkirk et al., 2003). In addition, additives such as gum and soap stocks may be added in the process to reduce the dustiness of the meal. This addition may increase the total oil content in canola meal by 1 to 2% (Spragg and Mailer, 2007, Newkirk, 2009; Barthet and Daun, 2011).

COMPOSITION OF CANOLA AND RAPESEED PRODUCTS

The chemical composition of canola meal, 00-rapeseed meal, canola expellers, and 00-rapeseed expellers is presented in Table 2.5. Nutrient composition in canola and 00-rapeseed products may be influenced by variety, environmental conditions during crop development, harvest conditions, and processing of the seed and meal (Barthet and Daun, 2011; Bell, 1993; Newkirk, 2009). Canola and rapeseed meal from yellow-seeded varieties have greater concentration of oil and CP, and less CF than meal obtained from black-seeded varieties (Slominski et al., 1994; Trindade Neto et al., 2012; Slominski et al., 2012). Canola and 00-rapeseed meal from the solvent extraction procedure have greater concentration of CP and AA and less concentration of oil than canola and rapeseed expellers (Sauvant et al., 2004; Spragg and Mailer, 2007; Newkirk, 2009; Seneviratne et al., 2010).

ENERGY

Canola meal and 00-rapeseed meal contain 2,770 to 3,270 kcal/kg DE, 2,532 to 3,013 kcal/kg ME, and 1,500 to 1,890 kcal/kg NE, whereas canola expellers and 00-rapeseed expellers contain 3,150 to 3,780 kcal/kg DE, 2,920 to 3,540 kcal/kg ME, and 1,900 to 2,350 kcal/kg NE (Table 2.5). The energy levels and energy digestibility in canola and 00-rapeseed products may vary depending on nutrient composition, especially for protein, oil, and fiber (Bourdon and Aumaître, 1990; Spragg and Mailer, 2007; Montoya and Leterme, 2010; Newkirk, 2011). The greater the concentration of ether extract and GE in canola and rapeseed meal is, the greater is the DE and ME when used in pig diets (Bourdon and Aumaître, 1990). In contrast, greater concentrations of NDF and ADF in canola meal results in decreased DE and NE in growing pig diets (Montoya and Leterme, 2010).

CRUDE PROTEIN AND AMINO ACIDS

Canola meal and 00-rapeseed meal contain 33.7 to 37.5 % CP, and canola expellers and 00-rapeseed expellers contain 31.2 to 35.2% CP (Table 2.6). The concentration of CP and AA in canola and rapeseed products varies depending on varieties, environmental factors, canola seed composition, and amount of residual oil and carbohydrates in the meal (Bell and Keith, 1990; Bell, 1993; Spragg and Mailer, 2007; Newkirk, 2009). The varieties of canola seeds or rapeseeds that contain greater concentration of CP and AA may result in more CP and AA in the meals (Bell, 1993; Slominske et al., 2012). The efficiency of oil removal using the solvent extraction procedure is greater than if the mechanical press procedure is used. Therefore, the concentration of residual oil in canola meal and 00-rapeseed meal is less than in canola expellers and 00-rapeseed expellers (1 to 2% vs. 8 to 13%), which results in greater amount of CP and AA in canola meal and 00-rapeseed meal than in canola expellers and 00-rapeseed expellers. Removal of the hulls from canola meal reduces the concentration of crude fiber, NDF, ADF, and total dietary fiber, and it also increases the concentration of CP in de-hulled canola meal (Bell, 1993). Canola meal and 00-rapeseed meal protein has relatively high concentration of Met, Cys, and Thr, whereas the concentration of Lys and Trp in canola protein is less than in soybean meal (Newkirk, 2009; Khajali and Slominski, 2012; Table 2.7).

CARBOHYDRATES

Carbohydrates in canola, rapeseed, and other brassica oilseeds may be categorized into soluble sugars, insoluble carbohydrates, and fiber (Barthet and Daun, 2011). The concentration of soluble carbohydrates in mature seeds is approximately 10% of the oil-free weight, with sucrose ranging from 3.9 to 9.8%, raffinose from 0.3 to 2.6%, stachyose from 0.8 to 1.6%, fructose from 0.1 to 0.5%, and glucose from 0.1 to 0.4% (Barthet and Daun, 2011). The concentration of hemicellulose is approximately 3%, cellulose ranges from 4 to 5%, and starch is approximately 1% (Salunkhe et al., 1992). The concentration of crude fiber, NDF, and ADF in canola meal and 00-rapeseed meal ranges from 10 to 12%, 22 to 30%, and 15 to 20%, respectively, whereas in canola expellers and 00-rapeseed expellers, concentrations of crude fiber, NDF, and ADF ranges from 7 to 12%, 24 to 28%, and 17 to 18%, respectively (Sauvant et al., 2004; Spragg and Mailer, 2007; Mailer et al., 2008; NRC, 2012). Canola meal has relatively high concentration of fiber because hulls in canola seeds stay with the meal (Newkirk, 2009; Barthet and Daun, 2011). However, canola and 00-rapeseed breeding programs have developed canola and rapeseed varieties with greater oil and protein content than traditional varieties. The new high-protein varieties of canola and 00-rapeseed also contain less fiber, and the resulting canola meal, therefore, has a reduced fiber concentration compared with conventional canola and rapeseed products (Spragg and Mailer, 2007).

MINERALS AND VITAMINS

Differences in the concentration of minerals among sources of canola and rapeseed products often is a result of differences in soil concentration of minerals and seasonal effects (Bell and Keith, 1990; Mahan et al., 2005). Canola meal, 00-rapeseed meal, and 00-rapeseed expellers are rich sources of Ca, P, and Se when compared to soybean meal (Bell, 1993; Newkirk, 2009; NRC, 2012). The concentrations of Ca, P, and Se in canola and rapeseed products range from 0.7 to 1.1%, 1.0 to 1.1%, and 1.1%, respectively, whereas in de-hulled soybean meal contains 0.33%, 0.71%, and 0.27%, respectively (Table 2.8). However, approximately 85% of total phosphorus in canola and rapeseed products is present as phytic acid; therefore, the digestibility of phosphorus in canola and rapeseed products is around 25-30% (Spragg and Mailer, 2007; Newkirk, 2009). The concentration of minerals is not affected by processing, and differences between in meals and expellers have not been reported (Spragg and Mailer, 2007). However, the concentration of sodium in canola meal may vary depending on adding soapstock from refining to the meal (Newkirk, 2009). Canola and rapeseed products also contain more biotin, choline, niacin, riboflavin, and thiamin when compared with de-hulled soybean meal, but the level of folic acid and pantothenic acid is less than in de-hulled soybean meal (Sauvant et al., 2004; Newkirk, 2009; FEDNA, 2010; NRC, 2012).

ANTINUTRITIONAL FACTORS

Glucosinolates

Glucosinolates are plant metabolites in canola seeds and rapeseeds (Tripathi and Mishra, 2007). The enzyme myrosinase, which is present in the plasmalemma (membrane) of the embryonic cells in canola seeds can hydrolyze glucosinolates into major glucosinolate degradation products such as thiocyanate ions, isothiocyanate, oxazolidinethione, and nitriles that all have negative effects on animal performance (Etienne and Dourmad, 1994; Tripathi and Mishra, 2007; Newkirk, 2009). Hydrolyzed products from glucosinolates can cause goiter, hemorrhagic liver, bitter taste, and reduced performance in animals (Salunkhe et al., 1992; Etienne and Dourmad,1994; Schone et al., 2001; Newkirk, 2009). However, myrosinase is usually inactivated during the prepressing and extraction process, and the level of glucosinolates is reduced by heat treatment during desolventizing-toasting process (Bell and Keith, 1990; Salunkhe et al., 1992; Jensen et al., 1994; Spragg and Mailer, 2007; Newkirk, 2009). The concentration of glucosinolates in canola meal and canola expellers produced from current varieties of canola is less than 20 µmol/g. Pigs can tolerate approximately 2 µmol glucosinolates per g diet (Perez-Maldonado, 2002; Mailer, 2004; Bonnardeaux, 2007; Newkirk, 2009). Canola meal and canola expellers have levels of glucosinolates that range from 2 to 12 µmol/g and 5 to 12 µmol/g, respectively (Spragg and Mailer, 2007; Zhou et al., 2013; Seneviratne et al., 2010), whereas rapeseed meal and rapeseed expellers contain between 5 and 69 µmol/g and 34 and 38 µmol/g, respectively (Bourdon and Aumaître. 1990; Mikulski et al. 2012; Rezvani et al. 2012). In animal diets, the negative effects of glucosinolates depend on the level and composition of glucosinolates and their degradation products, and the tolerance for glucosinolates is different among animal species (Tripathi and Mishra, 2007; Table 2.9). For pig diets, total glucosinolates concentration should not be greater than 2 μmol/g (Bell, 1993; Schone et al., 2001), and iodine should be supplemented in an amount of at least 1,000 μg/kg of diet to reduce the risk of glucosinolates inhibiting thyroid hormone production (Schone et al., 2001).

Phytic Acid

The concentration of P in canola and rapeseed products ranges from 1.0 to 1.1 (Liu et al., 1998; Newkirk, 2009; NRC, 2012), but approximately 85% of total P in canola meal is bound to phytic acid (Spragg and Mailer, 2007; Newkirk, 2009). The digestibility of P in canola and 00-rapeseed products by pigs and poultry is, therefore, around 25-30% of total P (Sauvant et al., 2004; FEDNA, 2010; NRC, 2012). The concentration of phytate P in canola meal and 00-rapeseed meal is between 0.65 and 0.80%, whereas canola expellers and 00-rapeseed expellers contain between 0.78 and 0.87% (FEDNA, 2010; NRC, 2012). However, oil extraction procedures may affect P availability in canola and 00-rapeseed products. Mechanical press may result in release of some P from the phytate molecule during the expeller process, which may have positive effects on digestibility of P (Spragg and Mailer, 2007).

Sinapine

Sinapine, the ester of sinapic acid, is a phenolic compound that may contribute to the dark color, bitter taste, and astringency in canola meal (Kozlowska et al., 1990). In addition, sinapine in canola meal can cause fishy tasting eggs when used in layer hen diets (Perez-Maldonado, 2002, Ward et al., 2009). Sinapic acid in sinapine can bind with choline, prevent choline absorption in the small intestine, and result in choline entering the large intestine. Choline will then be fermented, which results in synthesis of trimethylamine (**TMA**), which may be absorbed into the portal blood. Canola meal may, therefore, result in a fishy smell of eggs because TMA may be deposited in egg yolk (Ward et al., 2009). The concentration of sinapine in canola meal is between 1.0 and 1.5 % (Perez-Maldonado, 2002; Mailer, 2004; Bonnardeaux, 2007), and it has no negative effects on pig performance (Spragg and Mailer, 2007). Use of up to 16.2% canola meal in finishing pig diets does not affect carcass characteristics (Roth-Maier et al., 2004).

Tannins

Tannins, which are phenolic compounds with various molecular weights and complexities, are also present in canola meal (Kozlowska et al., 1990; Jansman, 1993). The negative effects of tannins on animal performance may include reductions in feed intake, weight gain, and feed conversion efficiency. The apparent digestibility of CP, AA, and energy may also be reduced, but the extent depends on the concentration of tannins in the diet (Jansman, 1993). However, most phenolic compounds including tannins are removed in the oil extraction process (Kozlowska et al., 1990), and canola meal usually contains less than 1.5% tannins (Mailer, 2004; Bonnardeaux, 2007).

ENERGY AND NUTRIENT DIGESTIBILITY

Energy digestibility in canola and 00-rapeseed products may vary depending on the concentration of GE and acid hydrolyzed ether extract (**AEE**), which may affect the DE and ME when used in pig diets. Canola expellers and rapeseed expellers have greater GE and EE than canola meal and rapeseed meal because of the increased concentration of oil in canola expellers compared with canola meal. Therefore, the concentration of DE and ME in canola and rapeseed expellers is greater than in canola and rapeseed meal (4,107 vs. 3,790 kcal/kg DE and 3,978 vs. 3,564 kcal/kg ME) when used in growing pig diets (Bourdon and Aumaître. 1990; Woyengo et al., 2010). Using canola meal from 7.5 to 22.5 % in growing pig diets decreased DE and NE because of an increase in NDF and ADF concentrations, but no negative effects on growth performance were observed (Montoya and Leterme, 2010).

The digestibility of AA in canola meal, rapeseed meal, canola expellers, and rapeseed expellers is variable depending on the processing temperature of canola meal, the age of pigs, and sources of canola meal (Tables 2.10 and 2.11). The age of pigs may affect the digestibility of AA in canola meal. The apparent ileal digestibility (**AID**) of AA in lactating sows is greater than in growing pigs (Stein et al., 1999), and gestating sows have greater standardized ileal digestibility (**SID**) of CP and AA compared with growing pigs and lactating sows (Stein et al., 2001). The digestibility of AA can be affected by the source of canola meal, and the AID of all AA among 6 canola meal samples was different (Fan et al., 1996). The digestibility of Arg, His, and Met is relatively high, ranging from 79.4 to 84.4%, from 76.5 to 81.0%, and from 77.3 to 82.4%, whereas the digestibility of Thr and Trp is relatively low, ranging from 59.7 to 66.5% and from 61.7 to 67.5 % (Fan et al., 1996). The digestibility of indispensable AA (except Arg) is negatively correlated with the concentration of NDF in canola meal (Fan et al., 1996). The SID of Lys, Met, Thr, and Trp in rapeseed meal is relatively high, ranging from 74 to 75%, from 85 to 87%, from 73 to 75%, and from 76 to 80% (Sauvant et al., 2004; FEDNA, 2010). The SID of Lys, Met, Thr, and Trp in canola expellers is 70 to 73%, 83 to 87%, 67 to 79%, and 73 to 83% (Table 2.9), and in rapeseed expellers these values are 73, 84, 72, and 75%, respectively (FEDNA, 2010). Different methods to extract oil from canola seeds also may affect SID values of canola and rapeseed products. Canola expellers have greater SID of N, Arg, Ile, Leu, Phe, Glu, and Pro than canola meal (Woyengo et al., 2010).

Because most P in canola meal is bound to phytic acid (Spragg and Mailer, 2007; Newkirk, 2009), the digestibility of P in canola meal by pigs and poultry is around 25-30% of total phosphorus (Sauvant et al., 2004; FEDNA, 2010; NRC, 2012). The apparent total tract digestibility (**ATTD**) of P in canola and rapeseed meal by growing pigs ranges from 24 to 52% (Rodehutscord et al., 1997; Akinmusire and Adeola, 2009; Woyengo et al, 2009; Rodríguez et al., 2013). However, addition of microbial phytase at 500, 750, or 1,000 units/kg to growing pig diets can improve the digestibility of P in canola meal and rapeseed meal (Rodehutscord et al., 1997; Akinmusire and Adeola, 2009; Woyengo et al, 2009; Rodríguez et al., 2013). The ATTD of Ca in canola meal by growing pigs was 43%, and supplementation of microbial phytase at 1,500 units/kg in the diets increased the digestibility of Ca in canola meal (González-Vega et al., 2013).

USE OF CANOLA AND RAPESEED PRODUCTS IN PIG DIETS

Using solvent-extracted canola meal in concentrations of up 20% in lactating sow diets did not have adverse effects on production performance because the concentration of glucosinolates in canola meal was low (4-5 µmol/g), which results in a level of glucosinolates in diets that was below the tolerance limit of sows (King et al., 2001). Inclusion of up to 25% solvent-extracted canola meal in diets fed to weanling pigs (6 to 23 kg BW) did not affect ADG or voluntary feed intake, and improved G:F (Eason and King, 2000; King et al., 2001), and using canola meal or canola expellers in concentrations of up to 15 to 20% in diets had no negative effects on ADG, ADFI, and G:F in weanling pigs (Seneviratne et al., 2010; Landero et al., 2011; Landero et al., 2012). Canola products can be used in weanling pig diets if the diets are formulated using values for NE and SID of AA to reduce the risk of negative effects from using co-products (King et al., 2001; Landero et al., 2011; Landero et al., 2012). The level of glucosinolates in the diets should also be less than 2 µmol/g (Bell, 1993; Schone et al., 2001). In growing-finishing pigs (30.1 to 114.1 kg BW), canola meal can be used by 50% with no effect on ADFI, G:F, and carcass quality

(Shelton et al., 2001). Using up to 25.9% solvent-extracted canola meal in diets fed to growing pigs (30 to 60 kg BW) resulted in greater ADG, but no change in G:F or ADFI (Roth-Maier et al., 2004). However, using 16.2% canola meal in diets fed to finishing pigs (60 to 120 kg BW) resulted in reduced ADG compared with pigs fed the control diet without canola meal, but there was no difference in G:F, ADFI, or carcass quality, and no differences were observed for the entire growing-finishing (Roth-Maier et al., 2004). Canola and rapeseed products can be used in growing-finishing diets by up to 20 to 30% without adverse effect on ADG, ADFI, G:F, and carcass characteristics (Bourdon and Aumaître, 1990; Mullan et al., 2000; Brand et al., 2001; King et al., 2001; McDonnell et al., 2010). In contrast, increasing the inclusion of canola expellers in diets from 0 to 22.5%, linearly decreased ADG and ADFI, but linearly increased G:F in grower-finisher pigs (Seneviratne et al., 2010). Canola and rapeseed products are alternative protein sources in growing-finishing pig diets because new varieties of canola and rapeseed contain higher protein and less glucosinolates than older varieties (Newkirk, 2009; Arntfield and Hickling, 2011). However, using canola or rapeseed products at high inclusion levels in diets for long periods may affect growing-finishing performance and thyroid hypertrophy (Roth-Maier et al., 2004; Mullan et al., 2000). Therefore, inclusion rates of canola and rapeseed products at 15 to 20% in growing-finishing diets with a level of total glucosinolates at less than 2.2 μmol/g is recommended (Roth-Maier et al., 2004; McDonnell et al., 2010).

CONCLUSION

Canola meal, 00-rapeseed meal, and 00-rapeseed expellers are alternative ingredients that may replace soybean meal in diets fed to pigs because these ingredients have low levels of erucic acid, low levels of glucosinolates, and high concentrations of CP and AA, energy, vitamins, and minerals. However, the nutrient composition and digestibility of nutrients in canola meal and rapeseed products may be affected by many factors. The effect of varieties of seeds and methods used to extract the oil are 2 factors that influence the nutrient composition and digestibility of these ingredients.

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TABLES

Table 2.1. Major oilseeds: Global production[1] (million metric tons)

Item	2009/10	2010/11	2011/12	2012/13	Percent of total 2012/13
Soybean	260.40	263.92	239.46	269.11	57.33
Rapeseed	60.98	60.57	61.12	61.14	13.02
Cottonseed	38.91	43.55	46.41	45.30	9.65
Peanut	33.60	36.14	35.13	37.05	7.89
Sunflower seed	32.21	33.63	40.64	36.36	7.75
Palm kernel	12.28	12.73	13.51	14.53	3.10
Copra	5.88	6.02	5.66	5.96	1.27
Total	444.25	456.56	441.93	469.43	100.00

[1]USDA (2013).

Table 2.2. Major protein meals: Global production[1] (million metric tons)

Item	2009/10	2010/11	2011/12	2012/13	Percent of total 2012/13
Soybean	164.94	174.58	179.36	180.99	67.50
Rapeseed	33.39	34.66	35.91	35.65	13.29
Cottonseed	13.81	14.84	15.74	15.78	5.88
Sunflower seed	13.08	13.23	16.01	14.96	5.58
Palm kernel	6.56	6.69	7.10	7.60	2.83
Peanut	5.83	6.22	6.23	6.48	2.42
Fish	4.32	4.55	4.64	4.70	1.75
Copra	1.92	2.03	1.86	1.99	0.74
Total	243.84	256.80	266.86	268.15	100.00

[1]USDA (2013).

Table 2.3. Canola and rapeseed: Global production[1] (thousand metric tons)

Country	2011/12	2012/2013	Percent of total 2012/13
EU-27	19,177	19,074	31.2
China	13,426	13,500	22.08
Canada	14,608	13,310	21.77
India	6,200	6,800	11.12
Other	7,712	8,451	13.82
Total	61,123	61,135	100.00

[1] USDA (2013).

Table 2.4. Canola and rapeseed meal: Global production[1] (thousand metric tons)

Country	2011/12	2012/2013	Percent of total 2012/13
EU-27	12,441	12,665	35.53
China	10,122	9,809	27.52
Canada	3,870	3,750	10.52
India	3,645	3,645	10.23
Japan	1,296	1,303	3.66
Other	4,537	4,473	12.55
Total	35,911	35,645	100.00

[1] USDA (2013).

Table 2.5. Chemical composition of soybean meal, canola meal, canola expellers, 00-rapeseed meal, and 00-expellers, as-fed basis

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
DM, %	89.98	91.33	93.11	88.70	89.20
DE, kcal/kg	3,619	3,273	3,779	2,771	3,155
ME, kcal/kg	3,294	3,013	3,540	2,532	2,920
NE, %	2,087	1,890	2,351	1,505	1,900
CP, %	47.73	37.50	35.19	33.70	31.20
Ether extract, %	1.52	3.22	9.97	2.30	7.30
NDF, %	8.21	22.64	23.77	28.30	26.90
ADF, %	5.28	15.42	17.57	19.60	17.00
Crude fiber, %	3.89	10.50	9.77	12.40	11.60
Ca, %	0.33	0.69	0.69	0.83	0.70
Total P, %	0.71	1.08	1.15	1.14	1.04

[1] NRC, 2012.

[2] Sauvant et al., 2004.

[3] FEDNA, 2010.

Table 2.6. Amino acid composition of soybean meal, canola meal, canola expellers, 00-rapeseed meal, and 00-expellers, as-fed basis

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
Indispensable AA, %					
Arg	3.45	2.28	1.76	2.03	1.90
His	1.28	1.07	0.82	0.88	-
Ile	2.14	1.42	1.67	1.36	1.24
Leu	3.62	2.45	1.95	2.26	-
Lys	2.96	2.07	1.58	1.80	1.78
Met	0.66	0.71	0.61	0.69	0.63
Cys	0.70	0.86	0.79	0.82	-
Met + Cys	1.36	1.57	1.40	1.51	1.37
Phe	2.40	1.48	1.48	1.31	-
Tyr	1.59	1.06	0.78	0.98	-
Phe + Tyr	3.99	2.54	2.26	2.30	-

Table 2.6. (Cont.)

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
Thr	1.86	1.55	1.22	1.45	1.40
Trp	0.66	0.43	0.32	0.41	0.42
Val	2.23	1.78	1.63	1.70	1.61

[1] NRC, 2012.

[2] Sauvant et al., 2004.

[3] FEDNA, 2010.

Table 2.7. Amino acid composition of soybean meal, canola meal, canola expellers, 00-rapeseed meal, and 00-expellers, as % of CP

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
Indispensable AA, %					
Arg	7.23	6.08	5.00	6.02	6.09
His	2.68	2.85	2.33	2.61	-
Ile	4.48	3.79	4.75	4.04	3.97
Leu	7.58	6.53	5.54	6.71	-
Lys	6.20	5.52	4.49	5.34	5.71
Met	1.38	1.89	1.73	2.05	2.02
Cys	1.47	2.29	2.24	2.43	-
Met + Cys	2.85	4.19	3.98	4.48	4.39
Phe	5.03	3.95	4.21	3.89	-
Tyr	3.33	2.83	2.22	2.91	-
Phe + Tyr	8.36	6.77	6.42	6.82	-

Table 2.7. (Cont.)

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
Thr	3.90	4.13	3.47	4.30	4.49
Trp	1.38	1.15	0.91	1.22	1.35
Val	4.67	4.75	4.63	5.04	5.16

[1] NRC, 2012.

[2] Sauvant et al., 2004.

[3] FEDNA, 2010.

Table 2.8. Mineral and vitamin concentration in soybean meal, canola meal, canola expellers, 00-rapeseed meal, and 00-expellers, as-fed basis

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
Ca, %	0.33	0.69	0.69	0.83	0.70
P, %	0.71	1.08	1.15	1.14	1.04
Na, %	0.08	0.07	-	0.04	0.04
Cl, %	0.49	0.11	-	0.07	0.04
K, %	2.24	1.69	-	1.23	1.15
Mg, %	0.27	0.28	0.52	0.49	0.45
S, %	0.40	0.85	-	-	0.58
Cu, mg/kg	15.13	4.90	5.40	7.00	7.00
Fe, mg/kg	98.19	163	232	172	180
Mn, mg/kg	35.49	76.90	60.30	52.00	52.00
Se, mg/kg	0.27	1.10	-	1.10	-
Zn, mg/kg	48.81	49.73	72.00	65.00	55.00

Table 2.8. (Cont.)

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
Biotin, mg/kg	0.26	0.98	-	-	0.90
Choline, mg/kg	2,731	6,700	-	-	6,500
Folacin, mg/kg	1.37	0.83	-	-	-
Niacin, mg/kg	22.00	160	-	-	-
Pantothenic acid, mg/kg	15.0	9.50	-	-	-
Rivoflavin, mg/kg	3.10	5.80	-	-	-
Thiamin mg/kg	3.20	5.20	-	-	-

[1] NRC, 2012.

[2] Sauvant et al., 2004.

[3] FEDNA, 2010.

Table 2.9. Biological effects of glucosinolates on animals[1]

Animal	Glucosinolate (μmol/g diet)	Effect on animals
Rat	3.3-4.4	Reduced intake and growth
	7.7	Depressed intake and growth
	6.6	Poor gain, increase thyroid weight and changed thyroid morphology
	0.5	No adverse effect
Pig	1.3-2.79	Reduced feed intake and growth
	7.0	Severe growth depression
	9-10	Induced iodine deficiency, Hypothyroidism, reduced bone and serum zinc content and alkaline phosphatase activity
	0.16-0.78	No adverse effect during growth , pregnancy and lactation
	2.2	No adverse effect during growing period
	1.3	Reduced gain during finishing period
Poultry	5.4-11.6	No adverse effect on intake and gain
	2.3-8.18	No adverse effect on weight gain
	7.6-15.3	Severe growth depression
	34.0	Severe growth depression

Table 2.9. (Cont.)

Animal	Glucosinolate (μmol/g diet)	Effect on animals
Poultry	5.4-11.6	No adverse effect on intake and gain
	2.3-8.18	No adverse effect on weight gain
	7.6-15.3	Severe growth depression
	34.0	Severe growth depression
	0.9	No adverse effect on intact and growth
	4.6	Reduced feed intake by 0.09%
Rabbit	7.9	No apparent adverse effect on growth and health of broiler rabbits
	17.9-25.3	Severe growth depression and increased mortality
Calf	1.2-2.4	No adverse effect on thyroid and liver function
Dairy cow	11.0	Induced iodine deficiency
	11.7-24.3	Depressed feed intake and milk production
	≥23.0	Reduced intake and milk production
	31.0	Thyroid disturbance and depressed fertility
Sheep	1.2-2.2	Weight loss during lactation
	15.0	Reduced growth in lambs
	17.5	No effect on intake but increased thyroid weight in lamb
	33.0	Growth depression in lamb
	<4.22	No adverse effect on lamb performance

Table 2.9. (Cont.)

