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Nutritional Characterization of Canola Co-products for Swine

by

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Dedication

This thesis is dedicated to my beloved mother and husband

ABSTRACT

The nutritional value of biodiesel co-products were studied for swine. In Exp. 1, expeller-pressed canola meal was nutritionally characterized and validated for grower-finisher pigs. Expeller-pressed canola meal provided adequate energy and AA; ADG was reduced 3 g/d per 1% expeller-pressed canola meal inclusion in diets formulated to equal NE and SID AA, due to 5 µmol/g dietary glucosinolates. In Exp. 2, cold-pressed canola cake samples from 4 different processing conditions were tested against expeller-pressed canola meal and seed in a digestibility study. Higher residual oil in the cake increased the DE and NE content. In Exp. 3, 15% of either solvent-extracted or expeller-pressed canola meal with or without 5% glycerol was tested against a soybean meal diet for weanlings. Solvent-extracted or expeller-pressed canola meal, or in combination with 5% glycerol can partially replace soybean meal in weaner diets formulated to equal NE and SID AA content without affecting growth performance.

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LIST OF ABBREVIATIONS

AA	Amino acid
ADF	Acid detergent fiber
ADFI	Average daily feed intake
ADG	Average daily gain
AID	Apparent ileal digestibility
ATTD	Apparent total tract digestibility
BW	Body weight
CAD	Canadian dollar
CP	Crude protein
CVB	Centraal Veevoederbureau
DE	Digestible energy
DF	Dietary fiber
DM	Dry matter
EP	Expeller-pressed
G: F	Gain to feed ratio
GC	Gas chromatography
GE	Gross energy
ME	Metabolizable energy
N	Nitrogen
NDF	Neutral detergent fiber
NE	Net energy
NRC	National Research Council

NSP	Non-starch polysaccharide
SAS	Statistical analysis system
SEM	Standard error of the mean
SID	Standardized ileal digestibility
VFA	Volatile fatty acid(s)

Chapter 1. Literature Review

1.1 Introduction

In an effort to reduce dependence on petroleum-based fuel products and reduce their negative impact on the environment (Hill et al., 2006), production of biodiesel from renewable energy sources has experienced explosive growth (Kerr et al., 2007). Canola meal and glycerol are the main co-products of the Canadian biodiesel industry. The sustainability and profitability of the biofuel industry depend on the value and market of biodiesel and co-products. Co-products without market have no value, and add to the costs and not the income of biofuel production. Economic stimulus indicated that in addition to the price of biodiesel, prices of the feedstock and the meal are the most important factors in the profitability of biodiesel production (Weber, 1993). Therefore, the value of biodiesel co-products must be characterized and validated to maximize the profitability of the biodiesel industry.

With concerns of environmental pollution, consumer acceptance of go-green concepts, and high prices of fossil fuels production, use of biofuel is promoted globally. The use of biofuel as an alternative source of transportation energy is promoted via national and international legislation and protective measures because; biofuel production enhances sustainability and economic growth (Bezergianni and Kalogianni, 2009). Given the dependence of biofuel production on natural systems, demonstrating that production proceeds in an environmentally sound and sustainable manner is essential for its success (Hecht et al., 2009). The conversion of biomass to transportation fuel involves many steps from growing,

harvesting, transporting, and converting the feedstock to finally distributing and using the end product as a fuel (Hecht et al., 2009). Global production of biofuels is booming because high oil prices and technological breakthrough have made this business a profitable one (Forge, 2007).

The biodiesel industry was promoted in various countries with different objectives. Europe is the global leader in biodiesel production (Phan and Phan, 2008). Biodiesel production and commercial use in the European Union (EU) has expanded due to the EU's Common Agricultural Policy that enables farmers to receive a premium for growing industrial oil seeds on set aside land (United States Department of Agriculture, 1995). Reducing greenhouse gas emissions, boosting the decarbonisation of transport fuels, diversifying fuel supply sources, offering new income opportunities in rural areas, and developing long-term replacement for non-renewable fossil fuels is the aim of this policy (European Commission, 2006). In the EU, 185 biodiesel plants existed in 2008 with a production capacity of about 11.2 million metric tonnes and another 58 plants were under construction (Phan and Phan, 2008). In Canada and USA, the biodiesel industry developed more recently than its fuel ethanol counterpart and experienced a period of rapid growth in 2006 and 2007. Returns were attractive and many new plants were constructed (Wisner, 2009). Most biofuel production in North America today is corn-based ethanol. Most of this ethanol is used as an additive in petroleum-based gasoline, producing a blend of 90% gasoline and 10% ethanol (Federick, 2008). In USA in 2006, the minimum biofuel consumption level was set at 15 billion liters, with expectations of doubling consumption by

2012 (Groesbeck et al., 2008). Furthermore, 105 biodiesel production facilities were operating in the USA in 2008 and 77 facilities were in the planning or construction stage. Higher world crude oil and refined petroleum products prices provide incentives for both developed and developing countries to seek to increase production of ethanol and other biofuel (Shapouri, 2007).

1.2 Biodiesel production

Various definitions of biodiesel are available in the published literature. Biodiesel is an alternative to petroleum diesel that can be commercially produced through transesterification of vegetable oils or animal fats using methanol or ethanol with an alkaline or acidic catalyst (Marchetti et al., 2007; Shu et al., 2007; Groesbeck et al., 2008). Biodiesel, however, is not always accepted for use in blends with conventional diesel fuel for transportation applications (Sarin et al., 2007). Biodiesel is defined as a diesel equivalent, processed fuel, derived from biological sources of which the most common are tallow, yellow grease or vegetable oils (AAFC, 2006).The properties of the biodiesel are decided by the structure of the fatty acid methyl esters that constitute biodiesel (Knothe, 2005; Knothe and Steidley, 2005; Agarwal, 2007; Yuan, 2009).

Chemistry of biodiesel

Biodiesel can be produced by a variety of esterification technologies, using new or used vegetable oils and animal fats as initial feedstock (Kerr et al., 2007; Galan et al., 2009). In general, fats and oils are filtered and preprocessed to

remove water and contaminants, followed by mixing with an alcohol and catalyst (Soni, 2007). This chemical reaction causes the oil molecules (tryglicerides) to be broken apart into methyl esters and glycerin, which are then separated from each other and purified [Organization for Economic Cooperation and Development (OECD), 2008]. The continuous flow process requires only the stoichiometric amount of alcohol, while the batch process requires an excess of at least 75% to drive the reaction to completion (Bender, 1999). However, 60% of the excess alcohol can be recovered (Noordam and Withers, 1996). Biodiesel is the name given to these esters when they are intended for use as fuel (Kerr et al., 2007).

Feedstock used in biodiesel industry

Feedstocks used in biodiesel production depend on their availability in a particular country or a region. Biodiesel is made from renewable feedstocks such as vegetable oils or animal fats. Biodiesel can be manufactured from a wide range of feedstock including vegetable oils such as soybean, cottonseed, rapeseed, sunflower seed, peanut, sesame, palm, palm kernel, olive, and coconut oil (Wisner, 2009). Approximately half of the biodiesel industry can use any fat or oil feedstock, including recycled cooking grease; while the other half of the industry is limited to vegetable oils, the least expensive of which has been soy oil (Kerr et al., 2007). In North America, the most common feedstock for biodiesel is soybean oil or yellow grease and tallow (AAFC, 2007; Sarin et al., 2009) because of their widespread of availability (Wisner, 2009). In Canada, soy, canola and yellow greases are of primary use as inputs to the biodiesel process (Bell et al., 2007). In

Montreal, biodiesel is being produced from yellow grease and tallow while in Nova Scotia fish biodiesel is burned in diesel engines (AAFC, 2006). Rapeseed is the most common feedstock for biodiesel production in Europe and palm oil is being exploited in South East Asia (AAFC, 2007; Sarin et al., 2009). Sunflower seed oil was one of the most expensive oils in EU while rapeseed oil is the cheapest (AAFC, 2006). Used cooking oil collected from restaurants and (or) homes, with a price at least 2–3 times lower than virgin vegetable oils is another feedstock for biodiesel production (Zhang et al., 2003). To explore additional oil resources, other non-traditional oil seeds have been screened for their potential as biodiesel feedstock. Possible feedstock for biodiesel include oils from "Drumstick" seeds (*Moringa oleifera)* (Rashid et al., 2008), sesame (*Sesamum indicum)* seed (Saydut et al., 2008), and almonds (Terminalia catappa L) (dos Santos et al., 2008).

Canola production

Canola is the major oil seed crop in Canada. Annual Canadian canola production averaged 6.4 million tonnes from 1999 to 2003. The goal of the Canola Council of Canada (CCC) is to increase annual production to 7.0 million tonnes on a sustainable basis (CCC, 2007). Each year, approximately 5% of total biodiesel production is off-grade, low-quality canola, which is available for use as a biodiesel feedstock (Riley, 2004). More than 52,000 Canadian farmers grow canola, generating economic activity of $1.4 billion in Ontario and Quebec and $7.5 billion in western Canada (CCC, 2007). In Canada, the 10-year average is

11.3 million acres harvested. Canadian canola production would have to increase to about 14 metric tonnes annually to meet the demand (CCC, 2007). Canada is the largest single producer of canola.

Biodiesel industry in Canada

The Canadian biodiesel industry was promoted by federal and provincial government policies with the objectives of environmental protection and to provide economic opportunities for agriculture. Development of the biodiesel industry was initially encouraged in 2003 by the government exempting from federal excise taxes any biodiesel portion of a blended diesel fuel (Bell et al., 2007). The federal government intends to develop and implement a federal regulation requiring renewable fuels under the Canadian Environmental Protection Act (CEPA, 1999). Amendments to the Fuels Division of CEPA (1999) were proposed under Canada's Clean Air Act and are needed for an effective and efficient regulation. According to this regulation, the requirement would be an average annual renewable fuel content of at least 5% calculated based on the volume of biofuel, commencing in 2010. The requirement could be met by renewable content in either gasoline or diesel and heating oil pools. The federal government also intends to put in place by 2012 an additional requirement for an average 2% renewable fuel content in diesel fuel and heating oil, upon verification of renewable diesel fuel use under the range of Canadian weather conditions (Government of Alberta, 2006). Further support to the biofuel industry would come from federal government incentives, bio-energy producer credit

programme, bio-energy refining commercialization and market development program, bio-energy infrastructure development program, and excise tax exemption of 4 cents/L of biodiesel blending (Kujuwa and Robertson, 2007). The federal government was working with the provinces to develop an integrated national renewable fuels strategy and to fulfill the government commitment to achieve 5% average renewable content in Canadian transportation fuel by 2010 (AAFC, 2007).