Animal	Glucosinolate (µmol/g diet)	Effect on animals
Sheep	≥4.22	Induced iodine deficiency and influenced thyroid weight and histology in lambs
	1.2-1.6	Reduced plasma levels of estradiol provoked reproductive disturbance
Fish	2.18	Reduced growth by 0.15 level
	19.3	Severe growth depression and thyroid disturbances

[1]Tripathi and Mishra (2007).

Table 2.10. Apparent ileal digestibility of CP and AA in soybean meal, canola meal, canola expellers, 00-rapeseed meal, and 00-expellers in pigs

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
CP, %	82.0	68.0	70.0	-	-
Indispensable AA, %					
Arg	92.0	82.0	80.0	86.0	80.0
His	87.0	75.0	76.0	83.0	-
Ile	87.0	72.0	76.0	77.0	73.0
Leu	86.0	74.0	77.0	81.0	-
Lys	87.0	71.0	70.0	74.0	72.0
Met	88.0	82.0	82.0	86.0	82.0
Cys	79.0	70.0	74.0	80.0	-
Phe	86.0	74.0	79.0	81.0	-
Tyr	84.0	72.0	72.0	77.0	-

Table 2.10. (Cont.)

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
Thr	80.0	65.0	67.0	72.0	69.0
Trp	88.0	66.0	72.0	77.0	72.0
Val	83.0	69.0	71.0	75.0	71.0

[1] NRC, 2012.

[2] Sauvant et al., 2004.

[3] FEDNA, 2010.

Table 2.11. Standardized ileal digestibility of CP and AA in soybean meal, canola meal, canola expellers, 00-rapeseed meal, and 00-expellers in pigs

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
CP, %	87.0	74.0	75.0	-	-
Indispensable AA, %					
Arg	94.0	85.0	83.0	87.0	82.0
His	90.0	78.0	78.0	84.0	-
Ile	89.0	76.0	78.0	78.0	75.0
Leu	88.0	78.0	78.0	82.0	-
Lys	89.0	74.0	71.0	75.0	73.0
Met	90.0	85.0	83.0	87.0	84.0
Cys	84.0	74.0	76.0	81.0	-
Phe	88.0	77.0	80.0	83.0	-
Tyr	88.0	77.0	74.0	80.0	-

Table 2.11. (Cont.)

	Soybean meal, dehulled	Canola meal[1]	Canola expellers[1]	00-rapeseed meal[2]	00-rapeseed expellers[3]
Thr	85.0	70.0	70.0	75.0	72.0
Trp	91.0	75.0	73.0	80.0	75.0
Val	87.0	77.0	73.0	77.0	75.0

[1] NRC, 2012.

[2] Sauvant et al., 2004.

[3] FEDNA, 2010.

CHAPTER 3. CHEMICAL COMPOSITION OF CANOLA MEAL, 00-RAPESEED MEAL, AND 00-RAPESEED EXPELLERS

ABSTRACT: The objective of this work was to compare the chemical composition of canola meal, 00-rapeseed meal, and 00-rapeseed expellers. Ten samples of canola meal were collected from crushing plants in North America, and 11 samples of 00-rapeseed meal, and 5 samples of 00-rapeseed expellers were collected from crushing plants in Europe. All samples were analyzed for GE, DM, CP, AA, ash, acid hydrolyzed ether extract (**AEE**), crude fiber (**CF**), ADF, NDF, ADL, glucose, fructose, maltose, sucrose, raffinose, stachyose, verbascose, starch, Ca, K, Mg, Na, P, S, Co, Cr, Cu, Fe, Mn, Mo, Se, Zn, phytic acid, and glucosinolates. Concentrations of these components in canola meals were compared with those in 00-rapeseed meals, and 00-rapeseed meals were compared with 00-rapeseed expellers. Results indicated that concentrations of sucrose, P, K, Zn, and glucosinolates are greater ($P < 0.05$) in 00-rapeseed meal than in canola meal. Concentrations of GE and AEE are greater ($P < 0.05$) in 00-rapeseed expellers than in 00-rapeseed meal, but concentrations of CP, Thr, ash, sucrose, crude fiber, NDF, ADL, hemicellulose, Ca, K, Mg, Mn, P, and S are greater ($P < 0.05$) in 00-rapeseed meal than in 00-rapeseed expellers. For canola meal, concentrations of CP, Ca, Fe, and Mn are greater than values published by NRC (2012), but concentrations of most other nutrients in canola meal are in good agreement with NRC (2012) values. In conclusion, the concentration of glucosinolates is much less in canola meal than in 00-rapeseed meal, and concentrations of AEE and GE are greater in 00-rapeseed expellers than in 00-rapeseed meal. However, concentrations of most other nutrients are greater in 00-rapeseed meal than in 00-rapeseed expellers.

Key words: composition, canola meal, energy, nutrients, 00-rapeseed meal, 00-rapeseed expellers

INTRODUCTION

The concentration of nutrients in canola and rapeseed varies depending on variety and environment in which the seeds were grown (Salunkhe et al, 1992; Barthet and Daun, 2011; Newkirk, 2011). Two species, *B. napus* and *B. rapa*, qualify as canola-quality rapeseed, and these 2 species are used in the canola industry (Khachatourians et al., 2001). Rapeseed with low levels of erucic acid (< 2%) and glucosinolates (< 30 μmol/g) are called canola in North America, but they are called "double-zero" or "double-low" rapeseeds in Europe (Shahidi, 1990; Spragg and Mailer, 2007; Newkirk, 2009).

Oil is extracted from canola seeds and 00-rapeseeds using a 2-step process (Adams et al., 2006). The first step involves mechanical expelling of oil, which results in removal of approximately 60 to 70% of the oil. The remaining oil is removed using either solvent extraction or a second mechanical expelling. Solvent extraction of oil results in removal of 97 to 99% of all the oil in the seeds and the resulting canola meal or 00-rapeseed meal contains less than 3% oil. Mechanical expelling results in removal of 90 to 92% of the oil and the resulting canola expellers or 00-rapeseed expellers contain 8 to 10% oil (Sauvant et al., 2004; Spragg and Mailer, 2007; Newkirk, 2009; Seneviratne et al., 2010; Woyengo et al., 2010; Barthet and Daun, 2011). The temperature, moisture, and additives used during oil extraction can affect AA digestibility, hydrolysis of glucosinolates into toxic metabolites, and the total oil content in canola and 00-rapeseed products (Newkirk, 2009). The nutritional value of canola and 00-rapeseed products may, therefore, be different depending on the processing procedure used.

Although both canola and 00-rapeseed were selected for low concentrations of glucosinolates and erucic acid, the nutritional value of the 2 ingredients may be different, but to our knowledge, there are no comparative data for the composition of canola meal and 00-rapeseed meal.

Likewise, there is a lack of data comparing the composition of 00-rapeseed meal and 00-rapeseed expellers.

The objective of this work, therefore, was to compare the nutrient composition of canola meal obtained from North America and 00-rapeseed meal from Europe, and to compare 00-rapeseed meal and 00-rapeseed expellers.

MATERIALS AND METHODS

General

Ten samples of canola meal were collected from 10 different crushing plants in Canada and the U.S. Eleven samples of 00-rapeseed meal were collected from 11 different solvent extraction plants in Europe, and 5 samples of 00-rapeseed expellers were collected from 5 different expeller plants in Europe. All samples were shipped to the University of Illinois at Urbana-Champaign where they were cataloged and stored, and subsamples were collected for analysis.

Sample Analysis

Canola meal, 00-rapeseed meal, and 00-rapeseed expellers were analyzed for DM (Method 930.15; AOAC Int., 2007), ash (Method 942.05; AOAC Int., 2007), GE by bomb calorimetry (Model 6300, Parr Instruments, Moline, IL), acid hydrolyzed ether extract (**AEE**), which was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (Method 954.02; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN), CP by combustion (Method 990.03; AOAC Int., 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ), AA [Method 982.30 E (A, B, and C); AOAC Int., 2007], crude fiber (**CF**) (Method 978.10; AOAC Int., 2007), ADF and lignin (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), sugar profile (glucose, fructose, sucrose, lactose, maltose; Churms, 1982; Kakehi and Honda, 1989), oligosaccharides (raffinose, stachyose, verbascose; Churms, 1982), minerals (Ca, P, Fe, Mg, Mn, Cu, Na, K, S, Mo, Zn, Se, Co, Cr) by Inductive Coupled Plasma-Optical Emission Spectoscopy [ICP-OES; Method 985.01 (A, B, and C); AOAC Int., 2007], phytate (Ellis et al., 1977), and glucosinolates (ISO, 1992).

Calculations and Statistical Analysis

The concentration of NFE in canola meal, 00-rapeseed meal, and 00-rapeseed expellers was calculated as the difference between DM and the summation of AEE, ash, CF, and CP, the concentration of hemicellulose was calculated as the difference between NDF and ADF, and the concentration of cellulose was calculated as the difference between ADF and ADL. The concentration of phytate bound P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers was calculated as 28.2% of analyzed phytate (Sauvant et al., 2004), and the concentration of non-phytate bound P was calculated by subtracting phytate bound P from total P. The nutrient composition values were calculated on a DM basis for each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

Data were analyzed using the ANOVA procedure of SAS (SAS Inst. Inc., Cary, NC). The presence of outliers was verified using UNIVARIATE procedure of SAS. Continent (North America or Europe) and processing procedure (solvent extraction or mechanical expelling) were considered fixed effects, and the sources of canola meal, 00-rapeseed meal, and 00-rapeseed expeller were random effect. The source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers was the experimental unit. Means for canola meal, 00-rapeseed meal, and 00-rapeseed expellers were compared using Duncan’s multiple range test and significance among means was assessed at an alpha level of 0.05.

RESULTS AND DISCUSSIONS

Gross Composition

The average chemical composition obtained from the proximate analysis of canola meal, 00-rapeseed meal, and 00-rapeseed expellers is presented in Table 3.1. Canola meal had a greater ($P <$ 0.05) concentration of DM and crude fiber than 00-rapeseed meal, and 00-rapeseed meal contained more ($P < 0.05$) CP, ash, and crude fiber than 00-rapeseed expellers. However, 00-rapeseed meal contained less ($P < 0.05$) DM, GE, and AEE than 00-rapeseed expellers.

The chemical composition of canola and rapeseed meal may vary depending on variations in concentrations of nutrients in the seeds and differences in oil extraction procedures (Bell and Keith, 1990; Bell, 1993; Barthet and Duan, 2011, Newkirk, 2011). Yellow-seeded varieties of canola and rapeseed have greater concentration of oil and CP, and less CF than black-seeded varieties, which is a consequence of a bigger seed size, which results in less seed coat and reduced concentration of lignin (Slominski et al., 1994; Slominski et al., 2012; Trindade Neto et al., 2012). The ingredients used in this study were from black-seeded varieties of canola or 00-rapeseed and no yellow-seeded varieties were used. The average concentrations of DM, CP, and ash in canola meal, 00-rapeseed meal, and 00-rapeseed expellers agree with the values for canola meal reported by Rostagno et al. (2011) and NRC (2012), and the average concentration of AEE in canola meal is in agreement with the values reported by Spragg and Mailer (2007), Seneviratne et al. (2010), and Woyengo et al. (2010). However, the concentrations of GE and crude fiber in canola meal, 00-rapeseed meal, and 00-rapeseed expellers used in this experiment were less than the values for canola meal, rapeseed meal, and rapeseed expellers reported by Sauvant et al. (2004), Spragg and Mailer (2007), FEDNA (2010), Rostagno et al. (2011), and NRC (2012).

The observation that AEE and GE levels are similar in canola meal and in 00-rapeseed meal indicates that the oil extraction procedures used in North America are as efficient as the procedures used in Europe. This observation also indicates that the gross composition of 00-rapeseeds is likely similar to that of canola seeds. This is likely a consequence of the fact that both canola and 00-rapeseed were selected from the same base material of *Brassica napus*. However, the mechanical press procedure that was used to expel oil and produce 00-rapeseed expellers is less efficient in extraction of oil than the solvent-extraction procedure used to produce 00-rapeseed meal, which is the reason for the greater amount of oil in 00-rapeseed expellers compared with 00-rapeseed meal. This increased concentration of oil is the main reason for the increased concentration of GE in 00-rapeseed expellers compared with 00-rapeseed meal.

Amino Acids

No differences between canola meal and 00-rapeseed meal for the concentration of any indispensable AA in percent and the concentration as percent of CP (DM-basis) were observed (Table 3.2 and 3.3), but the average concentration of Cys, Glu, and Pro in canola meal was greater ($P < 0.05$) than in 00-rapeseed meal. However, 00-rapeseed meal had a greater ($P < 0.05$) concentration of CP and Thr, Ala, Gly, and Tyr than 00-rapeseed expellers.

The concentrations of AA in canola meal and 00-rapeseed meal that were analyzed in this study are in agreement with the values for canola meal and rapeseed meal reported by Sauvant et al. (2004), Spragg and Mailer (2007), FEDNA (2010), PHILSAN (2010), Woyengo et al. (2010), Rostagno et al. (2011), and NRC (2012), but the concentrations of AA in 00-rapeseed expellers were less than the values in canola expellers reported by Spragg and Mailer (2007), Seneviratne et al. (2010), and Woyengo et al. (2010).

The lack of a difference in the concentrations of CP and most AA between canola meal and 00-rapeseed meal indicates that CP and AA profiles and the efficiency of oil removal procedures for the meals from North America and Europe are not different. However, the concentrations of some AA in 00-rapeseed meal are greater than in 00-rapeseed expellers, which is in agreement with data reported by NRC (2012) indicating that canola meal has greater concentration of AA than canola expellers. The greater concentration of some AA in 00-rapeseed meal compared with 00-rapeseed expellers is most likely a result of the more complete oil removal in 00-rapeseed meal, which results in a greater concentration of nutrients in the resulting meal than in 00-rapeseed expellers. The greater CV for the concentration of Lys in 00-rapeseed expellers compared with 00-rapeseed meal indicates that the mechanical press procedure may result in more variability than the solvent extraction procedure.

Minerals

The concentrations of P, K, and Zn in 00-rapeseed meal were greater ($P < 0.05$) than in canola meal, whereas concentrations of Mg, Mn, and Mo in canola meal were greater ($P < 0.05$) than in 00-rapeseed meal (Tables 3.4 and 3.5). Average Ca, P, K, Mg, Mn, and S concentrations in 00-rapeseed meal were also greater ($P < 0.05$) than in 00-rapeseed expellers.

The concentrations of Ca and K in canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were determined in this study are in agreement with the values for canola meal, rapeseed meal, and canola expellers reported by NRC (2012) and FEDNA (2010). However, the concentrations of Ca and Mg in canola and 00-rapeseed meal were greater than the values reported by FEDNA (2010) and Rostagno et al. (2011), and the concentration of S in 00-rapeseed expellers was greater than the value in rapeseed expellers reported by FEDNA (2010). The concentration of total P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers is in agreement with the value in rapeseed meal and rapeseed expellers reported by Sauvant et al. (2004), FEDNA (2010), and NRC (2012). The differences in mineral concentration between canola meal and 00-rapeseed meal is likely a result of differences in soil concentration of minerals and environmental factors between North America and Europe because mineral levels in plants often reflect soil concentrations of minerals (Bell and Keith, 1990; Mahan et al., 2005). The increased concentration of Ca, P, K, Mg, Mn, and S in 00-rapeseed meal compared with 00-rapeseed expellers, is likely also a result of the more complete oil removal that resulted in production of 00-rapeseed meal. However, this observation is contrary to values reported by NRC (2012), where it is indicated that P, K, Mg, and S concentrations in canola expellers are greater than in canola meal. Canola and rapeseed products have a greater concentration of many minerals compared with soybean meal, and these ingredients are rich sources of Ca, P, and Se (Newkirk, 2009; NRC, 2012). Concentrations of Ca and P in canola and rapeseed products range from 0.7 to 1.1% and 1.0 to 1.1%, respectively, whereas de-hulled soybean meal contains 0.33% and 0.71%, respectively, of Ca and P (Sauvant et al., 2004; FEDNA, 2010; NRC, 2012). The concentration of Se in canola meal is 1.1 mg/kg, whereas soybean meal contains 0.27 mg/kg (NRC, 2012). Thus, canola and rapeseed products provide more Ca, P, and Se to the diets than soybean meal. The concentration of minerals is not affected by processing, and differences between meals and expellers have not been reported (Spragg and Mailer, 2007). However, the concentration of sodium may vary among sources of canola meal because of differences in the amount of soapstock that is added to the meals (Newkirk, 2009).

Phytic acid

The concentrations of phytate and phytate bound P in 00-rapeseed meal were greater ($P < 0.05$) than in canola meal, but the values were not different between 00-rapeseed meal and 00-rapeseed expellers. The concentration of non-phytate bound P was not different between canola meal and 00-rapeseed meal, and the value for 00-rapeseed meal was not different from 00-rapeseed expellers.

The concentrations of phytate bound P and non-phytate bound P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers determined in this study are in agreement with the values for 00-rapeseed meal and 00-rapeseed expellers reported by FEDNA (2010), and the concentrations of phytate bound P and non-phytate bound P for 00-rapeseed expellers are in agreement with the values for canola expellers reported by NRC (2012). However, the concentration of phytate bound P in canola meal is greater than the values reported by Rostagno et al. (2011) and NRC (2012). In fact, most of the P in canola and rapeseed meal is bound to phytic acid (Spragg and Mailer, 2007; Newkirk, 2009). As a consequence, the digestibility of P in canola and rapeseed products by pigs and poultry is only 25 to 30% (Sauvant et al., 2004; FEDNA, 2010; NRC, 2012). However, inclusion of microbial phytase to growing pig diets can increase the digestibility of P in canola meal to more than 50% (Akinmusire and Adeola, 2009; Rodríguez et al., 2013).

Carbohydrates

The average sucrose level in 00-rapeseed meal was greater ($P < 0.05$) than in canola meal, but raffinose concentration was less ($P < 0.05$) in 00-rapeseed meal than in canola meal (Table 3.6). The average concentration of sucrose, NDF, ADL, and hemicellulose was greater ($P < 0.05$) in 00-rapeseed meal than in 00-rapeseed expellers.

The concentration of starch, NDF, and ADF in canola meal, 00-rapeseed meal, and 00-rapeseed expellers is in agreement with the values for rapeseed meal reported by FEDNA (2010) and Sauvant et al. (2004). However, the concentration of starch is less than values reported by NRC (2012) and Slominski et al. (2012), and the concentration of NDF, ADF, ADL, and hemicellulose in canola meal and 00-rapeseed meal was greater than the values for canola meal reported by NRC (2012).

The increased concentration of sucrose in 00-rapeseed meal compared with canola meal may be a result of differences in growing conditions between North America and Europe, because variation in climatic conditions may affect the amounts of soluble carbohydrates in seeds (Barthet and Daun, 2011). The concentrations of NDF and ADF in 00-rapeseed expellers were less than values reported by FEDNA (2010) and NRC (2012), but the concentrations of ADL and hemicellulose were greater than values reported by FEDNA (2010) and NRC (2012). The increased concentrations of sucrose, NDF, lignin, and hemicellulose in 00-rapeseed meal compared with expellers were expected, but this result is not in agreement with values reported by NRC (2012), where canola meal has less concentration of NDF, lignin, and hemicellulose than canola expellers.

Glucosinolates

Canola meal had a concentration of total glucosinolates that was less ($P < 0.05$) than in 00-rapeseed meal (Table 3.7). However, 00-rapeseed meal contained fewer glucosinolates than 00-rapeseed expellers. The mean value for total glucosinolates in canola meal is in agreement with the value reported by Tripathi and Mishra (2007; 3.55 vs. 3.62 µmol/g), but the mean value for total glucosinolates in 00-rapeseed meal observed in this study was much less than the value reported by Tripathi and Mishra (2007; 11.3 vs. 38.0 µmol/g). The mean concentration of total glucosinolates in 00-rapeseed expellers observed in this study was slightly greater than the value reported for canola expellers by Seneviratne et al. (2010; 14.5 vs. 11.3 µmol/g), and the value was also greater than the values reported by Spragg and Mailer (2007) and Tripathi and Mishra (2007).

Glucosinolate concentrations in canola and rapeseed meal may vary among varieties because of differences in genetic background, growing conditions, or differences in oil extraction procedures (Tripathi and Mishra, 2007). The meal from *Brassica juncea* has a greater concentration of glucosinolates than meal from *Brassica napus* and *Brassica rapa* (Mailer, 2008; Zhou et al., 2013). Harvest in hot and dry conditions and water deficiency during the growing season increase concentrations of glucosinolates (Tripathi and Mishra, 2007). The reduced concentration of glucosinolates in canola meal compared with 00-rapeseed meal that was observed in this study indicates that canola breeders in North America have been more successful in identifying and selecting varieties with very low concentrations of glucosinolates than their European colleagues. There is also much more variation in glucosinolate concentrations among sources of 00-rapeseed meal than among sources of canola meal with some 00-rapeseed meals containing more than 20 μmol/g. Processing after solvent extraction or oil expelling may result in a reduction in the concentration of glucosinolates (Spragg and Mailer, 2007). Some glucosinolates may be destroyed by heat during the desolventizer-toaster phase following solvent extraction of oil (Bell and Keith, 1990; Jensen et al., 1994). However, because 00-rapeseed expellers are usually not toasted or heated, glucosinolates are not destroyed if the oil is removed by mechanical expelling. This is the reason why the concentration of total glucosinolates in 00-rapeseed meal is less than in 00-rapeseed expellers. A similar observation has been previously reported (Seneviratne et al., 2011; Landero et al., 2011; 2012).

The implication of the differences in concentrations of glucosinolates between canola and 00-rapeseed products is that more canola meal than 00-rapeseed meal or 00-rapeseed expellers may be used in diets for pigs because it is generally recommended that pig diets should contain no more than 2 μmol/g of glucosinolates (Schone et al., 2001). Thus, most sources of canola meal can be included in diets fed to pigs at 25 to 50%, whereas most sources of 00-rapeseed meal or 00-rapeseed expellers can only be used by 10 to 20% in the diets without exceeding a dietary level of 2 μmol glucosinolates per gram of diet.

CONCLUSION

There is very little difference in the nutritional composition of canola meal and 00-rapeseed meal. However, 00-rapeseed expellers contain more energy and AEE, but have slightly less concentrations of some nutrients, than 00-rapeseed meal, because of the increased oil concentration. Because of the greater concentration of glucosinolates, less 00-rapeseed meal and 00-rapeseed expellers can be included in diets fed to pigs than if canola meal is used. As a consequence, results of feeding experiments with canola meal may not always be representative of feeding 00-rapeseed meal or 00-rapeseed expellers.

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TABLES

Table 3.1. Proximate analysis of canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM-basis

Sample origin	DM (%)	CP (%)	GE (kcal/kg)	Ash (%)	AEE[1] (%)	Crude fiber (%)	NFE[2] (%)
Canola meal							
1	90.5	43.5	4,675	9.28	4.76	8.75	24.2
2	89.2	41.2	4,714	7.39	4.26	12.3	24.0
3	90.2	44.1	4,666	8.11	3.34	11.3	23.3
4	89.8	42.4	4,718	8.20	4.95	11.4	22.8
5	90.4	40.6	4,641	8.18	4.19	12.0	25.4
6	89.4	42.0	4,735	7.74	4.00	7.85	27.8
7	95.2	35.6	4,462	8.11	3.90	7.04	40.5
8	88.4	40.7	4,846	7.36	4.12	8.93	27.3
9	90.4	40.9	4,799	7.46	3.60	8.00	30.4
10	88.9	43.0	4,825	7.43	4.27	9.38	24.8
Average	90.2	41.4	4,708	7.93	4.14	9.70	27.1
CV (%)	2.09	5.73	2.35	7.46	11.62	19.60	19.49

Table 3.1. (Cont.)

Sample origin	DM (%)	CP (%)	GE (kcal/kg)	Ash (%)	AEE[1] (%)	Crude fiber (%)	NFE[2] (%)
00-rapeseed meal							
1	89.1	40.8	4,658	7.4	4.0	8.6	28.2
2	90.3	42.1	4,710	8.2	4.6	7.7	27.7
3	88.1	42.6	4,737	7.5	3.9	8.2	25.8
4	89.1	40.0	4,779	7.7	5.9	7.7	27.8
5	90.0	36.5	4,812	7.3	6.6	8.5	31.2
6	88.0	41.5	4,750	7.5	4.1	7.8	27.1
7	88.6	41.9	4,775	7.5	4.2	8.0	27.0
8	89.0	41.9	4,756	7.7	4.1	8.0	27.3
9	88.6	40.2	4,677	7.8	3.1	8.7	28.8
10	88.9	41.7	4,702	8.0	3.4	7.9	27.9
11	88.6	38.6	4,717	9.1	3.8	8.6	28.5
Average	88.9	40.7	4,734	7.8	4.3	8.2	27.9
CV (%)	0.79	4.45	0.98	6.53	23.93	4.70	4.86

Table 3.1. (Cont.)

Sample origin	DM (%)	CP (%)	GE (kcal/kg)	Ash (%)	AEE[1] (%)	Crude fiber (%)	NFE[2] (%)
00-rapeseed expellers							
1	89.9	40.2	5,194	7.04	12.0	6.33	24.4
2	89.9	38.4	5,310	6.39	14.5	6.17	24.5
3	91.2	39.7	5,226	6.6	15.2	6.08	23.7
4	95.2	37.0	5,081	6.9	12.3	6.09	32.9
5	93.0	38.5	4,902	7.0	8.89	7.13	31.5
Average	91.8	38.8	5,143	6.8	12.6	6.36	27.4
CV (%)	2.47	3.23	3.06	4.13	19.71	6.95	16.13
Canola meal vs. 00-rapeseed meal							
P-value	0.04	0.4	0.48	0.56	0.57	0.02	0.59
SEM	0.42	0.64	25.3	0.17	0.25	0.41	1.15
00-rapeseed meal vs. 00-rapeseed expellers							
P-value	<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	0.69
SEM	0.52	0.64	34.8	0.17	0.61	0.16	1.01

[1] AEE = acid hydrolyzed ether extract.
[2] NFE = nitrogen free extract.