Biodiesel production in Canada has showed progress during the past years. Canadian production of biodiesel was slowly coming on stream with the target of 5% renewable content in transportation fuels such as ethanol and biodiesel by 2010 (AAFC, 2006). Over the medium-term, biodiesel production in Canada is projected to rise to between 0.30 to 0.40 billion liters to support the mandate of 5% biofuel content. Most of the biodiesel manufactured in Canada has been exported to USA (AAFC, 2007). The annual Canadian diesel fuel market is approximately 25 billion liters in 2004, the industry depended upon the availability of off-grade canola seed to meet its needs in Western Canada (Riley, 2004). Theoretically, the potential of a local biodiesel industry is large in western Canada. The limited supplies of yellow grease and tallow, the successful expansion of biodiesel sector in Canada is dependent on securing supplies of oilseeds such as canola and soybean (AAFC, 2007). The feedstock supply assessment performed by BBI Biofuels Canada and Saville (2006) indicates that there is sufficient feedstock to support a number of canola-based biodiesel production facilities in Western Canada. Major activities of biodiesel and ethanol

will occur in Western Canada irrespective of grain availability (Racz, 2007). Biodiesel production in Eastern Canada has depended upon the availability of yellow grease and tallow from the restaurant and rendering industries there, and the limited supply of soybean oil (Riley, 2004). Current crushing operations in Canada are at capacity, and thus additional crushing capacity would be necessary if the canola based biodiesel industry is developed (BBI Biofuels Canada and Saville, 2006). These combined resources would allow for the production of approximately 2.5 billion liters of biodiesel fuel, or 10% of the total Canadian diesel fuel market (Riley, 2004). Increased canola yield and oil yield due to hybrid technology, extended acreage of crop due to rotational opportunities, would increase canola production to 13 to 14 million tonnes by 2015 and therefore there will be sufficient canola to support a renewable fuels standard (BBI Biofuels Canada and Saville, 2006). Therefore, Canadian biodiesel industry has a stable market and ample opportunities to grow in the future.

1.3 Processing of biodiesel from canola seed

The Canadian oilseed processing or the crushing industry consists of 13 crushing and refining/packaging plants, owned by 5 companies. Crush capacity in 2006 was 3.7 million tonnes, and was expected to increase to 5.7 by 2007, and to 7 million tonness in 2010 as several major new plants come on stream (CCC, 2007). Canola oil may be extracted using different methods depending on technology used at different crushing plants.

Canola oil extraction

Prior to oil extraction, canola seed that will be processed for oil and meal is preconditioned mildly using steam (heat and moisture) to improve oilflow during the subsequent oil extraction [Canola Info (CI), 2007]. Preconditioned seed is then crushed, flaked, and heated again slightly to maximize the oil recovery. Canola flakes are then pre-pressed by using screw presses or expellers (CI, 2007). If the oil is extracted using hexane extraction, pre-pressed canola flakes are used. Conventional processing of canola involves mechanical pressing and solvent extraction to separate oil and meal (Thobani and Diosdy, 1997), but the oil is further refined for human consumption.

Solvent extraction

Canola oil is extracted by using a solvent (hexane) to maximize oil recovery from the seed (Leming and Lamber, 2005). Hexane has long been the preferred solvent for extracting oil from oil-rich seeds (Fredrich et al., 1982) such as soybean and canola. Hexane extraction reduces the residual oil content of the pressed cake to very low levels, 2%. Solvent extraction process involves a 2-stage oil extraction process (Spragg and Mailer, 2007). An initial expeller extraction operating at 100 to 120°C produces a seed cake with approximately 20% oil (Eggers, 1985; Spragg and Mailer, 2007). This cake then undergoes solvent oil extraction using hexane, and subsequently a desolventising process, and toasting process reaching temperatures of 100 to 115°C (Spragg and Mailer, 2007). Oil recovery from canola seed is 96% when hexane extraction is used (CI, 2007).

Expeller pressing

Expeller pressing is a chemical-free method used to extract oil from oil seeds. The cleaned and flaked seeds are heated in a cooker for 20 to 25 min where the temperature is rapidly increases from 30 to 80ºC; at the end of the process the temperature is increased to 100 to 110ºC. Moisture content is initially reduced from 6 to 9%, and then down to 2 to 3%. Then oil is extracted in a rotating screw running in a cylindrical barrel (Leming and Lember, 2005). In some other oil extracting plants, seed is steam-conditioned and the expeller press is operated to optimize oil extraction, generating meal temperatures as high as 135°C. Some plants operate double-pass systems that reprocess seed cake to increase oil recovery (Spragg and Mailer, 2007).

Cold pressing

In cold-pressing, seed is directed straight to the mechanical screw press and temperature rises shortly to between 50 to 60ºC (Leming and Lamber, 2005; Spragg and Mailer, 2007) due to the heat generated within the press due to frictional forces (Spragg and Mailer, 2007). Cold pressing of canola seeds involves the similar steps as those used in hexane extraction except for heating the seed and the oil is solely removed solely mechanical pressing (CI, 2007). Oil recovery ranges from 75 to 85 % for cold pressing (CI, 2007).

From canola oil to biodiesel

Biodiesel is processed from crude canola oil (BBI Biofuels Canada; Saville (2006). The degummed, crude canola oil first undergoes transesterification. This is a base-catalyzed chemical reaction in which triglycerides (fats and oils) react with an alcohol (generally methanol) in the presence of an alkaline catalyst. As a result, a fatty acid methyl esters areformed liberating glycerol. Conversion rate depends on the process conditions and equipment; conversion of more than 99% may take anywhere from 10 min to 8 h.