Table 3.2. Concentration (%) of AA in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM-basis

Sample origin	Indispensable AA										Dispensable AA							
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
Canola meal																		
1	2.59	1.18	1.73	2.99	2.45	0.82	1.69	1.71	0.54	2.25	1.84	3.00	0.98	6.76	2.13	2.48	1.43	1.17
2	2.27	1.04	1.57	2.69	2.18	0.75	1.54	1.55	0.46	2.05	1.67	2.65	0.85	5.91	1.92	2.20	1.27	1.08
3	2.48	1.13	1.69	2.93	2.28	0.80	1.65	1.69	0.52	2.20	1.80	2.94	0.93	6.52	2.08	2.42	1.42	1.14
4	2.36	1.09	1.63	2.80	2.26	0.77	1.57	1.66	0.50	2.13	1.75	2.82	0.91	6.11	1.99	2.32	1.37	1.12
5	2.16	1.03	1.52	2.65	2.02	0.70	1.48	1.52	0.46	2.00	1.64	2.62	0.85	5.83	1.88	2.17	1.28	1.02
6	2.39	1.11	1.69	2.90	2.21	0.82	1.62	1.71	0.46	2.18	1.82	2.88	0.94	6.40	2.08	2.35	1.53	1.12
7	2.22	1.02	1.51	2.64	1.97	0.71	1.47	1.57	0.47	1.96	1.65	2.63	0.84	5.99	1.89	2.17	1.44	1.03
8	2.32	1.06	1.67	2.78	2.28	0.78	1.56	1.61	0.51	2.09	1.73	2.72	0.89	6.44	1.97	2.46	1.31	1.12
9	2.36	1.08	1.69	2.81	2.33	0.80	1.59	1.62	0.52	2.12	1.75	2.75	0.93	6.48	2.00	2.45	1.32	1.13
10	2.49	1.15	1.78	3.01	2.31	0.85	1.71	1.77	0.53	2.24	1.86	2.96	0.99	7.24	2.14	2.67	1.52	1.21
Average	2.37	1.09	1.65	2.82	2.23	0.78	1.59	1.64	0.50	2.12	1.75	2.80	0.91	6.37	2.01	2.37	1.39	1.11
CV (%)	5.54	4.91	5.42	4.78	6.44	6.22	5.11	4.90	6.37	4.64	4.52	5.12	5.84	6.75	4.77	6.76	6.77	5.22

Table 3.2. (Cont.)

Sample origin	Indispensable AA										Dispensable AA							
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
00-rapeseed meal																		
1	2.23	1.03	1.55	2.68	2.14	0.75	1.51	1.64	0.45	2.06	1.69	2.78	0.83	5.80	1.96	2.20	1.36	1.09
2	2.40	1.09	1.67	2.87	2.26	0.79	1.63	1.69	0.50	2.18	1.76	2.98	0.90	6.33	2.06	2.34	1.42	1.12
3	2.52	1.15	1.73	2.96	2.43	0.82	1.71	1.72	0.54	2.25	1.81	3.07	0.93	6.43	2.11	2.40	1.43	1.16
4	2.28	1.07	1.62	2.73	2.21	0.75	1.54	1.61	0.47	2.11	1.70	2.79	0.90	5.98	1.98	2.24	1.30	1.06
5	1.91	0.90	1.35	2.26	1.83	0.63	1.27	1.39	0.38	1.78	1.47	2.34	0.76	5.01	1.71	1.80	1.18	0.94
6	2.35	1.06	1.61	2.83	2.25	0.80	1.60	1.72	0.50	2.12	1.76	2.97	0.86	6.16	2.03	2.32	1.47	1.13
7	2.35	1.09	1.60	2.77	2.33	0.78	1.57	1.65	0.47	2.10	1.70	2.79	0.91	6.03	1.98	2.27	1.35	1.12
8	2.17	1.01	1.58	2.66	2.08	0.71	1.51	1.58	0.51	2.07	1.65	2.82	0.78	5.71	1.92	2.13	1.27	1.05
9	2.25	1.03	1.52	2.71	2.16	0.80	1.53	1.72	0.43	2.00	1.71	2.75	0.90	6.31	1.98	2.23	1.47	1.14
10	2.21	1.03	1.59	2.69	2.12	0.72	1.52	1.60	0.49	2.07	1.66	2.84	0.82	5.74	1.92	2.17	1.30	1.06
11	2.11	0.97	1.51	2.58	2.03	0.76	1.46	1.61	0.45	1.95	1.63	2.73	0.83	5.92	1.89	2.28	1.34	1.09
Average	2.25	1.04	1.58	2.70	2.17	0.75	1.53	1.63	0.47	2.06	1.69	2.81	0.86	5.95	1.96	2.22	1.35	1.09
CV (%)	7.16	6.39	6.21	6.71	7.38	7.14	7.22	5.83	9.28	5.99	5.28	6.72	6.59	6.65	5.34	7.14	6.63	5.57

Table 3.2. (Cont.)

Sample origin	Indispensable AA										Dispensable AA							
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
00-rapeseed expellers																		
1	2.32	1.05	1.57	2.69	2.31	0.76	1.53	1.58	0.48	2.07	1.65	2.85	0.91	6.13	1.93	2.23	1.41	1.06
2	2.29	1.04	1.54	2.63	2.32	0.75	1.50	1.59	0.43	2.02	1.63	2.80	0.88	5.94	1.90	2.21	1.41	1.04
3	2.07	0.94	1.46	2.46	2.00	0.66	1.41	1.47	0.43	1.90	1.52	2.63	0.77	5.22	1.77	2.01	1.22	0.98
4	2.08	0.94	1.44	2.46	1.97	0.67	1.41	1.49	0.45	1.89	1.54	2.56	0.79	5.32	1.78	2.00	1.24	1.00
5	2.00	0.93	1.44	2.43	1.75	0.68	1.37	1.45	0.46	1.87	1.52	2.48	0.75	5.34	1.77	2.00	1.19	0.95
Average	2.15	0.98	1.49	2.53	2.07	0.70	1.44	1.52	0.45	1.95	1.57	2.67	0.82	5.59	1.83	2.09	1.29	1.01
CV (%)	6.66	6.08	4.08	4.64	11.77	6.71	4.69	4.26	4.71	4.57	4.01	5.90	8.62	7.41	4.29	5.69	8.30	4.42
Canola meal vs. 00-rapeseed meal																		
P-value	0.10	0.07	0.09	0.11	0.37	0.27	0.20	0.80	0.15	0.23	0.10	0.88	0.03	0.03	0.27	0.04	0.40	0.32
SEM	0.05	0.02	0.03	0.05	0.05	0.02	0.03	0.03	0.01	0.03	0.03	0.05	0.02	0.13	0.03	0.05	0.03	0.02
00-rapeseed meal vs. 00-rapeseed expellers																		
P-value	0.24	0.12	0.09	0.07	0.36	0.07	0.12	0.03	0.33	0.09	0.02	0.17	0.29	0.12	0.03	0.13	0.27	0.02
SEM	0.06	0.02	0.03	0.06	0.07	0.02	0.04	0.03	0.02	0.04	0.03	0.07	0.02	0.15	0.04	0.06	0.04	0.02

Table 3.3. Concentration (%) of AA as percent of CP in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM-basis

Sample origin	Indispensable AA										Dispensable AA							
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
Canola meal																		
1	5.95	2.71	3.98	6.87	5.63	1.89	3.89	3.93	1.24	5.17	4.23	6.90	2.25	15.54	4.90	5.70	3.29	2.69
2	5.22	2.39	3.61	6.18	5.01	1.72	3.54	3.56	1.06	4.71	3.84	6.09	1.95	13.59	4.41	5.06	2.92	2.48
3	5.70	2.60	3.89	6.74	5.24	1.84	3.79	3.89	1.20	5.06	4.14	6.76	2.14	14.99	4.78	5.56	3.26	2.62
4	5.43	2.51	3.75	6.44	5.20	1.77	3.61	3.82	1.15	4.90	4.02	6.48	2.09	14.05	4.57	5.33	3.15	2.57
5	4.97	2.37	3.49	6.09	4.64	1.61	3.40	3.49	1.06	4.60	3.77	6.02	1.95	13.40	4.32	4.99	2.94	2.34
6	5.49	2.55	3.89	6.67	5.08	1.89	3.72	3.93	1.06	5.01	4.18	6.62	2.16	14.71	4.78	5.40	3.52	2.57
7	5.10	2.34	3.47	6.07	4.53	1.63	3.38	3.61	1.08	4.51	3.79	6.05	1.93	13.77	4.34	4.99	3.31	2.37
8	5.33	2.44	3.84	6.39	5.24	1.79	3.59	3.70	1.17	4.80	3.98	6.25	2.05	14.80	4.53	5.66	3.01	2.57
9	5.43	2.48	3.89	6.46	5.36	1.84	3.66	3.72	1.20	4.87	4.02	6.32	2.14	14.90	4.60	5.63	3.03	2.60
10	5.72	2.64	4.09	6.92	5.31	1.95	3.93	4.07	1.22	5.15	4.28	6.80	2.28	16.64	4.92	6.14	3.49	2.78
Average	5.43	2.50	3.79	6.48	5.12	1.79	3.65	3.77	1.14	4.88	4.03	6.43	2.09	14.64	4.62	5.45	3.19	2.56
CV (%)	5.54	4.91	5.42	4.78	6.44	6.22	5.11	4.90	6.37	4.64	4.52	5.12	5.84	6.75	4.77	6.76	6.77	5.22

Table 3.3. (Cont.)

Sample origin	Indispensable AA										Dispensable AA							
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
00-rapeseed meal																		
1	5.13	2.37	3.56	6.16	4.92	1.72	3.47	3.77	1.03	4.74	3.89	6.39	1.91	13.33	4.51	5.06	3.13	2.51
2	5.52	2.51	3.84	6.60	5.20	1.82	3.75	3.89	1.15	5.01	4.05	6.85	2.07	14.55	4.74	5.38	3.26	2.57
3	5.79	2.64	3.98	6.80	5.59	1.89	3.93	3.95	1.24	5.17	4.16	7.06	2.14	14.78	4.85	5.52	3.29	2.67
4	5.24	2.46	3.72	6.28	5.08	1.72	3.54	3.70	1.08	4.85	3.91	6.41	2.07	13.75	4.55	5.15	2.99	2.44
5	4.39	2.07	3.10	5.20	4.21	1.45	2.92	3.20	0.87	4.09	3.38	5.38	1.75	11.52	3.93	4.14	2.71	2.16
6	5.40	2.44	3.70	6.51	5.17	1.84	3.68	3.95	1.15	4.87	4.05	6.83	1.98	14.16	4.67	5.33	3.38	2.60
7	5.40	2.51	3.68	6.37	5.36	1.79	3.61	3.79	1.08	4.83	3.91	6.41	2.09	13.86	4.55	5.22	3.10	2.57
8	4.99	2.32	3.63	6.11	4.78	1.63	3.47	3.63	1.17	4.76	3.79	6.48	1.79	13.13	4.41	4.90	2.92	2.41
9	5.17	2.37	3.49	6.23	4.97	1.84	3.52	3.95	0.99	4.60	3.93	6.32	2.07	14.51	4.55	5.13	3.38	2.62
10	5.08	2.37	3.66	6.18	4.87	1.66	3.49	3.68	1.13	4.76	3.82	6.53	1.89	13.20	4.41	4.99	2.99	2.44
11	4.85	2.23	3.47	5.93	4.67	1.75	3.36	3.70	1.03	4.48	3.75	6.28	1.91	13.61	4.34	5.24	3.08	2.51
Average	5.18	2.39	3.62	6.22	4.98	1.74	3.52	3.75	1.08	4.74	3.87	6.45	1.97	13.67	4.50	5.10	3.11	2.50
CV (%)	7.16	6.39	6.21	6.71	7.38	7.14	7.22	5.83	9.28	5.99	5.28	6.72	6.59	6.65	5.34	7.14	6.63	5.57

Table 3.3. (Cont.)

Sample origin	Indispensable AA										Dispensable AA							
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
00-rapeseed expellers																		
1	5.33	2.41	3.61	6.18	5.31	1.75	3.52	3.63	1.10	4.76	3.79	6.55	2.09	14.09	4.44	5.13	3.24	2.44
2	5.26	2.39	3.54	6.05	5.33	1.72	3.45	3.66	0.99	4.64	3.75	6.44	2.02	13.66	4.37	5.08	3.24	2.39
3	4.76	2.16	3.36	5.66	4.60	1.52	3.24	3.38	0.99	4.37	3.49	6.05	1.77	12.00	4.07	4.62	2.80	2.25
4	4.78	2.16	3.31	5.66	4.53	1.54	3.24	3.43	1.03	4.34	3.54	5.89	1.82	12.23	4.09	4.60	2.85	2.30
5	4.60	2.14	3.31	5.59	4.02	1.56	3.15	3.33	1.06	4.30	3.49	5.70	1.72	12.28	4.07	4.60	2.74	2.18
Average	4.95	2.25	3.43	5.83	4.76	1.62	3.32	3.49	1.03	4.48	3.61	6.12	1.89	12.85	4.21	4.80	2.97	2.31
CV (%)	6.66	6.08	4.08	4.64	11.77	6.71	4.69	4.26	4.71	4.57	4.01	5.90	8.62	7.41	4.29	5.69	8.30	4.42
Canola meal vs. 00-rapeseed meal																		
P-value	0.10	0.07	0.09	0.10	0.37	0.27	0.20	0.06	0.15	0.23	0.10	0.88	0.03	0.03	0.27	0.04	0.75	0.32
SEM	0.10	0.04	0.07	0.11	0.11	0.04	0.07	0.06	0.03	0.08	0.06	0.12	0.04	0.29	0.07	0.11	0.06	0.04
00-rapeseed meal vs. 00-rapeseed expellers																		
P-value	0.24	0.12	0.09	0.07	0.36	0.07	0.12	0.03	0.33	0.09	0.02	0.17	0.29	0.12	0.03	0.13	0.27	0.02
SEM	0.15	0.06	0.08	0.15	0.18	0.05	0.09	0.08	0.04	0.11	0.08	0.17	0.06	0.38	0.09	0.14	0.09	0.05

Table 3.4. Macro minerals and phytate in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM-basis

Sample origin	Ca (%)	P (%)	Phytate (%)	Phytate P (%)	Non phytate P (%)	Phytate P as % of total P	Non-phytate P as % of total P	K (%)	Mg (%)	Na (%)	S (%)
Canola meal											
1	1.34	1.15	3.24	0.91	0.24	79.31	20.69	1.26	0.60	0.20	0.83
2	0.84	1.17	3.60	1.01	0.15	86.89	13.11	1.28	0.59	0.01	0.80
3	0.88	1.16	3.27	0.92	0.24	79.09	20.91	1.28	0.68	0.01	0.84
4	0.75	1.06	3.03	0.85	0.21	80.60	19.40	1.24	0.63	0.02	0.81
5	0.92	1.04	2.87	0.81	0.23	77.56	22.44	1.29	0.60	0.07	0.80
6	0.85	1.13	3.32	0.93	0.19	82.78	17.22	1.24	0.56	0.10	0.81
7	0.71	1.08	3.10	0.87	0.21	80.62	19.38	1.30	0.59	0.03	0.77
8	0.73	1.20	3.28	0.92	0.28	77.01	22.99	1.32	0.66	<0.01	0.76
9	0.72	1.23	3.30	0.93	0.30	75.57	24.43	1.33	0.67	<0.01	0.76
10	0.80	1.14	2.96	0.83	0.30	73.30	26.70	1.32	0.62	0.13	0.83
Average	0.85	1.14	3.20	0.90	0.24	79.27	20.73	1.29	0.62	-	0.80
CV (%)	21.71	5.33	6.62	6.55	20.58	4.82	18.43	2.52	6.36	-	3.65

Table 3.4. (Cont.)

Sample origin	Ca (%)	P (%)	Phytate (%)	Phytate P (%)	Non phytate P (%)	Phytate P as % of total P	Non-phytate P as % of total P	K (%)	Mg (%)	Na (%)	S (%)
00-rapeseed meal											
1	0.76	1.08	2.92	0.82	0.26	76.24	23.76	1.40	0.54	0.04	0.86
2	0.79	1.25	3.55	1.00	0.25	79.97	20.03	1.47	0.50	0.07	0.83
3	0.85	1.27	3.71	1.05	0.23	82.19	17.81	1.46	0.49	0.05	0.82
4	0.85	1.18	3.37	0.95	0.23	80.43	19.57	1.43	0.48	0.07	0.83
5	0.82	1.20	3.47	0.98	0.22	81.32	18.68	1.42	0.52	<0.01	0.76
6	0.81	1.18	3.45	0.97	0.21	82.28	17.72	1.47	0.55	0.02	0.81
7	0.80	1.16	3.48	0.98	0.18	84.18	15.82	1.46	0.47	<0.01	0.94
8	0.75	1.18	3.40	0.96	0.22	81.23	18.77	1.49	0.51	0.01	0.79
9	0.99	1.29	3.84	1.08	0.21	83.96	16.04	1.47	0.45	<0.01	0.85
10	0.82	1.23	3.46	0.98	0.25	79.54	20.46	1.47	0.48	0.09	0.85
11	0.89	1.35	3.53	0.99	0.36	73.42	26.58	1.51	0.63	0.13	0.86
Average	0.83	1.22	3.47	0.98	0.24	80.43	19.57	1.46	0.51	-	0.84
CV (%)	8.03	6.02	6.59	6.65	19.41	3.97	16.34	2.16	9.69	-	5.51

Table 3.4. (Cont.)

Sample origin	Ca (%)	P (%)	Phytate (%)	Phytate P (%)	Non phytate P (%)	Phytate P as % of total P	Non-phytate P as % of total P	K (%)	Mg (%)	Na (%)	S (%)
00-rapeseed expellers											
1	0.79	1.22	3.68	1.04	0.19	84.71	15.29	1.32	0.46	<0.01	0.79
2	0.66	1.08	3.17	0.89	0.19	82.71	17.29	1.27	0.45	0.01	0.77
3	0.69	1.10	3.05	0.86	0.24	78.26	21.74	1.21	0.43	0.20	0.72
4	0.77	1.12	3.29	0.93	0.20	82.35	17.65	1.31	0.46	<0.01	0.74
5	0.82	1.14	3.24	0.91	0.23	79.94	20.06	1.37	0.47	<0.01	0.77
Average	0.74	1.13	3.29	0.92	0.21	81.59	18.41	1.30	0.45	-	0.76
CV (%)	9.12	4.77	7.24	7.43	11.17	3.09	13.68	4.62	3.34	-	3.66
Canola meal vs. 00-rapeseed meal											
P-value	0.70	0.01	0.01	0.01	0.90	0.46	0.468	<0.01	<0.01	-	0.06
SEM	0.04	0.02	0.07	0.02	0.01	1.07	1.07	0.01	0.01	-	0.01
00-rapeseed meal vs. 00-rapeseed expellers											
P-value	0.03	0.04	0.16	0.16	0.19	0.49	0.49	<0.01	0.02	-	<0.01
SEM	0.03	0.03	0.09	0.02	0.02	1.16	1.16	0.02	0.02	-	0.02

Table 3.5. Concentration of micro minerals (mg/kg) composition in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM-basis

Sample origin	Co	Cr	Cu	Fe	Mn	Mo	Se	Zn
Canola meal								
1	<0.20	<0.01	6.96	210	70.7	1.22	0.13	54.8
2	<0.20	<0.01	6.84	177	71.8	0.79	0.80	61.7
3	<0.20	<0.01	6.10	328	75.4	1.33	0.76	57.3
4	<0.20	<0.01	6.24	419	79.1	0.89	0.30	53.6
5	<0.20	<0.01	10.62	384	110	0.88	0.44	81.0
6	<0.20	<0.01	4.92	228	64.8	1.01	0.52	58.4
7	<0.20	<0.01	7.36	363	74.6	0.84	1.13	61.3
8	<0.20	2.68	6.45	169	68.5	1.02	0.38	58.5
9	<0.20	3.65	6.42	179	68.9	1.00	1.33	57.5
10	1.33	<0.01	5.96	150	63.6	1.12	0.21	58.5
Average	-	-	6.79	261	74.74	1.01	0.60	60.3
CV (%)	-	-	22.10	39.04	17.75	17.07	66.27	12.78

Table 3.5. (Cont.)

Sample origin	Co	Cr	Cu	Fe	Mn	Mo	Se	Zn
00-rapeseed meal								
1	<0.20	<0.01	5.28	138	68.5	0.90	0.12	61.1
2	<0.20	<0.01	5.32	335	64.2	0.89	0.06	72.1
3	<0.20	<0.01	5.79	176	64.7	0.79	0.11	72.0
4	<0.20	<0.01	8.87	172	73.0	0.79	0.04	87.0
5	<0.20	<0.01	4.89	133	68.9	0.44	0.37	61.8
6	<0.20	<0.01	7.95	190	71.6	0.91	0.17	62.1
7	<0.20	<0.01	5.65	124	68.9	0.90	0.04	75.3
8	<0.20	<0.01	5.17	188	70.8	0.90	0.11	73.9
9	<0.20	<0.01	5.42	114	60.9	0.56	< 0.04	74.8
10	<0.20	<0.01	5.29	222	66.4	0.79	0.05	70.5
11	<0.20	0.53	6.32	266	67.6	0.79	0.16	76.6
Average	-	-	5.99	187	67.8	0.79	0.12	71.6
CV (%)	-	-	21.13	35.59	5.23	19.51	80.40	10.73

Table 3.5. (Cont.)

Sample origin	Co	Cr	Cu	Fe	Mn	Mo	Se	Zn
00-rapeseed expellers								
1	<0.20	<0.01	5.8	170	57.8	1.00	0.08	85.9
2	<0.20	<0.01	4.8	122	56.7	0.78	0.04	68.8
3	<0.20	<0.01	5.0	144	59.2	0.77	0.10	68.8
4	<0.20	<0.01	4.6	141	59.9	0.74	0.13	59.8
5	<0.20	<0.01	4.6	130	61.3	0.86	0.08	63.8
Average	-	-	4.97	141	59.0	0.83	0.86	69.4
CV (%)	-	-	10.04	12.90	3.04	12.64	38.21	14.34
Canola meal vs. 00-rapeseed meal								
P-value	-	-	0.20	0.06	<0.001	<0.01	-	<0.01
SEM	-	-	0.42	25.9	2.93	0.05	-	2.34
00-rapeseed meal vs. 00-rapeseed expellers								
P-value	-	-	0.11	0.16	<0.01	0.59	-	0.64
SEM	-	-	0.43	22.0	1.20	0.05	-	3.24

Table 3.6. Concentration (%) of carbohydrates in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM-basis

Sample origin	Fructose	Glucose	Sucrose	Raffinose	Stachyose	Starch	ADF	NDF	ADL	Hemicell-ulose[1]	Cellulose[2]
Canola meal											
1	-	-	7.09	0.40	1.68	-	18.0	27.1	7.53	9.12	10.5
2	-	-	6.95	0.55	1.53	-	20.8	33.7	8.69	12.9	12.1
3	-	-	6.74	0.40	1.55	-	20.2	33.9	8.65	13.7	11.6
4	-	-	5.40	0.77	1.56	-	21.9	35.1	9.39	13.2	12.5
5	0.31	0.31	4.98	0.41	1.49	1.08	21.8	38.3	8.36	16.6	13.4
6	-	-	6.60	0.49	1.45	0.13	20.6	36.7	9.67	16.1	10.9
7	-	0.06	7.42	0.32	1.70	0.25	20.0	36.5	8.60	16.5	11.4
8	-	-	7.58	0.57	1.19	-	21.4	31.7	9.31	10.3	12.1
9	-	-	7.84	0.60	1.14	-	21.3	29.9	9.06	8.61	12.2
10	0.11		8.11	0.61	2.17	-	19.0	33.0	7.23	14.0	11.7
Average	0.21	0.04	6.87	0.51	1.55	-	20.5	33.6	8.65	13.1	11.8
CV (%)	-	-	14.68	26.17	18.49	-	6.09	10.04	9.08	22.45	6.94

Table 3.6. (Cont.)

Sample origin	Fructose	Glucose	Sucrose	Raffinose	Stachyose	Starch	ADF	NDF	ADL	Hemicell-ulose[1]	Cellulose[2]
00-rapeseed meal											
1	0.21	0.21	7.90	0.30	1.86	-	21.7	35.5	9.18	13.8	12.5
2	0.08	0.06	8.11	0.33	1.75	-	18.9	31.3	7.36	12.4	11.5
3	-	0.08	8.11	0.34	1.65	-	19.0	28.3	8.63	9.23	10.4
4	0.07	0.13	7.42	0.30	1.81	-	21.4	33.4	9.13	12.0	12.3
5	0.10	0.16	6.65	0.40	1.60	-	24.4	38.6	8.77	14.2	15.6
6	-	-	8.18	0.36	1.65	-	21.3	34.2	8.98	12.9	12.4
7	-	-	7.76	0.36	1.84	-	24.9	30.8	9.30	5.95	15.6
8	0.15	-	6.87	0.19	0.93	-	23.0	34.5	8.81	11.5	14.2
9	0.19	0.06	7.64	0.42	2.08	-	22.4	38.0	10.0	15.6	12.4
10	0.20	0.08	7.46	0.40	1.93	-	20.9	32.5	9.25	11.6	11.6
11	0.19	-	9.29	0.34	1.62	-	21.2	34.9	8.55	13.7	12.6
Average	0.11	0.07	7.76	0.34	1.70	-	21.7	33.8	8.91	12.1	12.8
CV (%)	38.61	51.40	9.13	18.65	17.35	-	8.72	9.01	7.30	21.83	12.86

Table 3.6. (Cont.)

Sample origin	Fructose	Glucose	Sucrose	Raffinose	Stachyose	Starch	ADF	NDF	ADL	Hemicellulose[1]	Cellulose[2]
00-rapeseed expellers											
1	-	0.23	7.53	0.26	1.39	-	17.4	23.1	7.15	5.74	10.2
2	0.42	1.31	6.89	0.33	1.16	-	17.5	22.0	7.28	4.53	10.2
3	-	-	7.38	0.24	1.19	-	18.6	26.8	7.90	8.20	10.7
4	0.26	0.23	5.50	0.40	1.85	-	18.8	28.1	7.65	9.28	11.1
5	-	-	6.99	0.29	1.54	-	25.0	35.2	9.01	10.1	16.0
Average	0.14	0.36	6.86	0.30	1.43	-	19.5	27.0	7.80	7.57	11.7
CV (%)	-	-	11.73	20.88	19.85	-	16.24	19.28	9.49	31.20	21.19
Canola meal vs. 00-rapeseed meal											
P-value	0.12	0.39	0.03	<0.01	0.24	-	0.10	0.89	0.42	0.41	0.12
SEM	0.03	0.03	0.26	0.03	0.09	-	0.49	0.98	0.22	0.85	0.40
00-rapeseed meal vs. 00-rapeseed expellers											
P-value	0.68	0.10	0.04	0.29	0.10	-	0.06	<0.01	0.01	0.01	0.29
SEM	0.05	0.12	0.28	0.02	0.11	-	0.90	1.46	0.26	0.99	0.74

[1] Hemicellulose was calculated as the difference between NDF and ADF.
[2] Cellulose was calculated as the difference between ADF and ADL.