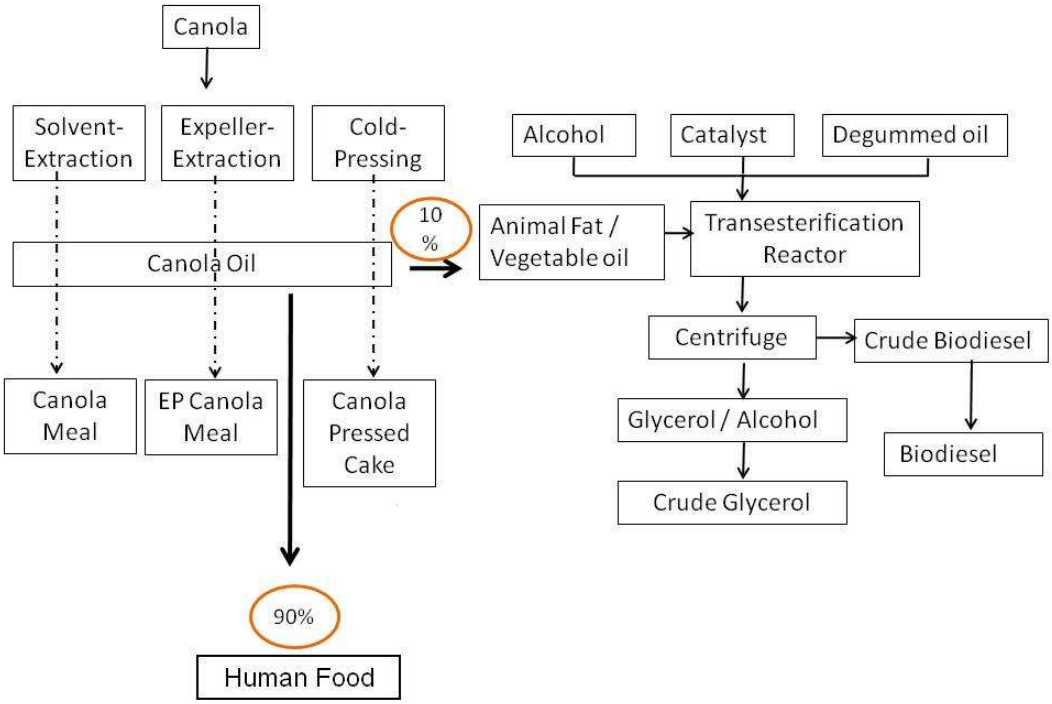

Fig 1.1 Conventional biodiesel production process (Adapted from BBI Bio fuel Canada and Saville, 2006)

The transesterification process forms a light, hydrophobic phase containing methyl esters and a heavy, hydrophilic or water-soluble phase. Even after phase separation, the ester rich phase still contains a small amount of methanol, traces of soaps and glycerol, catalysts and high boiling point components. The ester phase is then washed with water to remove water soluble substances. Small amount of acids are added to split any soaps present to avoid formation of emulsions. The washed ester is considered as wet with trace amount of moisture remaining removed by filtering through silicone bids column. Esters are dried using vacuum and then pumped into a storage tank.

1.4 Co-products from canola based biodiesel industry

Co-products of the biodiesel industry are canola meal and glycerol. Besides the importance of producing and using biofuel, other considerations such as availability of co-products are associated with the existing production processes (Bezergianni and Kalogianni, 2009). The price and availability of the co-product crude glycerol is an economic and environmental consideration (Bezergianni and Kalogianni, 2009). The products generated by a facility producing biodiesel from canola seed are fatty acid methyl esters, canola meal, and crude glycerol (BBI Biofuels Canada and Saville, 2006). From canola seed, canola oil is extracted using hexane extraction in large-scale biodiesel production and canola meal is the co-product (Spragg and Mailer, 2007). In small-scale or on-farm biodiesel production, oil is extracted mechanically by expeller pressing or cold pressing that produce expeller-pressed canola meal and cold-pressed canola cake, respectively

(Leming and Lamber, 2005). The primary co-product of the biodiesel production process is crude glycerol (Ma and Hanna, 1999; van Gerpen, 2005; Goesbeck et al., 2008) with 0.3 kg of crude glycerole generated for every gallon of biodiesel (Kerr et al., 2007). Worldwide, canola and rapeseed meal are the second most widely traded protein feedstuff used in livestock diets (Hickling, 2001) but, rapeseed meal is not an accepted feed ingredient in Canada and not listed in schedule IV of Feeds Act of Canada (Government of Canada, 2009). Local biodiesel production opens up opportunities for the livestock industry for co-products utilization.

Chemical compositions of biodiesel co-products

Chemical composition of canola based biodiesel co-products is different globally. Many factors influence the chemical composition of canola meal (Leming and Lember, 2005). The greatest differences are often seen in content of CP and ether extract and subsequently in GE content. These differences are most likely caused by various pressing technologies and conditions that are used in particular oil plant or in particular region. Pressing conditions and seed heating influence the effectiveness of oil removal and thereby also the nutrient content and quality of the resulting meal (Leming and Lember, 2005). The nutrient composition of canola meal is also affected by cultivar and growing conditions of the canola seed (Bell, 1993).

Table 1.1 Chemical composition of biodiesel co-products in DM basis

Item	Crude protein	Ether extract	Crude fiber	Ash	NDF	GE (Mcal/kg)	Reference
Solvent-extracted canola meal							
	39.6	3.9	14	7.9	-[1]	-	NRC, 1998
	41.8	3.8	11	8.2	-	-	Spragg and Mailer, 2007
Expeller-pressed canola meal							
	38.1	10.3	12.1	7.7	-	-	CVB, 1003
	41.8	5.9	-	-	23.8	-	Woyengo et al., 2009
	36.1	12.2	-	7.1	-	5.14	Leming and Lember, 2005
	38.9	Ng	-	-	-	4.66	Li et al ., 2002
	39.1	11.9	11.4	5.7	-	-	Spragg and Mailer, 2007
Cold-pressed canola cake							
	28	-	-	-	-	-	Van Barneveld, 2000
	28.3	19.7	-	-	-	-	Geier, 2004

[1]- = not provided.

Crude glycerol also differs in composition, crude glycerol contained 86% glycerin, 10% water, 3% NaCl, and a trace amount of free fatty acids on DM basis (Kerr et al., 2007). In a separate study, crude glycerol contained 87.0% glycerol, 9.2% moisture, 0.03% methanol, and 1.26% sodium on DM basis (Lammers et al., 2007). Pure glycerol has GE value of 4.1 Mcal/kg (Brambilla and Hill, 1966). In another study GE of 3.63Mcal/kg for crude glycerol was reported (Kerr et al., (2007).