Table 3.7. Concentrations of total glucosinolates in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM-basis

Item	Total glucosinolates (µmol/g)
Canola meal	
1	7.69
2	4.86
3	3.15
4	2.71
5	1.38
6	3.40
7	1.66
8	-
9	-
10	-
Average	3.55
CV (%)	60.88
00-rapeseed meal	
1	5.95
2	24.4
3	14.3
4	8.43
5	7.44
6	6.45
7	29.9
8	4.46

Table 3.7. (Cont.)

Item	Total glucosinolates (µmol/g)
9	5.72
10	5.88
11	-
Average	11.3
CV (%)	88.12
00-rapeseed expellers	
1	8.70
2	20.6
3	16.3
4	13.9
5	13.1
Average	14.5
CV (%)	30.10
Canola meal vs. 00-rapeseed meal	
P-value	0.04
SEM	2.46
00-rapeseed meal vs. 00-rapeseed expellers	
P-value	0.46
SEM	3.07

CHAPTER 4. AMINO ACID DIGESTIBILITY IN CANOLA MEAL, 00-RAPESEED MEAL, AND 00-RAPESEED EXPELLERS FED TO GROWING PIGS

ABSTRACT: The objective of this experiment was to determine the apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of CP and AA in canola meal, 00-rapeseed meal, and 00-rapeseed expellers fed to growing pigs. Twenty three barrows (initial BW: 28.8 ± 2.64 kg) that had a T-cannula installed in the distal ileum were allotted to a 9 × 23 Youden square design with 9 periods and 23 animals. Twenty three diets were prepared; 7 diets were based on 7 samples of canola meal from solvent-extraction crushing plants in North America, 10 diets were based on 10 samples of 00-rapeseed meal from solvent-extraction crushing plants in Europe, and 5 diets were based on 5 samples of 00-rapeseed expellers from mechanical-press crushing plants in Europe. A N-free diet based on cornstarch and sucrose was also used. Each source of canola meal, 00-rapeseed meal, or 00-rapeseed expellers was used as the only source of CP and AA in one experimental diet. Chromic oxide (0.5%) was included in all diets as an inert marker. Pigs were fed at 3 times their estimated energy requirement for maintenance. Each period was 7 d and digesta were collected during the final 2 d of each period. Results of the experiment indicated that the SID of CP and all AA except Val, Cys, and Glu were not different between canola meal and 00-rapeseed meal, but 00-rapeseed expellers had greater ($P < 0.01$) SID of CP and all AA except Thr, Trp, and Gly than 00-rapeseed meal. For Lys, Met, Thr, and Trp, SID values of 70.6, 84.5, 73.0, and 82.6%, and 71.9, 84.6, 72.6 and 82.6% were obtained in canola meal, and rapeseed meal, respectively, whereas values in 00-rapeseed expellers were 74.7, 87.1, 74.0, and 83.4%, respectively. It is likely that the main reason for the reduced AID and SID of most AA in canola meal and 00-rapeseed meal compared with 00-rapesseed expellers is that canola meal and

00-rapeseed meal are heat damaged during the desolventizing process. In conclusion, AA digestibility is not different between canola meal and 00-rapeseed meal, but 00-rapeseed expellers have greater digestibility of most AA than 00-rapeseed meal.

Key words: amino acid, canola meal, digestibility, pig, rapeseed expellers, rapeseed meal

INTRODUCTION

Varieties of *Brassica napus* with low levels of erucic acid (< 2%) in the oil and low concentrations of glucosinolates (< 30 μmol/g) in the defatted meal have been selected (Thomas, 2005; Newkirk, 2009).Varieties that meet these characteristics are called canola in North America, but they are called "double-zero" or "double-low" rapeseeds in Europe (Shahidi, 1990; Spragg and Mailer, 2007; Newkirk, 2009). Canola meal, 00-rapeseed meal, and 00-rapeseed expellers are the ingredients that are produced when oil has been extracted or expelled from canola or 00-rapeseed. The meals and expellers can be used as a protein source in animal diets because they have high concentrations of CP and AA, and relatively low concentrations of fiber and glucosinolates (Bell, 1993; Spragg and Mailer, 2007; Newkirk, 2011). However, the chemical composition of canola and rapeseed meal may vary depending on variety, climatic differences, and harvesting conditions (Barthet and Duan, 2011), and differences in crushing and oil extraction procedures also contribute to differences among different sources of meals (Bell, 1993; Newkirk et al., 2003).

The digestibility of CP and AA in canola meal may vary depending on the age of pigs (Stein et al., 1999a; 2001), the variety of canola and 00-rapeseed, and the processing method (Fan et al., 1996; Woyengo et al., 2010; Trindade Neto et al., 2012). However, there are no data comparing CP and AA digestibility of canola meal and 00-rapeseed meal, and between 00-

rapeseed meal and 00-rapeseed expellers. In many feed databases, canola and 00-rapeseed products are considered the same ingredients (Sauvant et al., 2004; NRC, 2012), but we are not aware of data that demonstrate that there is no differences between canola and 00-rapeseed products. Therefore, the objective of this experiment was to compare the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of CP and AA in canola meal obtained from North America and 00-rapeseed meal from Europe. The second objective was to compare AID and SID of CP and AA in 00-rapeseed meal and 00-rapeseed expellers from Europe.

MATERIALS AND METHODS

Animals, Experimental Design, and Housing

The experiment was approved by the Institutional Animal Care and use Committee at the University of Illinois. Twenty three growing barrows (initial BW: 28.8 ± 2.64 kg; G-Performer boars × F-25 females, Genetiporc, Alexandria, MN) were allotted to a 9 × 23 Youden square design with 9 periods and 23 diets. Pigs were equipped with a T-cannula in the distal ileum using the method described by Stein et al. (1998), and were housed individually in 1.2 × 1.5 m pens in an environmentally controlled room. A feeder and a nipple drinker were installed in each pen, and pens had smooth side walls and fully slated tri-bar floors.

Ingredients, Diets, and Feeding

Seven samples of canola meal were obtained from solvent-extraction crushing plants in North America with 4 samples being sourced from Canada and 3 samples from the U.S., 10 samples of 00-rapeseed meal were obtained from solvent-extraction crushing plants in Central and Western Europe, and 5 samples of 00-rapeseed expellers were obtained from mechanical-press crushing plants in Western Europe (Table 4.1).

Twenty three diets were prepared (Tables 4.2 and 4.3); 7 diets contained each of the 7 samples of canola meal, 10 diets contained each of the 10 samples of 00-rapeseed meal, 5 diets contained each of the 5 samples of 00-rapeseed expellers, and 1 diet was a N-free diet that was used to estimate the basal ileal endogenous losses of AA. Canola and 00-rapeseed products were the only AA-containing ingredients in the diets. All diets contained 0.5% chromic oxide as an indigestible marker. Vitamins and minerals were included in all diets to meet or exceed requirements for growing pigs (NRC, 1998).

Experimental diets were fed to the pigs at a daily level of 3 times the estimated maintenance requirement for energy (i.e., 106 kcal of ME per kg of $BW^{0.75}$; NRC, 1998). The daily feed allotments were divided into 2 equal meals and fed at 0700 and 1700h. Water was available at all times throughout the experiment.

Data and Sample Collection

All pig weights were recorded at the beginning of the experiment and at the end of each period, and the amount of feed supplied to each pig each day was recorded. The initial 5 d of each period was considered an adaptation period to the diet. Ileal digesta were collected for 8 h on d 6 and 7. A plastic bag was attached to the cannula barrel using a cable tie, and digesta flowing into the bag were collected. Bags were removed whenever they were filled with digesta, or at least every 30 min, and immediately frozen at -20℃ to prevent bacterial degradation of the AA in the digesta. On the completion of one experimental period, animals were deprived of feed overnight and the following morning, a new experimental diet was offered.

Chemical Analysis

At the conclusion of the experiment, ileal samples were thawed, pooled within animal and diet, and a subsample was collected for chemical analysis. A sample of each diet and of each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers was collected as well. Digesta samples were lyophilized and finely ground prior to chemical analysis. Ingredients, diets, and ileal digesta samples were analyzed for DM (Method 930.15; AOAC Int., 2007), CP by combustion (Method 990.03; AOAC Int., 2007), which was determined on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ), and AA [Method 982.30 E (A, B, and C); AOAC Int., 2007]. Ingredients and diets were analyzed for acid hydrolyzed ether extract (**AEE**), which was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (Method 954.02; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Ingredients were also analyzed for ADF (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), ash (Method 942.05; AOAC Int., 2007), and Ca and P via Inductive Coupled Plasma-Optical Emission Spectoscopy [ICP-OES; Method 985.01 (A, B, and C); AOAC Int., 2007]. All diets and ileal digesta samples were analyzed for Cr (Method 990.08; AOAC Int., 2007).

Calculations and Statistic Analysis

The values for AID, endogenous losses, and SID of CP and AA in the diets containing canola meal, 00-rapeseed meal, or 00-rapeseed expellers were calculated (Stein et al., 2007). Because canola meal, 00-rapeseed meal, and 00-rapeseed expellers were the only AA containing ingredients in the diet, the AID and SID for AA in each diet also represent the AID and SID of the canola or 00-rapeseed product that was included in the diet.

Data were analyzed using the PROC MIXED procedure of SAS (SAS inst. Inc., Cary, NC). The presence of outliers was verified using the UNIVARIATE procedure of SAS. The sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers were included in the model as fixed effects. Pig and period were included as random effects. The mean values for each diet were calculated using the LSMeans statement. If significant differences were detected, treatment means were separated using the PDIFF option in PROC MIXED. The pig was the experimental unit, and significance among means was assessed at an alpha level of 0.05. Equations to predict SID concentration of AA from CP, total AA, and the concentration of each AA in canola meal, 00-rapeseed meal, and 00-rapeseed expellers were developed using PROC REG in SAS.

RESULTS AND DISCUSSIONS

Concentrations of indispensable and dispensable AA in canola and 00-rapeseed meals are in agreement with the values for canola meal and rapeseed meal reported by Sauvant et al. (2004), Spragg and Mailer (2007), FEDNA (2010), PHILSAN (2010), Rostagno et al. (2011), Woyengo et al. (2010), and NRC (2012). However, the concentrations of indispensable and dispensable AA in 00-rapeseed expellers are less than values for canola expellers reported by Spragg and Mailer (2007), Seneviratne et al. (2010), and Woyengo et al. (2010). The CV for CP and most AA in canola meal, 00-rapeseed meal, and 00-rapeseed expellers ranged from 2 to 5%. This indicates that variations in the concentrations of CP and most AA among sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers are relatively small. However, the CV for Trp in canola meal was 6.99, the CV for Met, Phe, and Trp in 00-rapeseed meal was 6.95 to 9.58%, and the CV for Lys was 10.81% in 00-rapeseed expellers. These variations may be a result of differences in the concentration of these AA in the canola seeds and 00-rapeseeds that were used in the production of the meals and expellers. Differences in the efficiency of oil extraction among crushing plants may also affect the concentration of CP and AA in the canola and rapeseed meals that were used in this experiment.

Differences were observed in the AID and SID of CP and all AA among the 7 sources of canola meal that were used ($P < 0.01$; Tables 4.4 and 4.5). Differences were also observed in values for AID and SID of CP and all AA except for Ile, Leu, Thr, Val, and Tyr among the 10 sources of 00-rapeseed meal ($P < 0.05$). However, the AID and SID of CP were not different among the 5 sources of 00-rapeseed expellers, but the AID and SID of all AA except Ala, Asp, Cys, Glu, and Gly were different ($P < 0.05$) among the 5 sources of rapeseed expellers.

The AID and SID of CP in canola meal were not different from the AID of CP in 00-rapeseed meal, but the AID and SID of CP in 00-rapeseed expellers were greater ($P < 0.01$) than in 00-rapeseed meal. The AID and SID of all AA in canola meal were also not different from values for 00-rapeseed meal with the exception that the AID and SID of Val, Cys, and Glu in canola meal were greater ($P < 0.05$) than in 00-rapeseed meal. However, the AID and SID of most AA in 00-rapeseed expellers were greater ($P < 0.01$) than in 00-rapeseed meal, but for Thr, Trp, Gly, Pro, and Ser, no difference was observed for AID, and for Thr, Trp, and Gly, no difference between 00-rapeseed meal and 00-rapeseed expellers was observed for SID.

The AID and SID for CP and most AA in canola meal and 00-rapeseed meal that were calculated in this experiment are in agreement with the values for canola meal reported by NRC (2012). However, the AID and SID are less than the values in canola meal and rapeseed meal reported by Sauvant et al. (2004) and Stein et al. (2005). The AID for CP and most AA in 00-rapeseed expellers is in agreement with values in canola expellers and rapeseed expellers reported by FEDNA (2010) and NRC (2012), but the values are less than in canola expeller reported by Woyengo et al. (2010). However, the SID for CP and most AA in 00-rapeseed expellers obtained in this experiment are in agreement with the values reported for canola expellers by Woyengo et al. (2010), but the values are greater than in canola expellers and rapeseed expellers reported by FEDNA (2010) and NRC (2012).

The differences in the AID and SID of CP and AA within sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were observed indicates that there is some variations in the digestibility of CP and AA among sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers. The reasons for these differences may be that the canola and rapeseed products that were used in this experiment were produced from seeds that originated from different genetic selections, were grown in different environments, and had oil extracted using different processes. All of these factors may influence the concentrations of CP and AA in seeds, and it is possible that the AID and SID of CP and AA also are influenced. More research to elucidate reasons for differences in AID and SID of AA is, however, warranted.

The observation that the AID and SID for CP and most AA in canola meal and 00-rapeseed meal were not different is likely a result of the fact that canola and 00-rapeseeds are both selected from *B. napus*. Although mostly separate and independent breeding programs were used in North America and Europe to select varieties of canola and rapeseed with low concentration of erucic acids and glucosinolates, the chemical composition of the seeds were likely not changed, which is the reason the nutrient composition in the meals produced from canola and 00-rapeseed is similar.

In the present experiment, inclusion of canola meal, 00-rapeseed meal, and 00-rapeseed expellers was adjusted to a level that was expected to result in diets containing 15% CP. Diet analyses indicated that all diets contained between 15.0 and 15.5% CP. Concentration of AEE in diets influence the SID of AA because greater concentration of AEE reduces rate of passage for digesta in the intestinal tract, which results in increased absorption of AA (Cervantes-Pahm and Stein, 2008; Kil and Stein, 2011). The increased concentration of AEE in 00-rapeseed expellers compared with 00-rapeseed meal was, therefore, expected to result in increased SID of AA in 00-rapeseed expellers. However, to eliminate this effect, diets were balanced for concentration of AEE by adjusting the inclusion of soybean oil, and all diets were formulated to contain 6% AEE. However, even with this adjustment in oil concentration, the AID and SID for CP and most AA in 00-rapeseed expellers is greater ($P < 0.05$) when compared with 00-rapeseed meal. This observation is in agreement with Woyengo et al. (2010) who observed that SID of N, Arg, Ile, Leu, Phe, Glu, and Pro for canola expellers were greater than in canola meal. The greater AID and SID in the expellers may be a result of heat damage to some of the sources of 00-rapeseed meal that were used because Maillard reactions may occur during the desolventizing and toasting stages after oil extraction (Jensen et al., 1994; Newkirk et al., 2003; Klein-Hessling, 2007). In the desolventizing and toasting steps, temperature is increased and moisture is added to the meal, which negatively affects the AID and SID of CP and AA in canola or rapeseed meals (Newkirk et al., 2003; Klein-Hessling, 2007; Almeida et al., 2013). However, because oil is expelled from 00-rapeseed expellers without use of a solvent, the desolventizing step is not needed in the production of 00-rapeseed expellers, which eliminates the risk of heat damage during this step if 00-rapeseed expellers are produced. The fact that SEM values for the SID of Lys in 00-rapeseed meal was much greater than SEM values for the SID of other AA also indicates that some of the meals may have been heat damaged because Lys is the AA that is most negatively affected by the Maillard reaction (Almeida, 2013). The SEM of the SID of Lys in canola meal and 00-rapeseed meal were greater than in 00-rapeseed expellers, indicating that the level of heat damage in some of the sources of canola meal and 00-rapeseed meal is greater than in 00-rapeseed expellers. The SID of Thr is expected to be less than the SID of other indispensable AA, because the concentration of Thr in endogenous losses of protein is greater than the concentration of other indispensable AA (Stein et al., 1999b). This result was observed for 00-rapeseed expellers, but for canola meal and 00-rapeseed meal, the average SID of Lys was less than the SID of Thr and all other indispensable AA. This observation further indicates that some of the sources of canola meal and rapeseed meal were heat damaged.

One of the characteristics of canola and rapeseed protein is that it is relatively high in the sulfur-containing AA. As an example, dehulled soybean meal (47.73% CP) contains approximately 0.66% Met and 1.36% Met + Cys (NRC, 2012). However, despite the much lower concentrations of CP in canola and rapeseed products, the concentrations of Met and Met + Cys were 0.69 and 1.51% in canola meal, 0.67 and 1.43% in 00-rapeseed meal, and 0.64 and 1.39% in 00-rapeseed expellers used in this experiment. Thus, diets containing canola or rapeseed protein usually have relatively high concentrations of the sulfur containing AA. The fact that the SID of Met is greater than the SID of all other indispensable AA, except Arg, in canola meal, 00-rapeseed meal, and 00-rapeseed expellers further indicates that canola and rapeseed protein are rich sources of digestible Met in diets fed to pigs. In contrast, soybean meal contains approximately 2.96% Lys and 0.66% Trp NRC (2012), whereas concentrations of Lys and Trp in canola meal, 00-rapeseed meal, and 00-rapeseed expellers used in this experiment were 1.99 and 0.44%, 1.94 and 0.42%, and 1.90 and 0.41%, respectively. Therefore, diets containing canola or rapeseed protein are more likely to be limiting in Lys and Trp than diets containing soy protein.

Regression analyses indicated that the concentration of CP can be used to predict the concentration of total AA and indispensable AA with moderate coefficient of determination ($P <$

0.001; r^2 = 0.502 to 0.720; Table 4.6). In many feed formulation programs, the concentration of individual AA is changed as a consequence of changes in CP. The present data indicate that the concentration of individual AA are not always linearly related to the concentration of CP, and the concentration of CP could be used to estimate the concentration of indispensable AA in canola and rapeseed meal only with moderate correlation. The concentrations of SID of CP and indispensable AA in canola and rapeseed products can also be predicted from the concentration of CP and indispensable AA ($P < 0.001$; Tables 4.7 and 4.8) with only a low to moderate correlation (r^2 = 0.122 to 0.300 and 0.206 to 0.655, respectively). This observation indicates that SID of CP and indispensable AA are not always linearly related to the concentration of CP and individual indispensable AA in canola and rapeseed ingredients.

CONCLUSION

The AID and SID for CP and most AA in canola meal and 00-rapeseed meal were not different. However, 00-rapeseed expellers had greater AID and SID for CP and most AA than 00-rapeseed meal. It is likely that the reduced AID and SID in 00-rapeseed meal is a result of heat damage during processing, whereas 00-rapeseed expellers are not heat damaged. Thus, the protein quality of 00-rapeseed expellers is greater than that of 00-rapeseed meal. The differences in the AID and SID for CP and AA within sources of canola meal and within sources of 00-rapeseed products that were observed may be a result of differences in varieties, growing conditions, and oil extraction procedures. However, more research to determine the sources of variation in AA digestibility in canola meal and 00-rapeseed products is needed. Results of this experiment also indicate that the concentration of CP may not always be used to accurately predict the concentration of indispensable AA, and the concentration of CP and indispensable

AA cannot always be used to estimate the SID of indispensable AA in canola and rapeseed products.

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TABLES

Table 4.1. Concentration (%) of AA in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, as-fed basis

Item	Indispensable AA											Dispensable AA								
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Total	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr	Total
Canola meal																				
1	2.35	1.07	1.57	2.71	2.22	0.74	1.53	1.54	0.49	2.04	16.3	1.66	2.71	0.89	6.12	1.92	2.24	1.29	1.06	17.9
2	2.03	0.93	1.40	2.40	1.95	0.67	1.37	1.38	0.41	1.83	14.4	1.49	2.37	0.76	5.27	1.71	1.96	1.13	0.96	15.7
3	2.24	1.02	1.53	2.65	2.06	0.72	1.49	1.52	0.47	1.98	15.7	1.62	2.65	0.84	5.88	1.88	2.18	1.28	1.03	17.4
4	2.12	0.98	1.47	2.52	2.03	0.69	1.41	1.49	0.45	1.92	15.1	1.57	2.54	0.82	5.49	1.79	2.08	1.23	1.01	16.5
5	1.96	0.93	1.38	2.40	1.82	0.63	1.34	1.38	0.42	1.81	14.1	1.48	2.37	0.77	5.27	1.70	1.96	1.16	0.92	15.6
6	2.14	1.00	1.51	2.60	1.98	0.73	1.45	1.53	0.41	1.95	15.3	1.63	2.58	0.84	5.73	1.86	2.10	1.36	1.00	17.1
7	2.11	0.97	1.43	2.51	1.88	0.68	1.40	1.49	0.45	1.86	14.8	1.57	2.50	0.80	5.70	1.80	2.06	1.37	0.98	16.8
Average	2.14	0.99	1.47	2.54	1.99	0.69	1.43	1.48	0.44	1.91	15.1	1.57	2.53	0.82	5.64	1.81	2.08	1.26	0.99	16.7
CV (%)	6.04	5.07	4.79	4.69	3.68	5.57	4.70	4.61	6.99	4.39	4.99	4.40	5.14	5.49	5.59	4.63	5.01	7.33	4.66	5.07
00-rapeseed meal																				
1	1.98	0.91	1.38	2.39	1.91	0.67	1.34	1.46	0.40	1.83	14.3	1.51	2.48	0.74	5.16	1.74	1.96	1.21	0.97	15.8
2	2.17	0.99	1.51	2.59	2.05	0.71	1.48	1.53	0.45	1.97	15.5	1.59	2.70	0.81	5.71	1.86	2.11	1.28	1.01	17.1

Table 4.1. (Cont.)

Item	Indispensable AA											Dispensable AA								
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Total	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr	Total
3	2.22	1.01	1.52	2.60	2.14	0.72	1.50	1.52	0.48	1.98	15.7	1.59	2.71	0.82	5.67	1.86	2.11	1.26	1.03	17.1
4	2.03	0.95	1.45	2.43	1.97	0.67	1.37	1.44	0.42	1.88	14.6	1.52	2.49	0.80	5.33	1.77	2.00	1.16	0.94	16.0
5	1.72	0.81	1.22	2.04	1.65	0.57	1.15	1.25	0.34	1.60	12.4	1.33	2.11	0.68	4.51	1.54	1.62	1.06	0.84	13.7
6	2.07	0.94	1.42	2.49	1.98	0.70	1.41	1.52	0.44	1.86	14.8	1.55	2.62	0.76	5.42	1.79	2.04	1.29	1.00	16.5
7	2.08	0.96	1.41	2.45	2.06	0.69	1.39	1.46	0.42	1.86	14.8	1.51	2.47	0.81	5.34	1.76	2.01	1.19	0.99	16.1
8	1.93	0.9	1.41	2.37	1.85	0.63	1.35	1.41	0.45	1.84	14.1	1.47	2.51	0.69	5.09	1.71	1.9	1.13	0.93	15.4
9	2.00	0.91	1.35	2.40	1.91	0.71	1.35	1.52	0.38	1.77	14.3	1.51	2.44	0.80	5.59	1.75	1.98	1.31	1.01	16.4
10	1.97	0.91	1.41	2.39	1.88	0.64	1.35	1.42	0.44	1.84	14.3	1.48	2.53	0.73	5.1	1.71	1.93	1.16	0.94	15.6
Average	2.02	0.93	1.41	2.42	1.94	0.67	1.37	1.45	0.42	1.84	14.5	1.51	2.51	0.76	5.29	1.75	1.97	1.21	0.97	16.0
CV (%)	6.83	5.99	6.00	6.40	4.63	6.95	6.95	5.81	9.58	5.77	6.26	4.90	6.72	6.83	6.71	5.17	7.09	6.63	5.77	6.08
00-rapeseed expellers																				
1	2.08	0.94	1.41	2.42	2.07	0.68	1.38	1.42	0.43	1.86	14.7	1.49	2.56	0.82	5.51	1.73	2.00	1.27	0.95	16.3
2	2.06	0.94	1.39	2.36	2.09	0.67	1.35	1.43	0.39	1.82	14.5	1.47	2.52	0.79	5.33	1.71	1.99	1.27	0.94	16.0
3	1.89	0.86	1.34	2.24	1.83	0.60	1.29	1.34	0.39	1.74	13.5	1.39	2.40	0.70	4.76	1.61	1.83	1.11	0.89	14.7
4	1.98	0.90	1.37	2.35	1.88	0.64	1.34	1.42	0.43	1.80	14.1	1.47	2.44	0.75	5.06	1.69	1.9	1.18	0.95	15.4
5	1.86	0.87	1.34	2.26	1.63	0.63	1.28	1.35	0.43	1.74	13.4	1.41	2.31	0.70	4.97	1.64	1.86	1.10	0.89	14.9
Average	1.97	0.90	1.37	2.33	1.90	0.64	1.33	1.39	0.41	1.79	14.0	1.45	2.45	0.75	5.13	1.68	1.92	1.19	0.92	15.5
CV (%)	4.99	4.19	2.25	3.21	10.81	5.01	3.16	3.11	5.34	2.91	4.13	2.99	4.04	7.14	5.78	2.96	3.98	6.94	3.40	4.56

Table 4.2. Ingredient composition (%) of experimental diets, as-fed basis

Item	Canola meal	00-rapeseed meal	00-rapeseed expellers	Cornstarch	Soybean oil	Sucrose	Solka floc	Lime-stone	Mono-calcium phosphate	Chromic oxide	Salt	Vitamin-mineral premix	Total
Canola meal													
1	40.40	-	-	43.60	3.40	10.00	-	0.72	0.69	0.50	0.40	0.30	100.00
2	43.30	-	-	40.50	3.70	10.00	-	0.69	0.65	0.50	0.40	0.30	100.00
3	40.00	-	-	43.60	3.80	10.00	-	0.73	0.69	0.50	0.40	0.30	100.00
4	41.80	-	-	42.10	3.50	10.00	-	0.70	0.67	0.50	0.40	0.30	100.00
5	43.40	-	-	40.60	3.50	10.00	-	0.69	0.65	0.50	0.40	0.30	100.00
6	42.40	-	-	41.20	3.80	10.00	-	0.70	0.66	0.50	0.40	0.30	100.00
7	41.50	-	-	42.20	3.70	10.00	-	0.71	0.67	0.50	0.40	0.30	100.00
00-rapeseed meal													
1	-	43.80	-	39.90	3.80	10.00	-	0.69	0.64	0.50	0.40	0.30	100.00
2	-	41.80	-	42.20	3.40	10.00	-	0.71	0.66	0.50	0.40	0.30	100.00
3	-	42.50	-	41.10	3.80	10.00	-	0.70	0.66	0.50	0.40	0.30	100.00
4	-	44.80	-	39.70	3.00	10.00	-	0.68	0.62	0.50	0.40	0.30	100.00
5	-	48.50	-	36.60	2.50	10.00	-	0.64	0.57	0.50	0.40	0.30	100.00
6	-	45.20	-	40.00	3.80	10.00	-	0.68	0.65	0.50	0.40	0.30	100.00

Table 4.2. (Cont.)

Item	Canola meal	00-rapeseed meal	00-rapeseed expellers	Cornstarch	Soybean oil	Sucrose	Solka floc	Lime-stone	Mono-calcium phosphate	Chromic oxide	Salt	Vitamin-mineral premix	Total
7	-	42.90	-	40.80	3.70	10.00	-	0.69	0.66	0.50	0.40	0.30	100.00
8	-	42.70	-	41.00	3.70	10.00	-	0.69	0.66	0.50	0.40	0.30	100.00
9	-	44.70	-	38.80	4.00	10.00	-	0.66	0.64	0.50	0.40	0.30	100.00
10	-	42.90	-	40.50	4.00	10.00	-	0.69	0.66	0.50	0.40	0.30	100.00
00-rapeseed expellers													
1	-	-	44.10	42.90	0.50	10.00	-	0.69	0.63	0.50	0.40	0.30	100.00
2	-	-	46.20	41.30	-	10.00	-	0.66	0.61	0.50	0.40	0.30	100.00
3	-	-	44.00	43.50	-	10.00	-	0.69	0.63	0.50	0.40	0.30	100.00
4	-	-	45.20	42.30	-	10.00	-	0.67	0.62	0.50	0.40	0.30	100.00
5	-	-	44.50	41.20	1.80	10.00	-	0.68	0.63	0.50	0.40	0.30	100.00
N-free	-	-	-	77.40	5.00	10.00	4.00	1.14	1.24	0.50	0.40	0.30	100.00

Table 4.3. Analyzed composition (%) of experimental diets, as-fed basis

Item	DM	CP	Indispensable AA										Dispensable AA								AEE[1]
			Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr	
Canola meal																					
1	90.1	15.3	0.86	0.40	0.59	1.02	0.83	0.27	0.58	0.59	0.21	0.77	0.64	1.02	0.34	2.40	0.73	0.84	0.52	0.37	2.78
2	89.2	15.1	0.88	0.41	0.61	1.07	0.85	0.28	0.60	0.63	0.19	0.80	0.67	1.05	0.35	2.42	0.76	0.87	0.55	0.40	3.66
3	89.6	15.1	0.85	0.39	0.59	1.02	0.80	0.27	0.57	0.59	0.20	0.77	0.63	1.04	0.33	2.34	0.73	0.84	0.50	0.37	4.08
4	87.9	15.0	0.86	0.40	0.61	1.04	0.83	0.27	0.59	0.62	0.20	0.80	0.66	1.05	0.35	2.36	0.75	0.86	0.53	0.38	4.47
5	90.8	15.1	0.87	0.41	0.61	1.07	0.81	0.27	0.60	0.63	0.20	0.80	0.67	1.06	0.35	2.48	0.77	0.88	0.56	0.38	2.80
6	87.7	15.2	0.86	0.40	0.60	1.05	0.80	0.28	0.59	0.62	0.19	0.79	0.66	1.04	0.33	2.40	0.76	0.86	0.55	0.38	2.47
7	91.3	15.4	0.85	0.39	0.58	1.03	0.76	0.27	0.57	0.61	0.20	0.76	0.65	1.02	0.32	2.34	0.74	0.85	0.53	0.37	4.35
Average	89.5	15.2	0.86	0.40	0.60	1.04	0.81	0.27	0.58	0.61	0.20	0.78	0.65	1.04	0.34	2.39	0.75	0.86	0.53	0.38	3.52
00-rapeseed meal																					
1	89.8	15.1	0.84	0.39	0.60	1.03	0.80	0.27	0.58	0.62	0.20	0.79	0.66	1.07	0.32	2.31	0.76	0.83	0.54	0.40	4.73
2	89.8	15.3	0.85	0.39	0.60	1.02	0.81	0.26	0.59	0.59	0.20	0.79	0.63	1.06	0.31	2.34	0.74	0.83	0.50	0.38	3.34
3	89.5	15.5	0.89	0.40	0.60	1.05	0.85	0.28	0.60	0.63	0.21	0.78	0.66	1.10	0.33	2.38	0.76	0.85	0.57	0.39	2.33
4	87.1	15.5	0.88	0.41	0.59	1.07	0.85	0.28	0.59	0.66	0.19	0.78	0.68	1.10	0.34	2.44	0.78	0.88	0.59	0.41	2.96
5	87.0	15.1	0.88	0.41	0.61	1.05	0.85	0.28	0.58	0.66	0.17	0.81	0.70	1.10	0.34	2.39	0.80	0.87	0.59	0.40	3.88

Table 4.3. (Cont.)

Item	DM	CP	Indispensable AA										Dispensable AA								AEE[1]
			Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr	
6	88.1	15.3	0.86	0.39	0.60	1.04	0.82	0.27	0.59	0.63	0.21	0.79	0.66	1.09	0.32	2.33	0.75	0.84	0.55	0.39	2.81
7	91.0	15.2	0.88	0.41	0.61	1.06	0.89	0.28	0.60	0.64	0.20	0.79	0.66	1.07	0.35	2.37	0.76	0.88	0.55	0.38	4.28
8	91.3	15.2	0.90	0.41	0.62	1.11	0.84	0.28	0.62	0.68	0.20	0.82	0.69	1.17	0.31	2.45	0.80	0.89	0.59	0.42	3.87
9	91.7	15.1	0.83	0.40	0.58	1.02	0.81	0.27	0.57	0.63	0.21	0.77	0.65	1.01	0.33	2.31	0.75	0.85	0.54	0.38	4.10
10	91.0	15.3	0.89	0.41	0.61	1.09	0.84	0.28	0.61	0.66	0.19	0.80	0.68	1.15	0.32	2.39	0.78	0.88	0.59	0.40	4.68
Average	89.6	15.3	0.87	0.40	0.60	1.05	0.84	0.28	0.59	0.64	0.20	0.79	0.67	1.09	0.33	2.37	0.77	0.86	0.56	0.40	3.70
00-rapeseed expellers																					
1	88.9	15.3	0.90	0.42	0.62	1.07	0.91	0.28	0.61	0.63	0.20	0.83	0.66	1.13	0.34	2.52	0.77	0.85	0.57	0.40	4.75
2	85.3	15.1	0.88	0.40	0.59	1.02	0.89	0.27	0.58	0.62	0.19	0.78	0.64	1.09	0.34	2.36	0.74	0.83	0.54	0.39	5.27
3	88.2	15.4	0.78	0.35	0.54	0.93	0.75	0.25	0.53	0.56	0.18	0.71	0.58	0.99	0.29	2.08	0.67	0.75	0.49	0.35	5.38
4	89.8	15.2	0.89	0.41	0.61	1.07	0.85	0.28	0.60	0.65	0.20	0.81	0.68	1.11	0.34	2.42	0.78	0.87	0.57	0.39	4.68
5	87.1	15.2	0.83	0.38	0.57	1.01	0.71	0.25	0.57	0.62	0.20	0.76	0.65	1.04	0.32	2.30	0.74	0.83	0.54	0.37	4.70
Average	87.9	15.2	0.86	0.39	0.59	1.02	0.82	0.27	0.58	0.61	0.19	0.78	0.64	1.07	0.33	2.33	0.74	0.83	0.54	0.38	4.96
N-free	91.9	0.41	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.04	0.03	0.02	0.02	0.01	0.06	0.01	0.01	0.01	0.01	1.05

[1]AEE = acid hydrolyzed ether extract.

Table 4.4. Apparent ileal digestibility (%) of CP and AA in canola meal, 00-rapeseed meal, and 00-rapeseed expellers by growing pigs

Item	CP	Indispensable AA										Dispensable AA								All
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Mean	Ala	Asp	Cys	Glu	Gly	Ser	Tyr	Mean	
Canola meal																				
1	64.6	78.0	77.3	70.1	73.0	70.9	81.1	71.6	63.7	78.5	66.6	72.1	67.2	64.5	71.4	79.8	56.6	65.5	68.7	71.0	71.4
2	68.5	83.7	80.6	75.5	78.6	74.0	85.3	77.8	69.1	77.8	72.1	76.9	73.7	70.5	74.0	83.3	64.1	71.0	73.2	75.7	76.2
3	63.0	78.1	77.0	69.9	74.5	67.4	80.8	73.3	63.9	76.4	66.8	72.0	65.6	65.2	69.8	78.3	55.9	66.9	69.8	69.9	70.7
4	62.5	80.9	78.2	70.7	74.8	66.0	81.5	73.1	64.1	77.5	67.4	72.5	67.6	65.5	69.0	80.6	55.6	67.4	67.2	71.4	71.7
5	65.3	82.4	80.3	74.8	78.5	67.7	84.2	77.6	67.9	78.4	71.1	76.0	70.8	69.0	71.4	82.3	59.2	70.5	71.2	74.0	74.8
6	61.0	77.4	75.2	68.3	71.6	64.8	80.0	69.9	62.2	71.6	64.7	69.8	64.8	60.7	65.6	76.7	52.9	64.1	67.2	67.7	69.4
7	62.2	79.5	76.5	70.4	75.0	60.8	82.2	73.8	63.8	77.0	66.9	71.6	65.7	63.5	65.3	78.7	51.5	66.0	67.7	69.2	70.2
Average	63.9	80.0	77.9	71.4	75.1	67.4	82.2	73.9	65.0	76.7	67.9	73.0	67.9	65.6	69.5	80.0	56.5	67.3	69.3	71.3	72.1
CV (%)	3.92	3.01	2.54	3.77	3.48	6.30	2.34	3.95	3.88	3.11	3.91	3.47	4.75	5.03	4.57	2.89	7.37	3.80	3.27	3.89	3.47
P-value[1]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	< 0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01
SEM[1]	1.63	1.23	1.03	1.40	1.35	2.31	1.07	1.44	1.60	1.55	1.47	1.31	1.75	1.72	1.57	1.11	2.98	1.57	1.45	1.44	1.34
00-rapeseed meal																				
1	62.7	78.1	77.3	70.4	74.2	65.4	82.1	73.2	63.1	76.6	66.3	71.6	68.1	64.1	65.2	78.0	54.6	64.1	68.1	69.1	70.3
2	63.9	80.1	76.8	70.2	73.4	67.4	80.9	72.9	62.0	76.5	66.5	71.8	67.2	65.0	65.1	78.4	55.7	63.1	67.4	69.6	70.6

Table 4.4. (Cont.)

Item	CP	Indispensable AA											Dispensable AA								All
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Mean	Ala	Asp	Cys	Glu	Gly	Ser	Tyr	Mean	
3	65.9	79.5	78.3	71.1	74.5	72.8	82.1	73.2	65.6	78.1	67.0	73.4	69.5	67.7	70.5	80.0	59.1	68.0	69.4	72.1	72.6
4	65.7	82.4	79.2	71.9	76.9	70.2	84.0	75.4	66.9	76.3	67.9	74.4	71.1	68.2	66.7	80.0	58.5	69.3	70.4	72.1	73.2
5	65.7	82.6	79.4	72.7	76.6	70.6	83.6	74.4	68.3	77.5	69.6	74.8	72.0	69.6	69.7	80.9	61.4	70.5	69.9	73.3	74.2
6	62.4	78.5	75.6	68.6	73.1	66.5	80.0	71.9	62.1	78.4	65.7	71.5	66.8	65.2	64.5	77.1	55.6	65.9	67.1	68.8	69.8
7	66.6	83.4	79.9	73.0	76.3	74.3	83.6	74.7	66.4	76.1	68.6	75.1	72.4	69.8	72.4	82.0	62.6	69.1	68.8	74.5	74.7
8	60.6	78.2	76.1	69.4	73.8	65.3	80.7	72.6	64.8	73.8	65.9	71.3	67.1	64.4	63.1	77.5	53.0	66.9	68.6	68.9	70.0
9	61.8	79.4	77.3	70.6	74.9	65.9	82.9	73.7	63.5	78.3	66.3	72.2	67.3	63.6	64.3	78.5	51.6	64.7	67.8	68.8	70.4
10	65.4	81.9	78.4	72.6	76.6	69.8	83.1	75.3	67.3	74.9	68.6	74.3	71.8	68.9	67.8	79.8	60.5	70.1	69.9	72.5	73.4
Average	64.1	80.4	77.8	71.0	75.0	68.8	82.3	73.7	65.0	76.7	67.2	73.0	69.3	66.7	66.9	79.2	57.3	67.2	68.7	71.0	71.9
CV (%)	3.24	2.48	1.86	2.08	1.93	4.64	1.68	1.60	3.46	1.96	2.00	2.07	3.31	3.64	4.59	1.98	6.47	3.92	1.66	3.04	2.62
P-value[2]	0.03	<0.01	<0.01	0.14	0.07	<0.01	0.01	0.37	<0.01	0.05	0.21	0.05	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	0.22	<0.01	0.01
SEM[2]	1.41	1.25	1.02	1.32	1.19	1.40	0.97	1.32	1.40	1.70	1.32	1.18	1.49	1.54	2.16	1.09	2.61	1.47	1.41	1.38	1.24
00-rapeseed expellers																					
1	67.1	82.0	80.1	72.5	76.1	75.4	83.4	75.6	65.3	75.9	69.2	75.1	71.6	70.9	72.4	81.9	59.6	68.6	70.1	74.2	74.5
2	67.0	84.1	80.5	70.0	74.0	75.2	84.1	74.5	63.7	75.4	66.4	74.2	71.2	72.2	67.1	82.2	56.8	65.7	68.3	73.2	73.5
3	69.5	82.8	78.4	72.3	76.9	70.3	84.2	75.2	64.6	77.6	68.2	74.3	71.1	70.1	68.7	81.1	57.5	67.4	68.7	72.8	73.5

Table 4.4. (Cont.)

Item	CP	Indispensable AA											Dispensable AA								All
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Mean	Ala	Asp	Cys	Glu	Gly	Ser	Tyr	Mean	
4	65.9	81.7	79.4	74.0	78.6	70.0	85.1	77.0	67.6	77.5	70.5	76.6	72.8	73.5	67.8	82.8	52.7	69.5	69.7	72.8	74.0
5	68.4	85.1	79.8	77.1	81.6	67.1	86.8	81.7	69.7	80.9	73.4	77.7	74.9	72.4	69.6	84.0	60.3	71.8	74.1	75.6	76.6
Average	67.6	83.1	79.6	73.2	77.4	71.6	84.7	76.8	66.2	77.5	69.5	75.6	72.3	71.8	69.1	82.4	57.4	68.6	70.2	73.7	74.4
CV (%)	2.06	1.73	1.01	3.58	3.68	5.03	1.55	3.76	3.69	2.78	3.78	2.02	2.20	1.86	2.98	1.32	5.21	3.33	3.29	1.62	1.73
P-value[3]	0.13	<0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.02	<0.01	0.03	0.08	0.40	0.17	0.22	0.33	<0.01	<0.01	0.36	0.23
SEM[3]	1.83	1.13	0.98	1.12	1.08	1.63	1.02	1.10	1.54	1.71	1.39	1.02	1.53	1.45	2.53	0.89	3.55	1.59	1.53	1.32	1.16
Canola meal vs. 00-rapeseed meal																					
P-value	0.52	0.86	0.58	0.15	0.40	0.32	0.57	0.29	0.46	0.46	0.04	0.45	0.45	0.45	<0.01	0.03	0.63	0.29	0.08	0.21	0.19
SEM	1.07	0.94	0.77	1.08	0.91	1.27	0.88	1.00	1.16	1.70	1.14	0.95	1.26	1.19	1.14	0.81	1.97	1.12	1.06	1.07	1.01
00-rapeseed meal vs. 00-rapeseed expellers																					
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	0.15	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.91	0.06	0.03	<0.01	<0.01
SEM	1.01	0.91	0.62	0.89	0.75	1.13	0.80	0.80	1.05	1.65	0.89	0.75	0.98	1.03	1.15	0.68	2.15	1.07	0.91	1.00	0.88

[1]Comparison of the 7 sources of canola meal.
[2]Comparison of the 10 sources of 00-rapeseed meal.
[3]Comparison of the 5 sources of 00-rapeseed expellers.

Table 4.5. Standardized ileal digestibility (%) of CP and AA in canola meal, 00-rapeseed meal, and 00-rapeseed expellers by growing pigs

Item	CP	Indispensable AA											Dispensable AA								All
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Mean	Ala	Asp	Cys	Glu	Gly	Ser	Tyr	Mean	
Canola meal																					
1	75.3	84.4	81.5	74.7	77.3	74.0	83.5	76.0	72.1	84.1	73.2	77.2	75.3	70.9	75.1	83.2	78.4	74.2	74.4	78.2	77.6
2	79.2	89.9	84.7	79.9	82.6	77.0	87.6	81.9	76.8	83.9	78.4	81.8	81.4	76.7	77.6	86.7	84.9	79.1	78.5	82.6	82.1
3	73.8	84.5	81.2	74.5	78.8	70.6	83.2	77.6	72.2	82.3	73.4	77.2	73.8	71.5	73.6	81.8	77.8	75.8	74.1	77.1	77.0
4	73.0	87.1	82.2	75.1	78.8	69.1	83.8	77.3	71.8	83.3	73.6	77.4	75.1	71.6	72.5	83.9	75.9	75.3	72.7	78.1	77.6
5	76.2	88.8	84.4	79.3	82.6	70.9	86.6	81.9	75.8	84.3	77.5	81.0	78.6	75.2	75.1	85.7	80.2	78.6	76.8	81.0	80.8
6	71.4	83.6	79.2	72.7	75.6	68.0	82.2	74.1	69.9	77.6	70.9	74.8	72.4	66.8	69.3	80.0	73.5	72.2	72.6	74.7	75.3
7	72.9	86.0	80.9	75.1	79.3	64.3	84.6	78.3	72.0	83.0	73.7	76.9	73.8	70.1	69.3	82.3	76.0	74.5	73.5	76.6	76.6
Average	74.5	86.3	82.0	75.9	79.3	70.6	84.5	78.2	73.0	82.6	74.4	78.0	75.8	71.8	73.2	83.4	78.1	75.7	74.7	78.3	78.1
CV (%)	3.49	2.76	2.39	3.51	3.26	5.82	2.29	3.70	3.35	2.82	3.53	3.16	4.16	4.56	4.23	2.76	4.71	3.24	2.95	3.42	3.09
P-value[1]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01
SEM[1]	1.63	1.23	1.03	1.40	1.35	2.31	1.07	1.44	1.60	1.55	1.47	1.31	1.72	1.57	1.11	2.98	1.57	1.45	1.72	1.44	1.34
00-rapeseed meal																					
1	73.4	84.6	81.5	75.0	78.5	68.6	84.4	77.5	70.9	82.5	72.7	76.7	75.9	70.2	69.1	81.5	75.7	72.5	73.5	76.2	76.4
2	74.5	86.6	81.1	74.7	77.7	70.6	83.3	77.2	70.3	82.4	72.9	76.9	75.4	71.2	69.1	82.0	77.3	72.0	73.1	76.8	76.8

Table 4.5. (Cont.)

Item	CP	Indispensable AA											Dispensable AA								All
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Mean	Ala	Asp	Cys	Glu	Gly	Ser	Tyr	Mean	
3	76.3	85.7	82.5	75.7	78.7	75.8	84.4	77.4	73.3	83.6	73.5	78.3	77.4	73.6	74.3	83.4	80.1	75.9	74.8	79.1	78.6
4	75.9	88.4	83.2	76.3	80.9	73.2	86.2	79.5	74.1	82.3	74.2	79.2	78.5	74.0	70.2	83.3	78.4	76.8	75.4	78.8	79.0
5	76.1	88.6	83.4	77.0	80.6	73.5	85.8	78.6	75.5	84.2	75.6	79.6	79.2	75.3	73.3	84.2	80.6	77.9	75.0	80.0	80.0
6	72.9	84.7	79.8	73.0	77.2	69.6	82.3	76.1	69.8	83.9	72.0	76.4	74.6	71.1	68.3	80.5	76.5	73.8	73.1	75.8	75.8
7	77.4	89.7	84.0	77.5	80.5	77.3	86.0	78.9	74.2	82.0	75.1	80.1	80.3	76.0	76.0	85.6	83.8	77.4	74.4	81.6	80.8
8	71.4	84.3	80.2	73.9	77.9	68.4	83.0	76.7	72.2	79.8	72.2	76.2	74.7	70.1	67.2	80.9	73.4	74.6	73.7	75.7	75.9
9	72.8	86.2	81.6	75.4	79.3	69.1	85.3	78.2	71.5	84.0	73.0	77.4	75.4	70.2	68.2	82.1	73.3	73.1	73.5	76.2	76.7
10	76.2	88.2	82.6	77.1	80.7	73.0	85.5	79.4	74.8	81.1	75.0	79.3	79.4	74.7	71.7	83.3	81.3	77.8	75.3	79.4	79.4
Average	74.7	86.7	82.0	75.5	79.2	71.9	84.6	78.0	72.6	82.6	73.6	78.0	77.1	72.6	70.7	82.7	78.0	75.2	74.2	78.0	77.9
CV (%)	2.64	2.21	1.69	1.93	1.76	4.34	1.62	1.48	2.75	1.70	1.74	1.87	2.78	3.19	4.17	1.90	4.42	3.01	1.22	2.66	2.34
P-value[2]	0.05	0.012	<0.01	0.14	0.09	<0.01	0.02	0.35	0.01	0.07	0.30	0.07	0.01	0.01	<0.01	0.03	0.01	<0.01	0.30	<0.01	0.02
SEM[2]	1.41	1.25	1.02	1.32	1.19	1.40	0.97	1.32	1.40	1.70	1.32	1.18	1.49	1.54	2.16	1.09	2.62	1.47	1.41	1.38	1.24
00-rapeseed expellers																					
1	77.6	88.0	84.1	76.9	80.1	78.2	85.6	79.7	73.1	81.7	75.3	79.8	79.3	76.6	76.0	85.1	80.2	76.5	75.3	80.9	80.3
2	77.2	90.0	84.5	74.4	78.1	77.9	86.4	78.6	71.3	81.3	72.6	78.9	78.9	77.9	70.6	85.5	77.4	73.6	73.5	79.9	79.3
3	79.9	89.7	83.0	77.3	81.5	73.7	86.7	79.9	73.2	84.0	75.2	79.8	79.9	76.6	72.9	85.0	81.0	76.3	74.7	80.6	80.2

Table 4.5. (Cont.)

Item	CP	Indispensable AA										Dispensable AA								All
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Mean	Ala	Asp	Cys	Glu	Gly	Ser	Tyr	Mean	
4	76.6	87.8	83.5	78.5	82.7	73.0	87.4	81.2	75.2	83.4	76.8	81.5	80.4	79.3	71.4	86.2	73.1	77.4	75.1	79.7	79.9
5	78.8	91.4	84.1	81.7	85.8	70.6	89.3	86.0	77.4	86.6	79.8	82.8	82.7	78.5	73.4	87.5	81.1	79.9	79.7	82.7	82.7
Average	78.0	89.4	83.8	77.7	81.6	74.7	87.1	81.1	74.0	83.4	75.9	80.6	80.2	77.8	72.9	85.9	78.6	76.7	75.6	80.8	80.5
CV (%)	1.70	1.68	0.70	3.42	3.54	4.40	1.61	3.58	3.15	2.54	3.47	1.94	1.86	1.53	2.86	1.20	4.33	2.95	3.12	1.47	1.62
P-value[3]	0.17	<0.01	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.03	0.09	0.56	0.20	0.32	0.31	<0.01	<0.01	0.44	0.26
SEM[3]	1.83	1.13	0.98	1.12	1.08	1.63	1.02	1.10	1.57	1.71	1.39	1.02	1.53	1.45	2.53	0.89	3.55	1.59	1.53	1.32	1.16
Canola meal vs. 00-rapeseed meal																					
P-value	0.35	0.88	0.60	0.15	0.39	0.39	0.56	0.27	0.20	0.47	0.03	0.39	0.50	0.68	<0.01	0.04	0.42	0.13	0.08	0.18	0.16
SEM	1.06	0.93	0.76	1.07	0.91	1.26	0.87	0.99	1.15	1.7	1.06	0.94	1.25	1.18	1.13	0.81	1.95	1.1	1.09	1.06	1.00
00-rapeseed meal vs. 00-rapeseed expellers																					
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	0.16	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.68	0.04	0.03	<0.01	<0.01
SEM	1.00	0.91	0.62	0.89	0.75	1.12	0.8	0.8	1.04	1.65	0.89	0.75	0.97	1.02	1.15	0.68	2.15	1.06	0.89	1.00	0.88

[1]Comparison of the 7 sources of canola meal.
[2]Comparison of the 10 sources of 00-rapeseed meal.
[3]Comparison of the 5 sources of 00-rapeseed expellers.