Nutritional quality of biodiesel co-products

Expeller-pressed canola meal and cold-pressed canola cake have not been intensively studied in animal research. A DE content of 3.70 Mcal/kg (DM basis) was reported for expeller-pressed canola meal (Mullan et al., 2000). In the Dutch feedstuff tables, CP digestibility of expeller-pressed canola meal is listed as 75.0% (CVB, 2003). Expeller-pressed canola meal contained 41.1% of CP, 5.9% of ether extract, and 23.8% of NDF in a recent study (Woyengo et al., 2009).

Crude glycerol, a readily available energy source, may play an important role in meeting the energy needs of pigs as biodiesel production expands (Kerr et al., 2007; Lammers et al., 2007). Following digestion, intestinal absorption of glycerol is more than 97% in pigs (Bartelt and Schneider, 2002). Glycerol is water-soluble and can be absorbed at the stomach, but rate of absorption is slower than that of the intestine (Lin, 1977). Absorption rates are high due to its small molecular weight that facilitates passive absorption (Guyton, 1991). Some studies have assumed the ME of glycerol as ≥95% of GE in dietary formulation

(Rosebrough et al., 1980; Brambilla and Hill, 1996; Cerrate et al., 2006). Crude glycerol with 86.95% glycerol was determine to provide found 3.34 Mcal/kg of DE and 3.21 Mcal/kg of ME (Kerr et al., 2007). An increased diet energy digestibility was observed with glycerol inclusion in weaned pigs (Zijlstra et al., 2009).

Effects of biodiesel co-products on growth performances of pigs

German studies (Kijora and Kupsch, 2006; Kijora et al., 1995 and 1997) reported that up to 10% glycerol can be fed to pigs with little effect on growth performance in. Addition of 5% glycerol to diets of grower-finisher pigs did not affect growth performance (Mourot et al., 1994). Glycerol included at 10% did not affect ADG, ADFI, or G:F from d 0 to 19 post-weaning in pigs (Kerr et al., 2007). Adding crude glycerol may have positive effects on ADFI of weaned pigs (Groesbeck et al., 2008; Zijlstra et al., 2009). Up to 6% added crude glycerol has increased the pellet durability index (Groesbeck et al., 2008). Addition of glycerol to a meal diet containing hammer milled ground corn had improved flow ability of mash diets (McKinney, 2009).

1.5 Impact of high fiber and oil content of feedstuffs on nutrient digestibility in swine

Canola-based biodiesel co-products have high fiber content and mostly high residual oil content (Table 1.2). To use co-products in swine diet formulation, a

good understanding of the effects of high-fiber and oil on nutrient digestibility of swine is important.

Table 1.2 Carbohydrate components of canola meal (12% moisture basis)[1]

Component	Average
Starch	5.1
[2]Sugars	6.7
[2]Sucrose	6.2
[2]Fructose + glucose	0.5
Cellulose	4.5
Oligosaccharides	2.2
Non-starch polysaccharides	15.7
Soluble NSP	1.4
Insoluble NSP	14.4
Crude fiber	11.7
Acid detergent fiber	16.8
Acid detergent lignin	5.1
Neutral detergent fiber	20.7
Total dietary fiber	32.3

[1] Bell, 1993; Slominski and Campbell, 1990

[2] CCC, 2009

the effect of dietary fiber on digestibility of nutrients and the interaction of fiber with other nutrients are crucial to evaluate the present feed evaluation systems for their accuracy when a large amount of fiber is present in swine diets (Dégen et al., 2007).

Impact of high fiber content of feedstuffs on nutrient digestibility in swine

The effects of fiber on nutrient digestion of swine have been studied widely. The role of dietary fiber in pig nutrition has been investigated (Dégen et al., 2007), but the definition of fiber components keeps improving due to the development of new analytical and experimental (surgical) methods, research to understand the role of dietary fiber in pig nutrition is increasing (Souffrant, 2001). Numerous definitions for fiber exist. Now fiber was defined as a number of chemically different materials that cannot be digested by the endogenous enzymes of livestock (Dégen et al., 2007). Mostly the terms crude fiber, neutral or acid detergent fiber (NDF or ADF), or non-starch polysaccharides (NSP) are used (Varel and Yen, 1997). Dietary fiber may be defined as the sum of the polysaccharides and lignin that are not digested by the endogenous secretions of the gastrointestinal tract (Trowell et al., 1976). The substrates included in this definition are the structural polysaccharides associated with the plant cell wall (i.e., cellulose, hemicellulose, pectin), structural non-polysaccharides (i.e., lignin), and nonstructural polysaccharides, such as gums and mucilages secreted by the intestinal cells (Varen and Yen, 1997).

Fiber analyses have limitations. Depending on the relative contents of cellulose, hemicelluloses, pectins and lignin, crude fiber represents only a part of the fiber intake of animals (Van Soest, 1973). Even though swine do not produce enzymes capable of degrading dietary fiber (Varen and Yen, 1997), fiber must be considered as a factor in the overall energy-supplying system to the animal (Dierick et al., 1989). A reduction in nutrient digestion in the small intestine as a result of feeding fiber must be considered when evaluating the energetic significance of fiber fermentation in the hindgut (Dierick et al., 1989; Giusi-Perier et al., 1989; Mroz et al., 1996). Such effects may partially offset the significance of the VFA contribution to the overall energy supply of pigs (Li et al., 1990).

Microbial digestion of fiber

Fiber is degraded mainly in the hindgut due to microbial fermentation where resulting VFA are absorbed. Cellulases, hemicellulases, pectinases, and other enzymes secreted by microbial species involved in fiber degradation process and the degree of fermentation depends primarily on the source of dietary fiber and the presence of N, minerals, and vitamins that are essential for the overall nutrition of the microbial populations residing in the hindgut (Varen and Yen, 1997). High fiber diets enhance the number of cellulolytic bacteria in the colons of pigs. Bacteria populations may take 4 to 5 weeks to establish and stabilize in the gastrointestinal tract of swine (Anugwa et al., 1989), likely due to a slower bacterial growth rate related to more insoluble substances. These microorganisms are most numerous in the cecum and colon of nonruminants (Anugwa et al.,

1989). The lengthened residence time in the large intestine permits active bacterial fermentation of fiber and fiber digestion is inherently slower than that of non-fibrous dietary components (Wolin, 1981; Demeyer and DeGraeve, 1991). The final microbial fermentation products in the hindgut are the VFA, which mainly include acetate, propionate, and butyrate, and the gases H_2, CO_2, and CH_4 (Varen and Yen, 1997). The VFA are rapidly absorbed from the hindgut and may provide up to 30% of the maintenance energy requirements for growing pigs (Rérat et al., 1987; Yen et al., 1991) and even more for mature pigs (Varel, 1987). Although the fibrous components of feeds are fermented in the cecum and colon, they initially pass through the foregut and can have reduce or interfere on the utilization of other components such as protein of the diet (Dierick et al., 1989; Schulze et al., 1995).

Effects of high fiber on endogenous nitrogen losses

The effects of dietary fiber on digestive secretions in pigs have been studied. In pigs fed a high-fiber diet, more gastric, biliary, and pancreatic secretions are found than in pigs fed a low-fiber diet (Dierick et al., 1989). Dietary fiber can affect the digestive conditions in the stomach and small intestine even before it reaches the large intestine (Dégen et al., 2007). Nutrient digestion, especially for protein, AA, and minerals, is usually reduced when fiber is added to the diet (Eggum, 1995). The reasons behind the reduction in nutrient digestion are increased endogenous N losses (Li et al., 1990; Furuya and Kaji, 1992; Lenis et al., 1996; Yin et al., 2000) and the ability of fiber particles to bind some nutrients

and carry them into the hind gut where nutrient absorption is reduced (Lenis et al., 1996). Furthermore, mechanical erosion of the mucosal surface may increase loss of endogenous material.

Different fiber sources cause different ileal endogenous N losses in young pigs (Schulze et al., 1995). These losses could be due to physico-chemical properties of various fibers; soluble and insoluble dietary fibers affect the endogenous protein losses differently (Dégen et al., 2007). Pectin did not affect pancreatic juice and enzyme secretion (Mosenthin et al., 1994), but, insoluble NDF stimulated pancreatic digestive enzymes (Langlois et al., 1987). The endogenous N losses of the gastrointestinal tract must be significant in the case of a diet containing high amounts of soluble fiber due to increased viscosity (Dégen et al., 2007).

Effects of high fiber on rate of digesta flow

Some dietary fibers increase viscosity of the meal (Bach-Knudsen and Hansen, 1991; Noblet and Le Goff, 2001; Owusu-Asiedu et al., 2006). Thereby, the average retention time in the small intestine is increased (Bach-Knudsen and Hansen, 1991; Le Goff et al., 2002; Owusu-Asiedu et al., 2006) due to suppressed intestinal contractions (Cherbut et al., 1990). Endogenous N secretion is also increased (Li et al., 1990) as well because suppression of intestinal contractions leads to reduce mixing of dietary components with endogenous digestive enzymes (Johnston et al., 2003). The changes in the physical characteristics of the intestinal contents due to the presence of specific fiber components may influence gastric

emptying, dilute gastrointestinal enzymes and absorbable compounds in the gut and slow the diffusion or mobility of enzymes, substrates and nutrients to the absorptive surface (FAO, 1998). Fiber in the diet has physicochemical properties, such as a large water-holding capacity, that exert a diverse physiological action along the gastrointestinal tract. The amount of wet digesta flow at the terminal ileum of pigs fed a diet high in pea and pectin fiber was 5 to 6 times greater than in pigs fed a diet high-fiber than in pigs fed a low-fiber diet (Jørgensen et al., 1996). The extent to which fiber exerts these effects depends on its chemical nature, the way in which fiber is physically associated with other components, its concentration in the diet, the age and weight of the animals or their physiological state, and the transit time in the gastrointestinal tract (Varel and Yen 1997).

Effects of high fiber on protein digestibility

Effects of different dietary fibers on digestibility coefficients of CP and AA are varied. Inclusion of rapidly digestible NSP in pig diets may decrease digestibility of protein and AA (Mosenthin et al., 1994; Zervas and Zijlstra, 2002a). The reduction might be caused by pectin and other gel-forming polysaccharides that reduce absorbed AA and peptides, withholding them from absorption (Mosenthin et al., 1994). Dietary inclusion of NDF is also believed to negatively affect both the ileal and total tract apparent digestibility of protein and AA (Lenis et al., 1996; Yin et al., 2000; Dilger et al., 2004). However, approximately 10% or more inclusion of fiber did not reduce the protein digestibility further (Li et al., 1994). When dietary soluble NSP were increased by

3.2%, apparent ileal and total tract digestibility of protein were decreased by 0.14 units. In contrast, when insoluble NSP increased by 3%, apparent total tract digestibility of protein was decreased by 0.13 units (Bach-Knudsen and Hansen, 1991). This discrepancy indicated that solubility of NSP has an effect on digestibility of CP and AA. The lowest value for protein digestibility was measured when purified NDF was used in the diets and the reducing effect was greater when the soluble NDF increased in the fiber source (Dégen et al., 2007). The effects of various fiber components (e.g., soluble DF or insoluble DF) on digestibility are difficult to describe with certainty, because fibers are not homogeneous (Johnston et al., 2003). Effects of purified nutrients are different compared to nutrients present as constituents in feed, due to the interactions of nutrients (Dégen et al., 2007).