Table 4.6. Prediction equation for the concentration (%) of AA from the concentration of CP in canola meal, 00-rapeseed meal, and 00-rapeseed expellers by growing pigs

Dependent variable[1]	Prediction equation	SE		*P*-value		r^2	RMSE
		Intercept	Estimate	Intercept	Estimate		
Total AA	2.011 + 0.390(CP)	3.265	0.080	0.545	<0.001	0.541	0.819
Indispensable AA							
Arg	0.003 + 0.056(CP)	0.451	0.011	0.99	<0.001	0.559	0.113
His	0.047 + 0.024(CP)	0.187	0.005	0.802	<0.001	0.588	0.047
Ile	0.071 + 0.037(CP)	0.218	0.005	0.748	<0.001	0.705	0.055
Leu	0.003 + 0.066(CP)	0.437	0.011	0.995	<0.001	0.657	0.109
Lys	-0.154 + 0.057(CP)	0.528	0.013	0.774	<0.001	0.490	0.132
Met	0.039 + 0.017(CP)	0.157	0.004	0.805	<0.001	0.505	0.039
Phe	-0.024 + 0.038(CP)	0.246	0.006	0.921	<0.001	0.667	0.062
Thr	0.345 + 0.031(CP)	0.280	0.007	0.233	<0.001	0.502	0.070
Trp	-0.037 + 0.012(CP)	0.113	0.003	0.744	<0.001	0.507	0.028
Val	0.151 + 0.047(CP)	0.266	0.006	0.577	<0.001	0.720	0.067
Total	0.468 + 0.387(CP)	2.616	0.064	0.860	<0.001	0.643	0.656

[1] The dependent variables are concentrations (%) of AA.

Table 4.7. Prediction equation for the concentration (%) of standardized ileal digestible CP or AA from the concentration of CP in canola meal, 00-rapeseed meal, and 00-rapeseed expellers by growing pigs

Dependent variable[1]	Prediction equation	SE		*P*-value		r^2	RMSE
		Intercept	Estimate	Intercept	Estimate		
CP	4.844 + 0.632(CP)	3.354	0.083	0.150	< 0.001	0.228	2.053
Indispensable AA							
Arg	1.010 + 0.087(CP)	0.441	0.011	< 0.05	< 0.001	0.245	0.270
His	0.313 + 0.041(CP)	0.181	0.004	0.086	< 0.001	0.300	0.111
Ile	0.537 + 0.055(CP)	0.255	0.006	< 0.05	< 0.001	0.277	0.156
Leu	1.199 + 0.092(CP)	0.440	0.011	< 0.01	< 0.001	0.271	0.266
Lys	0.060 + 0.087(CP)	0.675	0.017	0.929	< 0.001	0.123	0.413
Met	0.514 + 0.023(CP)	0.135	0.003	< 0.001	< 0.001	0.198	0.083
Phe	0.695 + 0.051(CP)	0.271	0.007	< 0.05	< 0.001	0.228	0.166
Thr	1.217 + 0.036(CP)	0.281	0.007	< 0.001	< 0.001	0.122	0.172
Trp	-0.180 + 0.027(CP)	0.124	0.003	0.148	< 0.001	0.279	0.076
Val	0.720 + 0.069(CP)	0.351	0.009	< 0.05	< 0.001	0.242	0.215
Total	5.368 + 0.495(CP)	2.290	0.057	< 0.05	< 0.001	0.280	1.402

[1] The dependent variables are concentrations (%) of standardized ileal digestible AA.

Table 4.8. Prediction equation for the concentration (%) of standardized ileal digestible CP or AA from the concentration of each AA in canola meal, 00-rapeseed meal, and 00-rapeseed expellers by growing pigs

Dependent variable[1]	Prediction equation	SE		*P*-value		r^2	RMSE
		Intercept	Estimate	Intercept	Estimate		
CP	4.844 + 0.632(CP)	3.354	0.083	0.150	< 0.001	0.228	2.053
Indispensable AA							
Arg	0.403 + 0.693(Arg)	0.093	0.041	< 0.001	< 0.001	0.592	0.086
His	0.092 + 0.735(His)	0.040	0.039	0.024	< 0.001	0.649	0.034
Ile	0.316 + 0.559(Ile)	0.084	0.053	< 0.001	< 0.001	0.358	0.064
Leu	0.645 + 0.557(Leu)	0.124	0.046	< 0.001	< 0.001	0.430	0.102
Lys	-0.389 + 0.906(Lys)	0.127	0.059	< 0.01	< 0.001	0.546	0.129
Met	0.123 + 0.064(Met)	0.226	0.035	< 0.001	< 0.001	0.655	0.024
Phe	0.357 + 0.551(Phe)	0.078	0.051	< 0.001	< 0.001	0.370	0.065
Thr	0.461 + 0.440(Thr)	0.099	0.062	< 0.001	< 0.001	0.206	0.071
Trp	0.003 + 0.820(Trp)	0.021	0.045	0.085	< 0.001	0.631	0.023
Val	0.401 + 0.546(Val)	0.125	0.061	< 0.01	< 0.001	0.290	0.090
Total	2.513 + 0.606(Total)	0.624	0.044	< 0.001	< 0.001	0.487	0.514

[1] The dependent variables concentrations (%) of standardized ileal digestible AA.

CHAPTER 5. DIGESTIBILITY OF ENERGY AND DETERGENT FIBER AND CONCENTRATION OF DIGESTIBLE AND METABOLIZABLE ENERGY IN CANOLA MEAL, 00-RAPESEED MEAL, AND 00-RAPESEED EXPELLERS FED TO GROWING PIGS

ABSTRACT: This experiment was conducted to measure DE and ME in canola meal, 00-rapeseed meal, and 00-rapeseed expellers fed to growing pigs. Twenty three barrows (initial BW: 27.7 ± 2.92 kg) were allotted to a 8 × 23 Youden square design with 8 periods and 23 animals. Twenty three diets were prepared. One diet was a corn based basal diet, 6 diets were based on corn and each of 6 samples of canola meal (average of 4,218 kcal GE/kg, 38.0 % CP, and 3.82 % crude fat, as-fed basis) from solvent-extraction crushing plants in North America; 11 diets were based on corn and each of 11 samples of 00-rapeseed meal (average of 4,210 kcal GE/kg, 36.2 % CP, and 3.87 % crude fat, as-fed basis) from solvent-extraction crushing plants in Europe, and 5 diets were based on corn and each of 5 samples of 00-rapeseed expellers (average of 4,721 kcal GE/kg, 35.6 % CP, and 11.5 % crude fat, as-fed basis) from mechanical-press crushing plants in Europe. Pigs were fed at 3 times their estimated energy requirement for maintenance, and were placed in metabolism cages that allowed for the total, but separate, collection of feces and urine. The concentration of DE and ME in corn was calculated from the basal diet and the contribution of DE and ME from corn to the remaining diets was then calculated. The DE and ME of each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers were then calculated by difference. Average DE and ME values were 3,378 and 3,127 kcal/kg DM in canola meal, 3,461 and 3,168 kcal/kg DM in 00-rapeseed, and 4,005 and 3,691 kcal/kg DM in 00-rapeseed expellers. Results of the experiment indicated that DE and ME in canola meal are not different from DE and ME in 00-rapeseed meal, but 00-rapeseed expellers have greater ($P < 0.01$) DE and ME than 00-rapeseed meal. In conclusion, energy digestibility and concentrations of DE and ME are not different between canola meal and 00-rapeseed meal. However, 00-rapeseed expellers have greater energy digestibility and contain more DE and ME than 00-rapeseed meal.

Key words: canola meal, energy, pig, 00-rapeseed meal, 00-rapeseed expellers

INTRODUCTION

Canola and 00-rapeseeds were developed from rapeseed (*B. napus*) to obtain low levels of erucic acid in the oil and low levels of glucosinolates in the non-oil part of the plants (Thomas, 2005; Newkirk, 2009). Canola meal, 00-rapeseed meal, and 00-rapeseed expellers are the co-products derived after oil extraction processing, and can be used as ingredients in animal diets (Newkirk, 2009). However, the concentration of fat, protein, AA, and carbohydrates in canola seeds may be variable depending on variety, climate, and harvesting conditions (Barthet and Duan, 2011, Newkirk, 2011). These differences may affect digestibility of energy in the meals (Bourdon and Aumaître. 1990; Bell, 1993; Newkirk et al., 2003; Montoya and Leterme, 2010). Results of previous research have indicated that DE and ME in canola meal and rapeseed meal range from 2,800 to 3,273 and 2,550 to 3,013 kcal/kg (as fed basis), and in canola expellers and rapeseed expellers from 3,155 to 3,779 and 2,920 to 3,540 kcal/kg (as fed basis; FEDNA, 2010; NRC, 2012). However, there are no comparative data for the DE and ME in canola meal and 00-rapeseed meal, and there are no data comparing 00-rapeseed meal and 00-rapeseed expellers.

Therefore, the objective of this experiment was to compare DE and ME concentrations in canola meal obtained from North America and 00-rapeseed meal from Europe. The second objective was to compare DE and ME in 00-rapeseed meal and 00-rapeseed expellers.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The experiment was approved by the Institutional Animal Care and use Committee at the University of Illinois. Twenty three growing barrows (initial BW: 27.7 ± 2.92 kg; G-Performer boars × F-25 females, Genetiporc, Alexandria, MN) were allotted to a 8 × 23 Youden square design with 8 periods and 23 diets in each square. Each experimental period was 14 d. Pigs were placed in metabolic cages that were equipped with a feeder and a nipple drinker, a fully slatted floor, a screen floor, and urine trays. This allowed for the total, but separate, collection of urine and fecal materials from each pig. The average BW of pigs at the conclusion of the experiment was 108.9 ± 9.0 kg.

Ingredients, Diets, and Feeding

Six samples of canola meal were obtained from solvent-extraction crushing plants in North America, 11 samples of 00-rapeseed meal were obtained from solvent-extraction crushing plants in Europe, and 5 samples of 00-rapeseed expellers were obtained from mechanical-press crushing plants in Europe (Table 5.1). Twenty three diets were prepared (Tables 5.2 and 5.3). One diet was a corn based basal diet, 6 diets were based on corn and each of the 6 samples of canola meal, 11 diets were based on corn and each of the 11 samples of 00-rapeseed meal, and 5 diets were based on corn and each of the 5 samples of 00-rapeseed expellers. Vitamins and minerals were included in all diets to meet or exceed requirements for growing pigs (NRC, 1998).

Experimental diets were fed to the pigs at a daily level of 3 times the estimated maintenance requirement for energy (i.e., 106 kcal of ME per kg of $BW^{0.75}$; NRC, 1998), and divided into 2 equal meals. The daily feed allotments were divided into 2 equal meals and fed at 0700 and 1700h. Water was supplied at all times throughout the experiment.

Data and Sample Collection

Individual pig BW were recorded at the beginning and at the end of each period, and the amount of feed supplied to each pig each day was recorded. The initial 7 d of each period was considered an adaptation period to the diet. Fecal and urine samples were collected from d 8 through d 13 according to standard procedures using the marker to marker approach (Adeola, 2001). Urine samples were collected in urine buckets over a preservative of 50 mL of 3*N* HCl. Fecal samples and 20% of the collected urine samples were stored at -20^{o}C immediately after collection. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a subsample was collected for chemical analysis. Fecal samples were dried in a forced-air oven at 60^{o}C, ground, and thoroughly mixed before a subsample was collected for analysis.

Chemical Analysis

Samples of canola meal, 00-rapeseed meal, 00-rapeseed expellers, corn, diets, and feces were analyzed for DM (Method 930.15; AOAC Int., 2007), and GE using a bomb calorimeter (Model 6300, Parr Instruments, Moline, IL). Urine samples were lyophilized before being analyzed for GE (Kim et al., 2009). All samples of canola meal, 00-rapeseed meal, 00-rapeseed expellers, corn, and diets were also analyzed for ash (Method 942.05; AOAC Int., 2007), and CP by combustion (Method 990.03; AOAC Int., 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Canola meal, 00-rapeseed meal, and 00-rapeseed expellers were also analyzed for acid hydrolyzed ether extract (**AEE**), which was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (Method 954.02; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN), crude fiber (Method 978.10; AOAC Int., 2007), and lignin (Method 973.18; AOAC Int., 2007). Canola meal, 00-rapeseed meal, 00-rapeseed expellers, diets, and fecal samples were also analyzed for concentration of NDF (Holst, 1973) and ADF (Method 978.10; AOAC Int., 2007).

Calculations and Statistic Analysis

Following chemical analysis, the DE, ME, and apparent total tract digestibility (**ATTD**) of energy, ADF, and NDF were calculated in each diet. The amount of energy lost in the feces and in the urine was calculated to determine the DE and ME in each diet. The DE and ME in the corn diet were divided by 97.20 to calculate the DE and ME in corn. By subtracting the contribution of DE or ME from corn to the DE or ME in all other diets, the concentration of DE and ME in each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers were calculated using the difference procedure (Adeola, 2001). The ATTD of energy, ADF, and NDF in each diet was also calculated for each diet and for each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

Data were analyzed using the PROC MIXED procedure of SAS (SAS inst. Inc., Cary, NC). Outliers were identified using the UNIVARIATE procedure of SAS. The sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers were included in the model as fixed effects. Pig and period were included as random effects. The mean values of each diet were calculated using the LSMeans statement. If significant differences were detected, treatment means were separated using the PDIFF option in PROC MIXED. The pig was the experimental unit, and significance among means was assessed at an alpha level of 0.05. Equations to predict concentrations of DE and ME in canola meal, 00-rapeseed meal, and 00-rapeseed expellers were developed using PROC REG of SAS.

RESULTS AND DISCUSSIONS

The concentrations of DM, CP, and ash in canola meal, 00-rapeseed meal, and 00-rapeseed expellers (Table 5.1) agree with the values for canola meal and canola expellers reported by Spragg and Mailer (2007), Rostagno et al. (2011), and NRC (2012), and the average concentration of AEE in canola meal is in agreement with the values reported by Spragg and Mailer (2007), Seneviratne et al. (2010), and Woyengo et al. (2010). However, the concentration of GE in canola meal, 00-rapeseed meal, and 00-rapeseed expellers in this study are less than the values reported by NRC (2012). The ADF for canola meal, 00-rapeseed meal, and 00-rapeseed expellers are in agreement with values in canola meal, rapeseed meal, and rapeseed expellers reported by Sauvant et al. (2004) and FEDNA (2010), but the concentration of NDF is greater than the values for canola meal and canola expellers reported by Sauvant et al. (2004) and NRC (2012). Differences in the chemical composition among sources of canola meal, 00-rapeseed meal and 00-rapeseed expellers that were observed in this experiment are most likely a result of variations in concentrations of nutrients in the seeds and differences in oil extraction procedures (Barthet and Duan, 2011, Newkirk, 2011). The observation that the concentrations of AEE and GE are similar in canola meal and 00-rapeseed meal indicates that gross composition of canola seeds probably is similar to that in 00-rapeseed, and that the oil extraction procedures used in North America is as efficient as the procedures used in Europe. However, the concentration of AEE and GE in 00-rapeseed meal is less than in 00-rapeseed expellers. This observation indicates that the efficiency of oil removal using the solvent extraction procedure is greater than if the mechanical press procedure is used.

The GE intake and the excretion of GE in urine were not different among pigs fed diets containing canola meal or 00-rapeseed meal, but the excretion of GE in feces, DE, ME, ATTD of

GE, ATTD of ADF, and ATTD of NDF were different ($P < 0.05$; Table 5.4). The excretion of GE in urine, ATTD of ADF, and ATTD of NDF were not different among pigs fed 00-rapeseed expellers, whereas GE intake, the excretion of GE in feces, DE, ME, and ATTD of GE were different ($P < 0.05$).

The GE intake in pigs fed diets containing canola meal was not different from that of pigs fed diets containing 00-rapeseed meal, and GE intake was not different between pigs fed diets containing 00-rapeseed meal and 00-rapeseed expellers. The excretion of GE in feces from pigs fed diets containing canola meal was not different from that of pigs fed diets containing 00-rapeseed meal, but more GE was excreted in the feces from pigs fed diets containing 00-rapeseed meal than for pigs fed diets containing 00-rapeseed expellers ($P < 0.05$). The excretion of GE in urine for pigs fed diets containing canola meal was less ($P < 0.05$) than for pigs fed diets containing 00-rapeseed expellers, whereas no difference between 00-rapeseed meal and 00-rapeseed expellers were observed. The DE, ME, and ATTD of GE for diets containing canola meal did not differ from diets containing 00-rapeseed meal, but the DE, ME, and ATTD of GE were less ($P < 0.01$) in diets containing 00-rapeseed meal than in diets containing 00-rapeseed expellers. The ATTD of ADF for diets containing canola meal was less ($P < 0.01$) than for diets containing 00-rapeseed meal, whereas the values for 00-rapeseed meal diets were less ($P < 0.05$) than for 00-rapeseed expellers diets. The ATTD of NDF for diets containing canola meal was not different from values for diets containing 00-rapeseed meal, but the ATTD of NDF in diets containing 00-rapeseed meal was less ($P < 0.05$) than for diets containing 00-rapeseed expellers.

The GE intake, the excretion of GE in urine, and the ATTD of GE were not different among sources of canola meal, but the excretion of GE in feces, DE, ME, ATTD of ADF, and ATTD of NDF were different among sources of canola meal ($P < 0.05$; Table 5.5). The excretion of GE in urine and ATTD of GE were not different among pigs fed different sources of 00-rapeseed meal, whereas GE intake, the excretion of GE in feces, DE, ME, ATTD of ADF, and ATTD of NDF were different among the 11 sources of 00-rapeseed meal ($P < 0.05$). The excretion of GE in urine, ATTD of GE, and ATTD of ADF were not different among sources of 00-rapeseed expellers, however, differences among the 5 sources of 00-rapeseed expellers were observed for GE intake, the excretion of GE in feces, DE, ME, and ATTD of NDF ($P < 0.05$).

The GE intake from canola meal was not different from the intake of 00-rapeseed meal, but the GE intake of 00-rapeseed meal was less ($P < 0.01$) than from 00-rapeseed expellers. The excretion of GE in feces did not differ between pigs fed canola meal and 00-rapeseed meal, but the value was less ($P < 0.01$) for pigs fed 00-rapeseed meal than for pigs fed 00-rapeseed expellers. The excretion of GE in urine from pigs fed canola meal was less ($P < 0.05$) than for pigs fed 00-repeseed meal, whereas no difference in the excretion of urinary GE for 00-rapeseed meal and 00-rapeseed expellers were observed. The concentrations of DE and ME, and the ATTD of GE for canola meal and 00-rapeseed meal were not different. However, the concentrations of DE and ME, and the ATTD of GE in 00-rapeseed meal were less ($P < 0.01$) than in 00-rapeseed expellers. The ATTD of ADF in canola meal was less ($P < 0.01$) than in 00-rapeseed meal, whereas no difference between 00-rapeseed meal and 00-rapeseed expellers was observed. The ATTD of NDF was not different between canola meal and 00-rapeseed meal, and the ATTD of NDF in 00-rapeseed meal was not different from the ATTD of NDF in 00-rapeseed expellers.

The DE and ME of corn in this experiment were 3,907 and 3,780 kcal/kg (DM basis), which is in agreement with previously published values (Sauvant et al., 2004; NRC, 2012). The average concentrations of DE and ME for canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were calculated in this experiment are less than the values for canola meal and canola expellers reported by Woyengo et al. (2010) and NRC (2012), but the values are greater than the values for 00-rapeseed meal, 00-rapeseed expellers, and canola expellers reported by FEDNA (2010) and by Seneviratne et al. (2010). The reason for these differences among experiments may be that as we observed in this experiment, differences within each group of ingredients exist. The ATTD of GE for canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were calculated in this study are less than the values for canola meal and canola expellers reported by Woyengo et al. (2010), but the ATTD of GE for 00-rapeseed expellers is greater than the ATTD of GE for canola expellers reported by Seneviratne et al. (2010). The average ATTD of ADF for canola meal, 00-rapeseed meal, and 00-rapeseed expellers in this study were 38.62, 43.37, and 45.83, and the ATTD of NDF were 51.90, 52.37, and 53.47, respectively. To our knowledge, values for the ATTD of ADF and NDF in canola meal, 00-rapeseed meal, and 00-rapeseed expellers have not been previously reported, but results of this experiment indicate that the fiber in canola and rapeseed products is poorly fermentable. The most likely reason for this poor fermentability is that most of the fiber in these ingredients is insoluble (Bach Knudsen, 1997). The poor ATTD of ADF and NDF is also the reason for the reduced ATTD of GE in the canola or 00-rapeseed ingredients compared with the ATTD of GE for the diets containing corn and canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

The differences in DE and ME among sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers indicate that variations in energy values within canola meal and rapeseed products exist. This may be the results of differences in genetic selection and growing conditions for canola and rapeseed, which may affect the chemical composition of seeds, and consequently affect the energy value in the meals. Differences in the efficiency of oil extraction among crushing plants that influence the concentration of fat in the meals may also affect the energy values among sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

The observation that the DE, ME, and ATTD of GE for canola meal from North American were not different from the values for 00-rapeseed meal is most likely a result of the fact that both canola and rapeseeds are selected from the same variety (*B. napus)*, and the same extraction procedure (solvent extraction) was used to remove oil from seeds. As a result, the concentrations of nutrients in the meals are not different, which also resulted in DE and ME values not being different. However, 00-rapeseed expellers had greater DE, ME, and ATTD of GE than 00-rapeseed meal, which is likely a result of the concentration of AEE and GE in 00-rapeseed expellers being greater than in 00-rapeseed meal because of the less complete oil removal in the expeller procedure than in the solvent extraction procedure. The concentration of AEE, GE, ADF, and NDF in canola meal and rapeseed meal may influence DE, ME, and NE when used in pig diets (Bourdon and Aumaître, 1990; Montoya and Leterme, 2010). In this study, the reduced concentration of AEE and the greater concentration of ash, CF, ADF, NDF, and ADL in 00-rapeseed meal than in 00-rapeseed expellers may be the reasons for the reduced digestibility of energy in 00-rapeseed meal. This indicates that oil extraction procedures affect the digestibility of energy in rapeseed products, and the concentration of AEE, ash, CF, ADF, NDF, and ADL is related to DE, ME, and ATTD of GE in 00-rapeseed products.

Regression analyses indicate that the concentration of GE in canola meal, 00-rapeseed meal, and 00-rapeseed expellers is related to analyzed AEE ($r^2 = 0.945$; $P < 0.001$; Table 5.6). The concentration of GE and CP in canola meal, 00-rapeseed meal, and 00-rapeseed expellers influenced the DE and ME ($P < 0.001$), but the coefficient of determination (r^2) is not very high ($r^2 = 0.429$ to 0.555) indicating that other components in these ingredients contribute to differences in DE and ME. This observation indicates that the concentration of AEE can be used to predict the concentration of GE, and the concentration of GE and CP may be used to partly predict the DE and ME in canola and rapeseed products when used in diets fed to growing pigs.

CONCLUSION

The DE, ME, and ATTD of energy in canola meal and 00-rapeseed meal were not different, which indicates that values obtained with canola meal are also representative of values in 00-rapeseed meal. The DE, ME, and ATTD of energy in 00-rapeseed expellers were greater than in 00-rapeseed meal, which is likely a result of the less efficient oil removal in 00-rapeseed expellers, which results in a greater concentration of oil and GE than in 00-rapeseed expellers. Therefore, the digestibility of energy in 00-rapeseed expeller is greater than in 00-rapeseed meal. However, there are differences among sources of canola meal and 00-rapeseed products, which may be a result of differences in varieties, climate, soil, and efficiency of oil extraction. Therefore, procedures to rapidly estimate the concentration of DE and ME in a given source of canola meal or 00-rapeseed meal or 00-rapeseed expellers are needed.

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TABLES

Table 5.1. Analyzed composition of canola meal, 00-rapeseed meal, and 00-rapeseed expellers, as-fed basis

Sample origin	DM (%)	CP (%)	AEE (%)	Ash (%)	Crude fiber (%)	ADF (%)	NDF (%)	ADL (%)	GE (kcal/kg)
Corn	85.1	7.40	-	1.09	-	2.27	12.78	-	3,806
Canola meal									
1	90.5	39.3	4.31	8.40	7.92	16.3	24.6	6.81	4,229
2	89.2	36.8	3.80	6.59	10.9	18.5	30.0	7.75	4,204
3	90.2	39.8	3.01	7.32	10.2	18.2	30.6	7.80	4,207
4	89.8	38.1	4.44	7.36	10.3	19.7	31.5	8.43	4,237
5	90.4	36.7	3.79	7.39	10.9	19.7	34.7	7.56	4,196
6	89.4	37.6	3.58	6.93	7.02	18.4	32.8	8.65	4,235
Average	89.9	38.1	3.82	7.33	9.54	18.5	30.7	7.83	4,218
00-rapeseed meal									
1	89.1	36.4	3.58	6.57	7.69	19.3	31.6	8.18	4,150
2	90.3	38.0	4.19	7.39	6.99	17.0	28.2	6.65	4,254
3	88.1	37.5	3.47	6.61	7.24	16.8	24.9	7.60	4,173
4	89.1	35.6	5.25	6.89	6.88	19.0	29.7	8.13	4,257

Table 5.1. (Cont.)

Sample origin	DM (%)	CP (%)	AEE (%)	Ash (%)	Crude fiber (%)	ADF (%)	NDF (%)	ADL (%)	GE (kcal/kg)
5	90.0	32.8	5.91	6.55	7.68	21.9	34.7	7.89	4,331
6	88.0	36.5	3.61	6.63	6.83	18.8	30.1	7.90	4,180
7	88.6	37.1	3.72	6.61	7.09	22.0	27.3	8.24	4,229
8	89.0	37.3	3.68	6.86	7.14	20.5	30.7	7.84	4,234
9	88.6	35.6	2.71	6.93	7.75	19.9	33.7	8.89	4,146
10	88.9	37.1	3.01	7.08	7.04	18.5	28.9	8.22	4,179
11	88.6	34.2	3.39	8.03	7.64	18.8	30.9	7.58	4,181
Average	88.9	36.2	3.87	6.92	7.27	19.3	30.1	7.92	4,210
00-rapeseed expellers									
1	89.9	36.1	10.8	6.33	5.69	15.6	20.8	6.43	4,668
2	89.9	34.5	13.0	5.74	5.54	15.7	19.8	6.54	4,771
3	91.2	36.2	13.8	6.01	5.55	17.0	24.5	7.21	4,768
4	95.2	35.2	11.7	6.54	5.79	17.9	26.7	7.28	4,835
5	93.0	35.8	8.27	6.51	6.63	23.3	32.7	8.38	4,561
Average	91.8	35.6	11.5	6.23	5.84	17.9	24.9	7.17	4,721

Table 5.2. Ingredient composition (%) of experimental diets, as-fed basis

Item	Corn	Canola meal	00-rapeseed meal	00-rapeseed expellers	Lime-stone	Mono-calcium phosphate	Salt	Vitamin-mineral premix	Total
Corn	97.20	-	-	-	1.15	0.65	0.40	0.30	100.00
Canola meal									
1	63.00	35.00	-	-	0.75	0.58	0.40	0.30	100.00
2	59.70	38.30	-	-	0.71	0.54	0.40	0.30	100.00
3	63.40	34.60	-	-	0.75	0.58	0.40	0.30	100.00
4	61.50	36.50	-	-	0.72	0.56	0.40	0.30	100.00
5	59.70	38.40	-	-	0.70	0.54	0.40	0.30	100.00
6	60.80	37.20	-	-	0.71	0.55	0.40	0.30	100.00
00-rapeseed meal									
1	59.40	-	38.70	-	0.70	0.54	0.40	0.30	100.00
2	61.40	-	36.60	-	0.72	0.57	0.40	0.30	100.00
3	60.70	-	37.30	-	0.71	0.55	0.40	0.30	100.00
4	58.30	-	39.80	-	0.68	0.53	0.40	0.30	100.00
5	53.90	-	44.30	-	0.64	0.48	0.40	0.30	100.00
6	59.50	-	38.60	-	0.69	0.54	0.40	0.30	100.00

Table 5.2. (Cont.)