The possibility of potential interaction of fiber and protein on protein digestibility and on pig performance has been investigated. Dietary fiber and protein did not interact for N excretion or N retention (Kreuzer et al., 1998; Zervas and Zijlstra, 2002a, b), indicating that effects of NDF and CP were additive. With regard to apparent CP and AA digestibility, NDF did not interact with protein or AA (Fan and Sauer, 2002).

Some other factors affecting digestibility of fiber by pigs exist. Variability among individual animals (King and Taverner, 1975), restricted or ad libitum feeding, adaptation, age and live weight of the animal (Henry and Etienne, 1969; Gargallo and Zimmerman, 1981) are affected to digestibility of fiber. Level of fiber in the diet (Farrel and Johnson, 1972; Gargallo and Zimmerman, 1981) and

presence of other dietary components such as sugars (Skipitaris et al., 1957) also play a role.

Effects of high fiber on growth performance of pigs

Effects of high-fiber diets on growth performance of pigs have been studied. In theory, performance of growing and finishing pigs fed dietary fiber will not decline if formulations are such that pigs consume adequate amounts of NE, ileal digestible AA and other essential nutrients (Dégen et al., 2007). High fiber diets reduce weight gain in swine by reducing feed intake (Pond et al., 1989). High fiber not only reduces digestible energy intake, but also increases the basal metabolic rate of animal (Pond et al., 1988). Depression in ADG and feed efficiency with high fiber diets was observed during the first 17 d indicating that the adaptation to the high fiber diets by continued feeding in swine (Anugwa et al., 1989).

High fiber diets may be associated with gastrointestinal tract hypertrophy and reducing dressing percentage (Kass et al., 1980; Pekas et al., 1983; Pond et al., 1989; Bohman et al., 1955). Cellulolytic bacteria (Varel, 1987) and campylobacter (Pond et al., 1989) are increased in the large intestine of pigs fed high fiber and high protein diets, respectively. High fiber diets (containing 16.2% of ADF) have increased the relative weight of liver compared to control pigs which were fed 4.5% ADF (Anugwa et al., 1989). Energy expenditure by the metabolically active tissues such as liver, gut and kidneys is much higher than energy expenditure associated with the carcass (Baldwin et al., 1980). Therefore,

high dietary fiber and protein indirectly increase the animal's maintenance requirement by causing a repartitioning of nutrients from the growth of the edible carcass tissues to the visceral organs, consequently increasing visceral organ mass (Anugwa et al., 1989). The increase in organ mass and gastro-intestinal tract hypotrophy reduced dressing percentage at slaughter, which has negative economic consequences for the swine producers.

Impact of high oil content of feedstuffs on nutrient digestibility in swine

In practice, fibrous diet components dilute nutrients in feed. Therefore, a high-fiber pig diet is usually supplemented with fat or oil to compensate for the energy dilution (Dégen et al., 2007). Pigs performed worse when offered diets with a similar calculated NE supply but composed of by-products plus supplementary (animal) fat, compared to pigs given diets based on cereals or by-products without supplemented fat (Jongbloed et al., 1986; Bakker, 1996). Fats and oils are important dietary ingredients due to their high energy value, and their fatty acid pattern is reflected in that of monogastric animal products (Duran-Montagé et al., 2007).

Fiber has an effect on fat digestibility. Due to the high energy content, dietary fat contributes significantly to the energy content of feed. Therefore, the depressive effect of fiber on fat digestibility reduces the DE content of the diet (Dégen et al., 2007). The impact of the NDF fraction is significant, considering that each g of NDF per kg DM depresses the digestible fat content by 0.02 g digestible fat/kg DM (Noblet and Perez, 1993; Noblet and Le Goff, 2001). Chain

length, degree of saturation of fatty acids and their arrangement within the triglyceride molecule are important factors in determining the degree of fat digestibility in chicks (Calloway et al., 1956) and pigs (Eusebio et al., 1965). Fat also influence nutrient digestibility by altering intestinal morphology; dietary corn oil addition shortened the villus length of young pigs (Cera et al., 1988). Pigs performed better on diets containing either soybean oil**,** choice white grease, or coconut oil than on diets containing tallow (Turlington, 1988). Dietary fat absorption depends on the fatty acids present in the diet (Renner and Hill**,** 1961).

Interaction of high fiber and oil in diets on nutrient digestibility in swine

Interactions occur between dietary fiber and fat if both nutrients are presented in the diet at high concentrations (Noblet and Shi, 1994; Bakker, 1996). For example, 70 g/kg of additional animal fat reduced energy supply prior to the caecum by 2 and 5%, by combining fat in the diets with 270 g/kg soy hulls or 260 g/kg cellulose, respectively (Bakker, 1996). A combination of rapeseed oil and a 'fiber mixture' (wheat bran, soybean hulls, sugar beet pulp, and wheat straw) resulted in a higher measured ileal DE supply than was calculated (Noblet and Shi, 1994). The difference between the 2 results may be explained by either vegetable oil vs. animal fat or pure vs. 'mixed' fiber being used (Dégen et al., 2007). Also, the addition of 10% fat increased the energy density of the diet and depressed voluntary feed intake (Li et al., 1990).