Item	Corn	Canola meal	00-rapeseed meal	00-rapeseed expellers	Lime-stone	Mono-calcium phosphate	Salt	Vitamin-mineral premix	Total
7	60.20	-	37.80	-	0.68	0.54	0.40	0.30	100.00
8	60.40	-	37.60	-	0.70	0.56	0.40	0.30	100.00
9	58.30	-	39.80	-	0.68	0.53	0.40	0.30	100.00
10	60.20	-	37.80	-	0.70	0.56	0.40	0.30	100.00
11	56.10	-	42.00	-	0.65	0.51	0.40	0.30	100.00
00-rapeseed expellers									
1	60.00	-	-	39.10	0.69	0.54	0.40	0.30	100.00
2	56.60	-	-	41.50	0.66	0.51	0.40	0.30	100.00
3	59.10	-	-	39.00	0.69	0.54	0.40	0.30	100.00
4	57.70	-	-	40.40	0.68	0.52	0.40	0.30	100.00
5	58.60	-	-	39.80	0.68	0.54	0.40	0.30	100.00

Table 5.3. Analyzed composition of experimental diets, as-fed basis

Sample origin	DM (%)	CP (%)	Ash (%)	GE (kcal/kg)	ADF (%)	NDF (%)
Corn	85.3	6.95	1.09	3,682	2.27	12.78
Canola meal						
1	86.7	17.6	4.89	3,872	7.95	17.63
2	86.3	17.1	5.38	3,907	8.59	16.08
3	86.6	17.4	5.07	3,867	7.74	16.08
4	86.8	17.7	5.33	3,938	8.59	19.28
5	86.9	18.4	5.15	3,874	8.99	18.60
6	88.1	18.6	4.79	3,957	8.98	19.68
Average	86.9	17.8	5.10	3,902	8.47	17.89
00-rapeseed meal						
1	86.7	17.2	5.33	3,881	8.73	17.79
2	86.9	18.3	4.81	3,887	7.55	15.99
3	86.8	18.8	4.91	3,857	8.05	15.27
4	87.5	18.0	4.68	3,932	9.00	17.89
5	87.1	17.3	5.08	3,971	11.48	21.71
6	86.3	17.5	5.05	3,867	8.74	18.06
7	86.7	17.2	4.79	3,899	8.62	15.18
8	86.7	18.8	4.72	3,905	8.75	18.86
9	86.4	17.3	5.08	3,858	9.37	16.33
10	86.6	18.6	5.18	3,856	8.50	17.86
11	87.3	18.0	3.33	3,865	9.53	19.52
Average	86.8	17.9	4.81	3,889	8.93	17.68

Table 5.3. (Cont.)

Sample origin	DM (%)	CP (%)	Ash (%)	GE (kcal/kg)	ADF (%)	NDF (%)
00-rapeseed expellers						
1	87.2	17.4	4.68	4,047	7.04	14.16
2	87.6	18.0	4.27	4,136	7.92	15.19
3	87.4	16.9	4.96	4,107	7.97	14.94
4	88.4	17.2	4.93	4,108	8.30	17.09
5	87.3	17.4	4.79	4,030	8.88	18.92
Average	87.6	17.4	4.73	4,086	8.02	16.06

Table 5.4. Concentration of DE, ME, and apparent total tract digestibility (ATTD) of energy, ADF, and NDF in diets containing canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM basis

Item	GE Intake (kcal/d)	GE output fecal (kcal/d)	GE output urine (kcal/d)	DE, kcal/kg	ME, kcal/kg	ATTD of GE (%)	ATTD of ADF (%)	ATTD of NDF (%)
Corn	6,727	807.9	201.2	3,231	3,126	87.76	53.78	69.02
Canola meal								
1	7,917	1,392	253	3,183	3,046	82.22	46.76	63.65
2	8,002	1,534	253	3,143	2,999	80.46	37.60	54.27
3	7,727	1,394	321	3,166	3,006	81.86	41.99	58.19
4	8,095	1,525	334	3,189	3,021	81.00	38.77	60.39
5	7,969	1,610	278	3,075	2,896	79.37	39.90	57.82
6	8,430	1,663	359	3,156	2,987	79.77	43.09	60.39
Average	8,023	1,520	300	3,152	2,993	80.78	41.35	59.12
P-value[1]	0.08	<0.01	0.12	0.01	<0.01	<0.01	<0.01	<0.01
SEM[1]	881	140	43.21	29.30	39.75	0.75	1.66	1.57
00-rapeseed meal								
1	7,818	1,418	324	3,163	3,003	81.52	42.82	59.31
2	7,634	1,436	369	3,148	2,963	81.19	40.82	57.34
3	7,657	1,334	335	3,183	3,016	82.53	46.33	58.27
4	7,910	1,399	324	3,233	3,072	82.22	47.68	61.73
5	8,092	1,770	364	3,105	2,932	78.19	49.63	61.61
6	8,015	1,512	335	3,140	2,981	81.20	43.58	60.71
7	7,998	1,376	352	3,215	3,046	82.47	46.76	56.14
8	8,150	1,504	333	3,190	3,024	81.69	44.65	62.09
9	8,288	1,578	337	3,116	2,954	80.78	45.85	55.54
10	7,886	1,416	384	3,160	2,974	81.95	45.82	61.46

Table 5.4. (Cont.)

Item	GE Intake (kcal/d)	GE output fecal (kcal/d)	GE output urine (kcal/d)	DE, kcal/kg	ME, kcal/kg	ATTD of GE (%)	ATTD of ADF (%)	ATTD of NDF (%)
11	8,081	1,589	363	3,109	2,932	80.43	41.97	60.27
Average	7,957	1,485	347	3,160	2,991	81.29	45.08	59.50
P-value[2]	0.66	0.01	0.95	0.03	0.01	0.01	0.03	<0.01
SEM[2]	887	169	54.42	32.01	36.78	0.82	2.18	1.69
00-rapeseed expellers								
1	7,936	1,151	343	3,455	3,279	85.37	46.65	59.94
2	7,869	1,329	445	3,422	3,201	82.74	47.49	59.32
3	8,361	1,351	311	3,430	3,280	83.53	48.84	60.66
4	8,186	1,402	339	3,396	3,224	82.66	46.05	62.24
5	8,461	1,518	362	3,299	3,127	81.84	48.28	64.58
Average	8,163	1,350	360	3,400	3,222	83.23	47.46	61.35
P-value[3]	<0.01	<0.01	0.09	0.01	0.02	0.01	0.86	0.20
SEM[3]	1,051	160	56.42	35.88	38.79	0.88	2.49	1.83
Canola meal vs. 00-rapeseed meal								
P-value	0.69	0.87	0.02	0.80	0.78	0.48	0.001	0.65
SEM	1,215	204	52.14	25.11	33.70	0.66	1.44	1.22
00-rapeseed meal vs. 00-rapeseed expellers								
P-value	0.26	< 0.001	0.39	< 0.001	< 0.001	< 0.001	0.04	0.05
SEM	1,196	202	57.46	23.51	26.40	0.60	1.36	1.09

[1]Comparison of the 6 diets containing canola meal.
[2]Comparison of the 11 diets containing 00-rapeseed meal.
[3]Comparison of the 5 diets containing 00-rapeseed expellers.

Table 5.5. Concentration of DE, ME, and apparent total tract digestibility (ATTD) of energy, ADF, and NDF in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM basis

Item	GE Intake (kcal/d)	GE output fecal (kcal/d)	GE output urine (kcal/d)	DE, kcal/kg	ME, kcal/kg	ATTD of GE (%)	ATTD of ADF (%)	ATTD of NDF (%)
Corn	6,920	831.2	207.0	3,907	3,780	87.76	53.78	69.02
Canola meal								
1	4,440	1,028	144	3,442	3,225	75.15	44.53	59.89
2	3,867	1,037	129	3,388	3,156	68.02	34.13	44.07
3	3,342	868	190	3,395	3,102	71.52	39.17	48.31
4	3,838	1,014	206	3,491	3,182	69.92	35.69	55.03
5	3,840	1,114	154	3,143	2,816	68.68	37.19	48.73
6	4,220	1,157	233	3,408	3,096	65.64	41.00	55.36
Average	3,925	1,036	176	3,378	3,096	69.82	38.62	51.90
P-value[1]	0.09	<0.01	0.17	0.01	<0.01	0.20	<0.01	<0.01
SEM[1]	859	133	43.57	88.89	119.58	4.08	2.29	2.47
00-rapeseed meal								
1	3,710	925	201	3,452	3,172	65.96	40.54	52.31
2	3,385	925	242	3,347	2,989	68.78	37.79	47.68
3	3,454	829	209	3,543	3,236	73.33	44.48	47.11
4	4,614	1,061	238	3,652	3,378	75.70	46.88	54.30
5	4,364	1,322	253	3,294	3,007	68.11	49.03	58.78
6	3,901	1,017	212	3,423	3,146	71.04	41.68	55.79
7	3,829	875	227	3,622	3,313	76.24	45.07	42.84
8	3,967	1,001	208	3,527	3,229	68.65	42.94	58.09
9	4,254	1,094	216	3,341	3,059	69.95	44.47	46.64
10	3,717	915	260	3,444	3,087	68.06	44.09	56.37

Table 5.5. (Cont.)

Item	GE Intake (kcal/d)	GE output fecal (kcal/d)	GE output urine (kcal/d)	DE, kcal/kg	ME, kcal/kg	ATTD of GE (%)	ATTD of ADF (%)	ATTD of NDF (%)
11	4,197	1,123	247	3,338	3,028	71.10	40.15	56.17
Average[2]	3,945	1,008	228	3,453	3,149	70.63	43.37	52.37
P-value[2]	<0.01	<0.01	0.96	0.04	0.01	0.39	0.02	<0.01
SEM	838	166	53.97	92.65	104.9	4.17	2.56	2.85
00-rapeseed expellers								
1	4,446	759	221	4,252	3,933	81.57	44.67	46.95
2	4,567	858	328	4,129	3,700	77.69	45.98	51.17
3	4,273	860	188	4,122	3,879	78.74	47.34	51.28
4	4,193	923	220	3,844	3,560	76.84	44.24	56.64
5	4,407	1,031	241	3,676	3,382	76.78	46.93	61.31
Average[3]	4,377	886	240	4,005	3,691	78.32	45.83	53.47
P-value[3]	<0.01	<0.01	0.07	<0.01	<0.01	0.28	0.93	<0.01
SEM	1,044	163	56.42	98.16	105.78	2.70	2.98	3.59
Canola meal vs. 00-rapeseed meal								
P-value	0.01	0.61	0.01	0.14	0.34	0.45	< 0.001	0.81
SEM	1,183	196	50.97	73.13	97.43	4.49	1.69	1.96
00-rapeseed meal vs. 00-rapeseed expellers								
P-value	0.01	< 0.001	0.38	< 0.001	< 0.001	< 0.001	0.08	0.54
SEM	1,168	197	56.73	67.53	74.37	3.91	1.60	2.15

[1]Comparison of the 6 canola meal sources.
[2]Comparison of the 11 00-rapeseed meal sources.
[3]Comparison of the 5 00-rapeseed expellers sources.

Table 5.6. Prediction equations for GE, DE and ME in canola meal, 00-rapeseed meal, and 00-rapeseed expellers, DM-basis[1]

Equation	R^2	RMSE	*P*-value
GE = 4,499 + 51.09(fat)	0.945	47	<0.001
DE = -5,703 + 1.59(GE) + 38.93(CP)	0.555	250	<0.001
ME = -5,521 + 1.50(GE) + 38.30(CP)	0.429	302	<0.001

[1] Units for GE, DE, and ME are kcal/kg of DM; units for nutrients are % of DM.

CHAPTER 6. DIGESTIBLE PHOSPHORUS IN CANOLA MEAL, 00-RAPESEED MEAL, AND 00-RAPESEED EXPELLERS WITHOUT AND WITH MICROBIAL PHYTASE FED TO GROWING PIGS

ABSTRACT: This experiment was conducted to measure apparent total tract digestibility (**ATTD**) and standardized total tract digestibility (**STTD**) of P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers fed to growing pigs. Two hundred sixteen barrows (initial BW: 18.0 ± 1.5 kg) were allotted to a randomized complete block design with 36 diets and 6 replicate pigs per diet. Five samples of canola meal from solvent-extraction crushing plants in North America, 8 samples of 00-rapeseed meal from solvent-extraction crushing plants in Europe, and 5 samples of 00-rapeseed expellers from mechanical-press crushing plants in Europe were used in the experiment. Eighteen diets were prepared by including each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers in 1 diet. Eighteen additional diets that were similar to the previous 18 diets, with the exception that 1,500 units of microbial phytase was included in each diet, were also formulated. The only source of P in the diets was canola meal, 00-rapeseed meal, or 00-rapeseed expellers. Pigs were placed in metabolism cages that allowed for total feces collection. Pigs were fed at 2.5 times their estimated energy requirement for maintenance. Ingredients, diets, and feces were analyzed for P, and the ATTD and STTD of each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers were calculated. A constant value for endogenous phosphorus loss of 190 mg/kg DMI was used to calculate STTD of P. Results indicated that the ATTD and STTD of P for canola meal were not different from values obtained in 00-rapeseed meal, and the ATTD and STTD of P in 00-rapeseed meal were not different from values for 00-rapeseed expellers. The ATTD and STTD of P increased ($P < 0.001$) from 44.99 and 48.82% to 64.08 and 67.97% for canola meal, from 46.77 and 50.36% to 63.53 and 67.29%

for 00-rapeseed meal, and from 44.83 and 48.60% to 69.28 and 72.99% for 00-rapeseed expellers by using microbial phytase in the diets. In conclusion, The ATTD and STTD of P for canola and 00-rapeseed products are not different, and addition of microbial phytase can improve the digestibility of P in canola, 00-rapeseed meal, and 00-rapeseed expellers.

Key words: canola meal, digestibility, pig, phosphorus, 00-rapeseed meal, 00-rapeseed expellers

INTRODUCTION

Canola meal, 00-rapeseed meal, and 00-rapeseed expellers may be used as alternative ingredients in animal diets because these ingredients have low concentrations of glucosinolates, high concentration of CP, and relatively high concentration of minerals (Thomas, 2005; Newkirk, 2011). Canola meal and 00-rapeseed meal may contain 1.00 to 1.10 % total P (Liu et al., 1998; Newkirk, 2009; NRC, 2012), but approximately 85% of total P in canola meal is bound to phytic acid (Spragg and Mailer, 2007; Newkirk, 2009). As a consequence, the digestibility of P in canola meal by pigs is relatively low (Sauvant et al., 2004; NRC, 2012).

Results of recent experiments have demonstrated that microbial phytase may improve the digestibility of P in canola meal (Zhang et al., 2000; Akinmusire and Adeola, 2009; Arntfield and Hickling, 2011; Rodríguez et al., 2013). However, there are no comparative data for P digestibility of canola meal and 00-rapeseed meal, and it is not known if data for P digestibility in canola meal are also representative for 00-rapeseed meal.

If oil is removed from oilseeds using mechanical expelling rather than solvent extraction, the resulting expellers may be used as feed. Canola expellers and 00-rapeseed expellers contain more oil and GE than canola meal and 00-rapeseed meal, but there are limited data on the digestibility of P and effects of microbial phytase on P digestibility in 00-rapeseed expellers. It is also not known if values for P digestibility and effects of microbial phytase in 00-rapeseed meal are also representative of 00-rapeseed expellers.

Therefore, the objective of this experiment was to compare the apparent total tract digestibility (**ATTD**) and standardized total tract digestibility (**STTD**) of P in canola meal obtained from North America and 00-rapeseed meal from Europe, and to compare the ATTD and STTD of P between 00-rapeseed meal and 00-rapeseed expellers. The second objective was to determine the effect of microbial phytase on the ATTD and STTD of P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The experiment was approved by the Institutional Animal Care and use Committee at the University of Illinois. Two hundred and sixteen growing barrows (initial BW: 18.0 ± 1.50 kg; G-Performer boars × F-25 females, Genetiporc, Alexandria, MN) were allotted to a randomized complete block design with 36 diets and 6 replicate pigs per diet. Each of 36 experimental diets was fed to 1 pig for each of 6 periods. Each experimental period was 12 d. Pigs were placed in metabolism cages that were equipped with a feeder and a nipple drinker, fully slatted floors, and a screen floor. This allowed for the total collection of feces from each pig.

Ingredients, Diets, and Feeding

Five samples of canola meal were obtained from solvent-extraction crushing plants in North America, 8 samples of 00-rapeseed meal were obtained from solvent-extraction crushing plants in Europe, and 5 samples of 00-rapeseed expellers were obtained from mechanical-press crushing plants in Europe (Table 6.1).Thirty six diets were prepared by including each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers in 2 diets (Table 6.2). One of these diets contained no microbial phytase, but the other diet contained 1,500 units per kilogram of microbial phytase (Optiphos 2000, Enzyvia, Sheridan, IN). Vitamins and minerals other than P were included in all diets to meet or exceed requirements for growing pigs (NRC, 2012).

Experimental diets were fed to the pigs at a daily level of 2.5 times the estimated maintenance requirement for energy (i.e., 197 kcal of ME per kg of $BW^{0.60}$; NRC, 2012). The daily feed allotments were divided into 2 equal meals and fed at 0700 and 1700h. Water was supplied at all times throughout the experiment.

Data and Sample Collection

All pig weights were recorded at the beginning and at the end of each period, and the amount of feed supplied to each pig each day was recorded. The initial 5 d of each period was considered an adaptation period to the diet. Fecal samples were collected from d 6 through d 12 according to standard procedures using the marker to marker approach (Adeola, 2001). Fecal samples were stored at -20^{o}C immediately after collection. At the conclusion of the experiment, fecal samples were thawed and mixed within animal and diet, and a subsample was collected for chemical analysis. Fecal samples were dried in a forced-air oven at 60^{o}C, ground, and thoroughly mixed before a subsample was collected for analysis.

Chemical Analysis

Samples of canola meal, 00-rapeseed meal, 00-rapeseed expellers, diets, and feces were analyzed for DM (Method 930.15; AOAC Int., 2007) and Ca and P were analyzed by inductive Coupled Plasma-Optical Emission Spectoscopy [ICP-OES; Method 985.01 (A, B, and C); AOAC Int., 2007]. Canola meal, 00-rapeseed meal, and 00-rapeseed expellers were analyzed for phytate (Ellis et al., 1977) and for acid hydrolyzed ether extract (**AEE**), which was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (Method 954.02; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS

North America, Eden Prairie, MN), and ash (Method 942.05; AOAC Int., 2007). Canola meal, 00-rapeseed meal, 00-rapeseed expellers, and diets were also analyzed for CP by combustion (Method 990.03; AOAC Int., 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ) and GE by bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Diets were analyzed for phytase activity (Phytex Method, version 1, Eurofins, Des Moines, IA; Table 6.3).

Calculations and Statistic Analysis

Phytate bound P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers was calculated as 28.2% of the concentration of analyzed phytate (Tran and Sauvant et al., 2004), and non-phytate bound P was calculated by subtracting phytate bound P from total concentration of P. The apparent total tract digestibility (ATTD) of Ca and P, and standardized total tract digestibility (STTD) of P in each diet were calculated as described by Almeida and Stein (2010). The STTD was calculated using a constant value for endogenous phosphorus loss of 190 mg/kg DMI (NRC, 2012). Data were analyzed using the PROC MIXED procedure of SAS (SAS inst. Inc., Cary, NC). The presence of outliers was verified using the UNIVARIATE procedure of SAS. The sources of canola meal, 00-rapeseed meal, 00-rapeseed expellers, and phytase were included in the model as a fixed effect, and replicates were included as random effects. The mean values of each diet were calculated using the LSMeans statement. If significant differences were detected, treatment means were separated by using the PDIFF option in PROC MIXED. The pig was the experimental unit, and an alpha level of 0.05 was used to assess significance among means.

RESULTS AND DISCUSSIONS

The concentrations of CP and ash in canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were observed in this experiment (Table 6.1) are in agreement with values for canola meal and canola expellers reported by Spragg and Mailer (2007), Rostagno et al. (2011) and NRC (2012). The GE in canola meal and 00-rapeseed meal agree with the values for canola meal reported by Rostagno et al., (2011), but the concentrations of GE and AEE for canola meal, 00-rapeseed meal, and 00-rapeseed expellers are greater than the values for canola meal, 00-rapeseed meal, canola expellers, and 00-rapeseed expellers reported by FEDNA (2010); PHILSAN, (2010), and NRC (2012). The Ca and P for canola meal, 00-rapeseed meal, and 00-rapeseed expellers are in agreement with the values for canola meal, rapeseed meal, canola expellers, and rapeseed expellers reported by FEDNA (2010) and NRC (2012). The concentrations of phytate bound P and non-phytate bound P for canola meal, 00-rapeseed meal, and 00-rapeseed expellers are in agreement with the values for 00-rapeseed meal and 00-rapeseed expellers reported by FEDNA (2010), and the concentrations of phytate bound P and non-phytate bound P for 00-rapeseed expellers are in agreement with the values for canola expellers reported by NRC (2012). However, the concentration of phytate bound P for canola meal is greater than the values for canola meal reported by Rostagno et al. (2011) and NRC (2012). The concentration of phytate in canola and rapeseed is influenced by varieties and availability of phosphorus in soil (Uppström and Svensson, 1980). Therefore, the concentration of phytate bound P in canola meal and 00-rapeseed meal may vary due to the differences among varieties and environmental conditions where canola and rapeseeds are grown.

Feed intake, ATTD and STTD of P, excretion of P in feces, and ATTD of Ca were not different among pigs fed diets containing canola meal, the values were not different among pigs fed diets containing 00-rapeseed meal (Table 6.4 and 6.5), but the excretion of P in feces and

ATTD and STTD of P were different (*P* < 0.01) among pigs fed diets containing 00-rapeseed expellers (Table 6.6). Feed intake in pigs fed diets containing canola meal was less (*P* < 0.05) than in pigs fed diets containing 00-rapeseed meal, but feed intake was not different between pigs fed diets containing 00-rapeseed meal and 00-rapeseed expellers (Table 6.7). Phosphorus intake for diets containing canola meal was also less (*P* < 0.001) than for diets containing 00-rapeseed meal, and P intake was greater (*P* < 0.05) for 00-rapeseed meal diets than for 00-rapeseed expeller diets. Calcium intake was not different between pigs fed diets containing canola meal and 00-rapeseed meal, but Ca intake in pigs fed diets containing 00-rapeseed meal was greater (*P* < 0.001) than in pigs fed diets containing 00-rapeseed expellers. Phosphorus in feces from pigs fed canola meal diets was less (*P* < 0.001) than from pigs fed 00-rapeseed meal diets, whereas P in feces from pigs fed 00-rapeseed meal diets was greater (*P* < 0.001) than from pigs fed 00-rapeseed expellers. Calcium in feces was not different between pigs fed diets containing canola meal and 00-rapeseed meal, but Ca in feces for pigs fed 00-rapeseed meal diets was less (*P* < 0.001) than for pigs fed 00-rapeseed expellers diets.

Absorption of P by pigs fed canola meal diets was less (*P* < 0.01) than by pigs fed 00-rapeseed meal diets, but the value was not different between pigs fed 00-rapeseed meal diets and 00-rapeseed expellers diets. The ATTD and STTD of P were not different between canola meal diets and 00-rapeseed meal diets, and the values did not differ between 00-rapeseed meal and 00-rapeseed expellers. Absorption and ATTD of Ca were not different between pigs fed diets containing canola meal and 00-rapeseed meal, but absorption and ATTD of Ca were greater (*P* < 0.001) in 00-rapeseed meal diets than 00-rapeseed expellers diets.

The ATTD and STTD of P for canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were calculated in this experiment are greater than the values for canola meal, rapeseed meal, canola expellers, and rapeseed expellers reported by FEDNA (2010) or NRC (2012). The observation that the ATTD and STTD of P and ATTD of Ca were not different in pigs fed diets containing canola meal and 00-rapeseed meal indicate that the digestibility of P and Ca among sources of canola and rapeseed meal is not different. However, differences in the ATTD and STTD of P among pigs fed diets containing the different sources of 00-rapeseed expellers were observed. This observation indicates that there was some variation in the digestibility of P among sources of 00-rapeseed expellers that were used in this experiment. The ATTD of Ca for canola meal diets observed in this experiment is greater than the ATTD of Ca in canola meal reported by González-Vega et al. (2013). This is likely because in this experiment both limestone and canola meal contributed Ca to the diets, whereas all the Ca in the diets used by González-Vega et al. was from canola meal. Canola meal and 00-rapeseed meal are selected from the same variety (*B. napus*) and the same oil extraction procedure (solvent extraction) was used to extract the oil from the 2 ingredients. As a consequence, the concentration of phytate P and non-phytate P (80% and 20% respectively) were not different between canola meal and rapeseed meal, which likely is the reason that ATTD and STTD of P in canola meal are similar to the ATTD and STTD of P in 00-rapeseed meal. The observation that ATTD and STTD of P for 00-rapeseed meal did not differ from value for 00-rapeseed expellers indicates that different oil extraction procedures have no effects on the digestibility of P. The increased ATTD of Ca in diets containing 00-rapeseed meal compared with diets containing 00-rapeseed expellers indicates that the oil extraction procedure may influence Ca digestibility because the inclusion of limestone was similar for all diets. The concentration of phytate was also similar in 00-rapeseed meal and 00-rapeseed expellers, so the negative effect of phytate on Ca digestibility is also expected to be similar.

The concentrations of P in feces and daily P output were reduced ($P < 0.001$) by addition of microbial phytase to diets containing canola meal, 00-rapeseed meal, and 00-rapeseed expellers. As a consequence, the ATTD and STTD of P increased ($P < 0.001$) as microbial phytase was used. The concentrations of Ca in feces and daily Ca output were reduced ($P < 0.001$), and ATTD of Ca was increased ($P < 0.001$) by using microbial phytase in diet containing canola meal, 00-rapeseed meal, and 00-rapeseed expellers diets.

This observation is in agreement with the results reported by Akinmusire and Adeola (2009) and Rodríguez et al. (2013). Addition of microbial phytase to growing pig diets decreases excretion of P and increases digestibility of P because phytate P is degraded in the gastrointestinal tract of pigs (Adeola et al., 2004; Selle et al., 2009). This explains why P digestibility increased as microbial phytase was added to the diets. The increased digestibility of Ca that was observed when microbial phytase was used may be the result of an increased digestibility of Ca in limestone, because dietary Ca may bind to phytate in Ca-phytate complexes in the gastrointestinal tract of pigs. Therefore, adding microbial phytase to diets may reduce the Ca-phytate complex, which will then result in increased digestibility of Ca from limestone (Selle et al., 2009).

The reduction of P intake in pigs fed diets containing 00-rapeseed meal was greater than pigs fed diets containing canola meal if phytase was used resulting in an interaction ($P < 0.05$) between sources of canola and rapeseed meals and phytase. Calcium intake of pigs decreased ($P < 0.001$) when phytase was added to 00-rapeseed meal diets, but Ca intake was not different when phytase was added to canola meal diets (interaction, $P < 0.001$). However, Ca absorption was not affected by phytase for pigs fed diets containing the different sources of 00-rapeseed meal, whereas Ca absorption increased ($P < 0.001$) in pig fed canola diets as phytase was used, which resulted in an interaction between sources of canola and rapeseed meals and phytase. The reduction ($P < 0.001$) of P and Ca in feces caused by phytase and the increase ($P < 0.001$) in P absorption, ATTD of P and Ca, and STTD of P in pigs fed diets containing 00-rapeseed meal are greater ($P < 0.001$) than if pigs were fed diets containing 00-rapeseed expellers resulting in an interaction ($P < 0.01$) between source of rapeseed products and phytase.

The observation that ATTD of P and Ca and the STTD of P were not different in pigs fed diets containing canola and 00-rapeseed meal if phytase was used indicates that the digestibility of P and Ca in the diets containing the meals from different locations is not different when phytase is used. However, the increase caused by phytase in ATTD of P and Ca and STTD of P was greater in pigs fed diets containing 00-rapeseed expellers compared with pigs fed diets containing 00-rapeseed meal diets. This observation indicates that the effect of adding microbial phytase to 00-rapeseed expellers is greater than if phytase is added to 00-rapeseed meal. The ratio between phytate bound P and non phytate bound P was greater in 00-rapeseed expellers than in 00-rapeseed meal, which results in greater response to microbial phytase may explain the results obtained for diets containing 00-rapeseed meal or 00-rapeseed expellers diets, respectively.

CONCLUSION

The ATTD and STTD of P and ATTD of Ca were not different among sources of canola and 00-rapeseed meal. However, differences in ATTD and STTD of P among sources of 00-rapeseed expellers were observed. Differences among oil crushing plants using mechanical press to extract the oil may explain the variations in the digestibility of P among sources of 00-rapeseed expellers. The ATTD and STTD of P in canola meal were not different from the ATTD and STTD of P in 00-rapeseed meal, and the values did not differ between 00-rapeseed meal and 00-rapeseed expellers. Therefore, the digestibility of P in canola meal is also representative of the digestibility in 00-rapeseed meal and 00-rapeseed expellers. The ATTD of Ca in diets containing canola meal was also not different from values for diets containing 00-rapeseed meal.

However, the ATTD of Ca in diets containing 00-rapeseed meal was greater than in diets containing 00-rapeseed expellers, which indicates the oil extraction procedures may influence Ca digestibility. The ATTD and STTD of P and the ATTD of Ca are greater if microbial phytase is added to the diets, which is likely a result of microbial phytase hydrolyzing phytate-P bonds and reducing Ca-phytate complexes in the gastrointestinal tract of pigs.

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TABLES

Table 6.1. Analyzed composition of canola meal, 00-rapeseed meal, and 00-rapeseed expellers, as-fed basis

Sample origin	DM (%)	CP (%)	AEE (%)	GE (kcal/kg)	Ash (%)	Ca (%)	P (%)	Phytate (%)	Phytate bound P (%)	Phytate bound P (% of total P)	Non-phytate P, (%)	Non-phytate bound P (% of total P)
Canola meal												
1	90.47	39.35	4.31	4,229	8.40	1.21	1.04	2.93	0.82	79.31	0.22	20.69
2	90.18	39.79	3.01	4,207	7.32	0.79	1.05	2.95	0.83	79.09	0.22	20.91
3	89.81	38.11	4.44	4,237	7.36	0.67	0.95	2.72	0.77	80.60	0.18	19.40
4	90.40	36.71	3.79	4,196	7.39	0.83	0.94	2.59	0.73	77.56	0.21	22.44
5	89.44	37.57	3.58	4,235	6.93	0.76	1.01	2.97	0.84	82.78	0.17	17.22
Average	90.06	38.31	3.83	4,221	7.48	0.85	1.00	2.83	0.80	79.87	0.20	20.13
00-rapeseed meal												
1	89.09	36.37	3.58	4,150	6.57	0.68	0.96	2.60	0.73	76.24	0.23	23.76
2	90.31	38.03	4.19	4,254	7.39	0.71	1.13	3.21	0.90	79.97	0.23	20.03
3	88.08	37.50	3.47	4,173	6.61	0.75	1.12	3.27	0.92	82.19	0.20	17.81
4	89.09	35.60	5.25	4,257	6.89	0.76	1.05	3.00	0.84	80.43	0.21	19.57

Table 6.1. (Cont.)

Sample origin	DM (%)	CP (%)	AEE (%)	GE (kcal/kg)	Ash (%)	Ca (%)	P (%)	Phytate (%)	Phytate bound P (%)	Phytate bound P (% of total P)	Non-phytate P, (%)	Non-phytate bound P (% of total P)
5	88.56	37.10	3.72	4,229	6.61	0.71	1.03	3.08	0.87	84.18	0.16	15.82
6	89.02	37.25	3.68	4,234	6.86	0.67	1.05	3.03	0.85	81.23	0.20	18.77
7	90.47	39.35	4.31	4,229	8.40	1.21	1.04	2.93	0.82	79.31	0.22	20.69
8	90.18	39.79	3.01	4,207	7.32	0.79	1.05	2.95	0.83	79.09	0.22	20.91
Average	88.96	36.82	3.70	4,203	6.87	0.74	1.07	3.08	0.87	80.97	0.20	19.03
00-rapeseed expellers												
1	89.88	36.08	10.79	4,668	6.33	0.71	1.10	3.31	0.93	84.71	0.17	15.29
2	89.86	34.50	12.99	4,771	5.74	0.59	0.97	2.85	0.80	82.71	0.17	17.29
3	91.23	36.24	13.84	4,768	6.01	0.63	1.00	2.78	0.78	78.26	0.22	21.74
4	95.15	35.25	11.70	4,835	6.54	0.73	1.07	3.13	0.88	82.35	0.19	17.65
5	93.04	35.84	8.27	4,561	6.51	0.76	1.06	3.01	0.85	79.94	0.21	20.06
Average	91.83	35.58	11.52	4,721	6.23	0.68	1.04	3.02	0.85	81.59	0.19	18.41

Table 6.2. Ingredient composition (%) of experimental diets, as-fed basis

Item	Phytase, FTU/kg	Canola meal	00-rapeseed meal	00-rapeseed expellers	Cornstarch	Sugar	Soy oil	Limes-tone	Salt	Vitamin - mineral premix	Phytase premix	Total
Canola meal												
1	0	40.00	-	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	40.00	-	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
2	0	40.00	-	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	40.00	-	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
3	0	40.00	-	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	40.00	-	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
4	0	40.00	-	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	40.00	-	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
5	0	40.00	-	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	40.00	-	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
00-rapeseed meal												
1	0	-	40.00	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	-	40.00	-	45.53	10.00	3.00	0.70	0.40	0.30	0.03	100.00

Table 6.2. (Cont.)

Item	Phytase, FTU/kg	Canola meal	00-rapeseed meal	00-rapeseed expellers	Cornstarch	Sugar	Soy oil	Limes-tone	Salt	Vitamin - mineral premix	Phytase	Total
2	0	-	40.00	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	-	40.00	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
3	0	-	40.00	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	-	40.00	-	45.57	10.00	3.00	0.70.	0.40	0.30	0.03	100.00
4	0	-	40.00	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	-	40.00	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
5	0	-	40.00	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	-	40.00	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
6	0	-	40.00	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	-	40.00	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
7	0	-	40.00	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	-	40.00	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00
8	0	-	40.00	-	45.60	10.00	3.00	0.70	0.40	0.30	-	100.00
	1,500	-	40.00	-	45.57	10.00	3.00	0.70	0.40	0.30	0.03	100.00

Table 6.2. (Cont.)

Item	Phytase, FTU/kg	Canola meal	00-rapeseed meal	00-rapeseed expellers	Cornstarch	Sugar	Soy oil	Lime-stone	Salt	Vitamin-mineral premix	Phytase	Total
00-rapeseed expellers												
1	0	-	-	40.00	47.60	10.00	1.01	0.70	0.40	0.30	-	100.00
	1,500	-	-	40.00	47.57	10.00	1.01	0.70	0.40	0.30	0.03	100.00
2	0	-	-	40.00	48.59	10.00	-	0.70	0.40	0.30	-	100.00
	1,500	-	-	40.00	48.56	10.00	-	0.70	0.40	0.30	0.03	100.00
3	0	-	-	40.00	48.60	10.00	-	0.70	0.40	0.30	-	100.00
	1,500	-	-	40.00	48.57	10.00	-	0.70	0.40	0.30	0.03	100.00
4	0	-	-	40.00	48.10	10.00	0.49	0.70	0.40	0.30	-	100.00
	1,500	-	-	40.00	48.07	10.00	0.49	0.70	0.40	0.30	0.03	100.00
5	0	-	-	40.00	46.60	10.00	2.00	0.70	0.40	0.30	-	100.00
	1,500	-	-	40.00	46.57	10.00	2.00	0.70	0.40	0.30	0.03	100.00

Table 6.3. Analyzed composition of experimental diets, as-fed basis

Item	Phytase, FTU/kg	DM (%)	CP (%)	GE (kcal/kg)	Ca (%)	P (%)
Canola meal						
1	59.00	90.09	15.94	4,043	0.76	0.45
	1,700	89.92	15.01	4,021	0.74	0.46
2	68.00	90.37	15.33	4,043	0.58	0.47
	1,800	90.96	15.41	4,046	0.76	0.45
3	<50.00	90.03	14.97	4,085	0.66	0.44
	1,800	90.92	14.07	4,041	0.64	0.43
4	63.00	90.00	13.64	4,005	0.62	0.43
	1,700	91.06	13.88	3,981	0.65	0.43
5	<50.00	90.17	14.80	4,094	0.63	0.45
	1,700	91.21	14.81	4,100	0.57	0.45
00-rapeseed meal						
1	64.00	90.50	14.52	4,052	0.62	0.44
	1,800	91.46	13.94	4,086	0.51	0.42
2	<50.00	90.71	13.90	4,065	0.69	0.49
	1,800	91.60	15.59	4,066	0.55	0.48
3	<50.00	90.33	14.80	4,039	0.68	0.51
	1,600	91.04	15.00	4,053	0.62	0.50
4	<50.00	90.08	14.45	4,060	0.61	0.47
	1,800	90.91	13.88	4,047	0.56	0.45

Table 6.3. (Cont.)

Item	Phytase, FTU/kg	DM (%)	CP (%)	GE (kcal/kg)	Ca (%)	P (%)
5	66.00	90.88	14.71	4,006	0.60	0.46
	1,800	91.57	14.56	4,061	0.59	0.45
6	77.00	90.08	13.95	4,033	0.63	0.47
	1,700	90.03	14.06	4,032	0.56	0.44
7	<50.00	89.95	14.25	3,987	0.70	0.52
	1,700	90.90	14.97	4,067	0.63	0.50
8	<50.00	89.97	14.26	3,974	0.59	0.47
	1,600	90.80	14.71	4,007	0.56	0.46
00-rapeseed expellers						
1	57.00	90.53	15.34	4,110	0.64	0.50
	1,600	91.39	15.00	4,136	0.56	0.50
2	60.00	89.99	12.76	4,050	0.51	0.41
	1,500	90.99	14.21	4,083	0.62	0.43
3	53.00	90.95	14.53	4,044	0.47	0.46
	1,900	91.45	15.05	4,146	0.52	0.46
4	<50.00	91.54	13.82	4,069	0.56	0.47
	1,800	92.48	13.60	4,090	0.53	0.44
5	<50.00	90.94	14.20	4,080	0.62	0.46
	1,600	91.74	14.61	4,115	0.59	0.46

Table 6.4. Daily balance, apparent total tract digestibility (ATTD) of P and Ca, and standardized total tract digestibility (STTD) of canola meal

Item	Phytase, FTU/kg	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,%	Ca intake, g/d	Ca in feces, %	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
Canola meal													
1	0	718	3.59	2.43	2.03	1.55	44.03	47.84	6.06	3.20	2.70	3.35	60.10
	1,500	708	3.62	1.74	1.40	2.23	61.31	65.02	5.83	2.47	2.00	3.83	65.88
2	0	677	3.52	2.32	1.86	1.66	46.81	50.46	4.35	2.31	1.86	2.49	57.14
	1,500	681	3.37	1.78	1.34	2.03	59.76	63.60	5.69	2.17	1.66	4.03	71.22
3	0	741	3.62	2.10	1.91	1.71	47.32	51.21	5.43	2.05	1.88	3.56	65.58
	1,500	703	3.33	1.30	1.05	2.28	68.05	72.07	4.95	1.56	1.24	3.71	74.33
4	0	670	3.20	2.10	1.73	1.47	45.28	49.26	4.62	2.24	1.83	2.79	59.45
	1,500	717	3.39	1.24	1.22	2.16	66.47	70.49	5.12	1.48	1.35	3.77	73.58
5	0	705	3.52	2.33	2.07	1.45	41.52	45.33	4.93	2.08	1.86	3.07	62.62
	1,500	697	3.44	1.50	1.20	2.24	64.83	68.68	4.36	1.46	1.16	3.20	72.89
Average	0	702	3.49	2.26	1.92	1.57	44.99	48.82	5.08	2.38	2.02	3.05	60.98
	1,500	701	3.43	1.51	1.24	2.19	64.08	67.97	5.19	1.83	1.48	3.71	71.58

Table 6.4. (Cont.)

Item	Phytase, FTU/kg	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,%	Ca intake, g/d	Ca in feces, %	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
P-value[1]	0	0.105	0.042	0.014	0.106	0.084	0.286	0.282	<0.001	<0.001	<0.01	<0.01	0.275
	1,500	0.799	0.301	<0.001	<0.01	0.420	<0.01	<0.01	<0.001	<0.001	<0.01	0.094	0.206
SEM[1]	0	58.17	0.29	0.10	0.20	0.15	2.85	2.85	0.44	0.21	0.28	0.30	3.14
	1,500	53.75	0.26	0.06	0.10	0.21	1.80	1.80	0.39	0.20	0.19	0.35	3.00
P-value[2]		0.954	0.373	<0.001	<0.001	<0.001	<0.001	<0.001	0.527	<0.001	<0.001	<0.001	<0.001
SEM[2]		65.942	4.892	0.070	0.164	0.197	1.853	1.857	0.492	0.161	0.231	0.338	2.006

[1]Comparison of the 5 diets containing canola meal.
[2]Comparison of canola meal diets without vs. with microbial phytase.

Table 6.5. Daily balance, apparent total tract digestibility (ATTD) of P and Ca, and standardized total tract digestibility (STTD) of 00-rapeseed meal

Item	Phytase, FTU/kg	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,%	Ca intake, g/d	Ca in feces, %	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
00-rapeseed meal													
1	0	735	3.58	2.23	1.88	1.69	43.97	47.88	5.04	2.14	1.79	3.25	63.96
	1,500	715	3.29	1.36	1.13	2.15	65.42	69.56	3.99	1.53	1.29	2.70	68.06
2	0	715	3.86	2.71	1.93	1.93	49.53	53.05	5.44	2.52	1.80	3.64	66.60
	1,500	729	3.82	1.82	1.33	2.46	64.00	67.63	4.38	2.02	1.53	2.84	64.52
3	0	725	4.10	2.50	1.94	2.16	47.89	51.26	5.46	2.22	1.71	3.75	68.15
	1,500	704	3.87	2.00	1.53	2.34	60.16	63.62	4.80	1.85	1.41	3.39	70.32
4	0	750	3.92	2.57	2.29	1.63	42.38	46.02	5.08	2.46	2.08	2.91	57.92
	1,500	712	3.52	1.65	1.34	2.18	62.46	66.29	4.39	1.85	1.50	3.10	66.05
5	0	715	3.62	2.65	2.16	1.46	46.32	50.07	4.72	2.44	1.68	2.72	57.57
	1,500	695	3.42	1.48	1.18	2.24	65.31	69.18	4.48	1.57	1.25	3.22	71.95
6	0	728	3.80	2.50	2.05	1.75	46.25	49.90	5.09	2.46	2.00	3.09	60.76
	1,500	689	3.37	1.57	1.26	2.10	62.28	66.16	4.29	1.91	1.54	2.75	63.75

Table 6.5. (Cont.)

Item	Phytase, FTU/kg	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,%	Ca intake, g/d	Ca in feces, %	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
7	0	735	4.25	2.46	2.00	2.25	52.62	55.91	5.72	2.41	1.95	3.78	65.48
	1,500	683	3.75	1.88	1.36	2.40	62.81	66.26	4.73	2.06	1.49	3.25	67.30
8	0	714	3.73	2.52	2.07	1.67	45.18	48.81	4.69	2.33	1.92	2.76	59.49
	1,500	670	3.40	1.75	1.18	2.38	65.83	69.58	4.13	1.52	1.04	3.33	75.67
Average	0	727	3.86	2.52	2.04	1.82	46.77	50.36	5.15	2.37	1.87	3.24	62.49
	1,500	700	3.56	1.69	1.29	2.28	63.53	67.29	4.40	1.79	1.38	3.07	68.45
P-value[1]	0	0.944	<0.01	0.060	0.605	0.014	0.252	0.307	<0.01	0.428	0.738	<0.01	0.163
SEM[1]	0	52.45	0.28	0.13	0.22	0.20	3.10	3.10	0.38	0.19	0.19	0.32	3.80
	1,500	47.97	0.28	0.10	0.13	0.22	2.72	2.72	0.34	0.17	0.17	0.31	3.44
P-value[2]		0.024	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.083	<0.001
SEM[2]		62.64	0.33	0.11	0.18	0.20	1.83	1.83	6.77	0.16	2.33	0.32	2.82

[1]Comparison of the 8 diets containing 00-rapeseed meal.
[2]Comparison of 00-rapeseed meal diets without vs. with microbial phytase.

Table 6.6. Daily balance, apparent total tract digestibility (ATTD) of P and Ca, and standardized total tract digestibility (STTD) of 00-rapeseed expellers

Item	Phytase, FTU/kg	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,%	Ca intake, g/d	Ca in feces, %	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
00-rapeseed expellers													
1	0	724	4.00	3.18	2.30	1.71	42.79	46.23	5.12	3.39	2.61	2.68	52.39
	1,500	721	3.94	1.97	1.31	2.63	67.09	70.56	4.42	2.20	1.47	2.95	67.09
2	0	665	3.03	2.67	1.72	1.32	43.20	47.37	3.77	2.70	1.74	2.02	53.97
	1,500	575	2.72	1.43	0.73	1.99	73.22	77.24	3.92	1.79	0.76	3.00	76.60
3	0	728	3.68	2.59	1.80	1.88	50.24	54.00	3.76	2.64	1.84	1.93	50.55
	1,500	754	3.80	1.49	1.06	2.74	71.86	75.64	4.29	1.78	1.26	3.03	70.12
4	0	775	3.98	2.84	2.41	1.57	39.65	43.36	4.74	2.64	2.24	2.50	52.94
	1,500	756	3.60	1.72	1.23	2.37	65.40	69.39	4.33	2.31	1.65	2.92	61.15

Table 6.6. (Cont.)

Item	Phytase, FTU/kg	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,%	Ca intake, g/d	Ca in feces, %	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
5	0	690	3.49	2.58	1.83	1.67	48.26	52.02	4.71	3.24	2.37	2.34	51.09
	1,500	697	3.49	1.58	1.12	2.37	68.33	72.12	4.48	1.98	1.40	3.08	67.03
Average	0	716	3.64	2.77	2.01	1.63	44.83	48.60	4.42	2.92	2.16	2.29	52.19
	1,500	701	3.51	1.64	1.09	2.42	69.18	72.99	4.29	2.01	1.31	2.99	68.40
P-value[1]	0	0.207	<0.01	0.079	<0.001	0.195	<0.001	<0.001	<0.001	0.114	0.148	0.098	0.981
	1,500	<0.001	<0.001	<0.001	<0.01	0.083	0.081	0.072	0.41	0.113	0.304	0.893	0.027
SEM[1]	0	60.79	0.30	0.14	0.21	0.21	2.64	2.64	0.36	0.26	0.31	0.28	5.08
	1,500	146.72	0.28	0.09	0.14	0.21	2.48	2.48	0.38	0.19	0.21	0.30	3.61
P-value[2]		0.482	0.355	<0.001	<0.001	<0.001	<0.001	<0.001	0.391	<0.001	<0.001	<0.001	<0.001
SEM[2]		69.46	0.35	0.10	0.19	2.92	1.97	1.98	0.43	0.17	0.19	0.27	2.92

[1]Comparison of the 5 diets containing 00-rapeseed expellers.
[2]Comparison of 00-rapeseed expellers diets without vs. with microbial phytase.

Table 6.7. Daily balance, apparent total tract digestibility (ATTD) of P and Ca, and standardized total tract digestibility (STTD) of canola meal vs. 00-rapeseed meal and 00-rapeseed meal vs. 00-rapeseed expellers

Item	Phytase, FTU/kg	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,%	Ca intake, g/d	Ca in feces, %	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
Canola meal vs. 00-rapeseed meal													
P-value[1]	0	0.039	<0.001	<0.001	0.125	<0.01	0.251	0.316	0.572	0.959	0.141	0.187	0.324
	1,500	0.902	0.128	0.013	0.453	0.272	0.721	0.648	<0.001	0.705	0.280	<0.001	0.066
SEM[1]	0	65.58	0.34	0.11	0.23	0.17	1.90	1.90	0.47	0.18	0.22	0.33	2.75
	1,500	62.44	0.31	0.08	0.12	0.23	1.99	2.00	0.42	0.13	0.16	0.33	2.41
Source x phytase													
P-value[2]		0.15	0.028	0.203	0.368	0.143	0.225	0.251	<0.001	0.807	0.684	<0.001	0.055
SEM[2]		52.22	0.27	0.08	0.14	0.16	1.62	1.62	0.37	0.13	0.15	0.27	2.14

Table 6.7. (Cont.)

Item	Phytase, FTU/kg	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,%	Ca intake, g/d	Ca in feces, %	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
00-rapeseed meal vs. 00-rapeseed expellers													
P-value[3]	0	0.470	0.026	<0.001	0.744	0.050	0.255	0.304	<0.001	<0.001	0.019	<0.001	<0.001
	1,500	0.956	0.678	0.445	<0.01	0.076	<0.001	<0.001	0.313	0.020	0.639	0.585	0.976
SEM[3]	0	64.07	0.34	0.12	0.22	0.17	1.92	1.90	0.43	0.19	0.21	0.30	3.01
	1,500	66.42	0.34	0.09	0.14	0.23	2.13	2.13	0.41	0.13	0.16	0.30	2.60
P-value[4]		0.607	0.209	<0.001	0.166	<0.01	<0.01	<0.01	<0.01	0.032	0.061	<0.001	<0.001
SEM[4]		53.59	0.28	0.09	0.15	0.16	1.62	1.62	0.35	0.13	0.15	0.25	2.40

[1]Comparison of canola meal diets vs. 00-rapeseed meal diets.
[2]Interaction of location and phytase.
[3]Comparison of 00-rapeseed meal diets vs. 00-rapeseed expellers diets.
[4]Interaction of processing procedure and phytase.

GENERAL CONCLUSION

Variations among varieties, growing and harvesting conditions, and oil crushing and extraction procedures may affect the chemical composition of canola and rapeseeds, and consequently affect nutritional value of the defatted meals produced from canola or 00-rapeseed. This research was conducted to determine the composition and nutrient value in canola meal and 00-rapeseed products. Chemical composition indicates that variety and growing condition are factors that influence the concentration of glucosinolates in canola meal and 00-rapeseed meal, and differences in the efficiency of oil removal between oil extraction procedures can affect the concentration of acid hydrolyzed ether extract (AEE) and GE in 00-rapeseed products. The standardized ileal digestibility (SID) of CP and most AA in 00-rapeseed expellers are greater than in 00-rapeseed meal. The greater heat exposure used for meals that were defatted using the solvent extraction procedure can cause grater heat damage in the meal, and consequently affect the digestibility of CP and AA, which may be the reason for the greater digestibility in 00-rapeseed expellers compared with 00-rapeseed meal. The concentration of CP may be used to estimate the concentration of indispensable AA in canola or rapeseed products with only a medium accuracy, and the concentration of CP and indispensable AA may not always predict the SID of indispensable AA in canola and rapeseed products. The DE and ME in 00-rapeseed expellers are greater than in 00-rapeseed meal. The difference in oil removal efficiency between the mechanical press and the solvent extraction procedure may be the reason for differences in the concentration of AEE and GE between 00-rapeseed expellers and 00-rapeseed meal, and consequently affect energy digestibility between 00-rapeseed products. The concentration of AEE can be used to predict the concentration of GE, and the concentration of GE and CP may be used to partly predict the DE and ME in canola and rapeseed products when used in diets fed to growing pigs. However, growing location and oil extraction procedure do not affect P digestibility in canola meal and 00-rapeseed products, but addition of microbial phytase to diets containing canola meal, 00-rapeseed meal, or 00-rapeseed expellers will result in increased digestibility of P.

In conclusion, more canola meal than 00-rapeseed meal and 00-rapeseed expellers can be used in pig diets considering that the tolerance level of glucosinolates in pig diets is 2 µmol/g. The digestibility of CP, AA, and energy in canola meal and 00-rapeseed meal are not different, but the values are influenced by oil extraction procedures. The chemical composition can partly predict the nutritional value in canola meal and 00-rapeseed products. However, more research is needed to develop equations to predict digestibility of nutrients in canola meal and rapeseed products from different sources.