Soluble NSP depresses the digestibility of fat by means of changing the viscosity of the digesta (Dégen et al., 2007). The extent of in vitro lipolysis with

gastric and pancreatic lipase was significantly decreased by emulsion prepared in the presence of high viscosity guar gum compared with that obtained without fiber or with low or medium viscosity guar gum (Pasquier et al., 1996). Insoluble NSP reduces the transit time of the digesta in the total tract due to the faster flow in the hindgut and may result in a shorter time for digestive enzyme action (Dégen et al., 2007). Increased dietary fiber may reduce apparent total tract digestibility of fat (Dégen et al., 2007) due to fatty acid incorporation into bacteria in the hindgut (Dierick et al., 1990; Le Goff and Noblet, 2001). High fiber diet studies reduced total tract, but not ileal digestibility of fat (Bach Knudsen and Hansen, 1991; Mroz et al., 1996). Some fibrous components absorb bile acids in the digesta, leading to the prevention of absorption of fatty acids and enhancing fecal excretion of these derivates as reviewed by Kreuzer et al (2002). This mechanism may also explain decreased fat digestibility, because of less emulgence in the small intestine due to the binding of bile acid (Dégen et al., 2007). Increased solubility of dietary fiber increased the total tract digestibility of fat (Hogberg and Lindberg, 2004). Ileal digestibility of fat was 0.04 and 0.07 units lower than expected when 70 g/kg fat was added diets containing 270 g/kg soy hull or 260 g/kg cellulose (Bakker et al., 1995). Therefore, fermentable NSP and fat affect each other's total tract digestibility (Bakker, 1996).

1.6 Summary

Canola meal and glycerol are the main co-products of the Canadian biodiesel industry. Sustainability and profitability of the biofuel industry depend on the

value and market of biodiesel and co-products. Co-products without market have limited or no value, and add to the cost of biofuel production. Biodiesel is made from renewable feedstocks such as vegetable oils or animal fats. Depending on the technology used at different crushing plants solvent extraction, expeller pressing and cold-pressing are practiced for oil extraction. Therefore, solvent extracted canola meal, expeller-pressed canola meal and cold-pressed canola cake are produced as co-products, respectively. During the transesterferication step of the biodiesel production, crude glycerol is produced as a co-product. Nutritional qualities of canola based biodiesel co-products have not been intensively studied in swine. Canola based biodiesel co-products contains high fiber and oil contents. The effect of fiber on nutrient digestion of swine has been studied widely. Fiber is degraded mainly in the hindgut due to microbial secretions and then VFA absorbed. In practice, fibrous diet components dilute nutrients in feed. High fat diets also have a negative effect on fiber digestibility. High fat contents in diet reduce the hindgut fermentation which leads to reduction in fiber digestion. Energy evaluation systems such as DE, ME and NE are based on digestible nutrient profile present in the diet. Therefore, it is always recommended to use NE values and SID AA in swine diet formulation. Nutritional qualities of canola based biodiesel co-products are not intensively studied in swine research. Therefore in order to use the canola based biodiesel co-products in swine diet formulation, nutritional characterization and validation of these co-products are necessary.

In total, 3 studies were conducted to address the gap in knowledge. Study 1 was conducted to characterize the nutritional value of expeller-pressed canola meal in 2 animal experiments: digestibility and performance. The hypotheses of the studies were that expeller-pressed canola meal has a valuable energy and digestible AA content and that feeding expeller-pressed canola meal would result in equal growth performance if diets were formulated using NE and SID AA. Potential changes in carcass characteristics and fatty profile by feeding EP canola meal could be reduced by feeding decreasing graded levels of EP canola meal. The objectives were to determine the DE and NE content and digestibility AA profile of expeller-pressed canola meal using ileal-cannulated pigs (Exp. 1) and to evaluate growth performance and carcass characteristics of grower-finisher pigs fed 0, 7.5, 15, and 22.5% and decreasing graded levels of expeller-pressed canola meal (Exp. 2).

For study 2, residual crude fat content of cold-pressed canola cake was assumed to vary among processing conditions. The hypothesis of the second study was energy and AA digestibility of cold-pressed canola cake produced under different processing conditions were varied and AA and energy digestibility of cold-pressed canola meal would different from that of expeller-pressed canola meal with or without whole canola seed. The objectives of this study were to characterize the effect of processing condition on AA and energy digestibility of cold- pressed canola cake and to compare cold-pressed canola cake to expeller-pressed canola meal with or without whole canola seed.

For study 3, effect of inclusion of crude glycerol in weaned pig diets as a means of increasing energy content of solvent-extracted canola meal was studied. The hypothesis tested in this study was that diets containing solvent-extracted and expeller-pressed canola meal with or without glycerol could be fed in diets formulated to equal NE and SID AA content to weaned pigs without negative effects on growth performance. The objective of the study was to measure growth performance and apparent total tract digestibility of energy and protein in weaned pigs fed four diets containing combination of glycerol and solvent-extracted canola meal and expeller-pressed canola meal in comparison to a control soybean diet.

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Chapter 2. Nutritional value of expeller-pressed canola meal for grower-finisher pigs

2.1 Abstract

Expeller-pressed (EP) canola meal contains more residual oil than solvent-extracted canola meal, and might thus be an attractive feedstuff for swine, but has been poorly characterized. In Exp.1, 6 ileal-cannulated barrows (36 kg BW) were fed at 3 x maintenance either a 44% EP canola meal or N-free diet in a cross-over design to measure energy and AA digestibility and calculate standardized ileal digestible (SID) AA and NE content. In 10-d periods with sequentially a 5-d diet adaptation, a 2-d feces and 3-d digesta collection, 6 observations per diet were obtained. The EP canola meal contained 38.5% CP, 13.3% ether extract, 2.42% Lys, 1.54% Thr, 0.62% Met, and 23.2 µmol/g glucosinolates (DM basis). Apparent total tract energy digestibility was 75.0% and the calculated DE and predicted NE content was 3.77 and 2.55 Mcal/kg (in DM), respectively. The SID AA content (% DM) was 1.77% Lys, 1.04% Thr, and 0.52% Met. In Exp. 2, 1,100 pigs (25 kg BW) housed in 50 pens were fed 5 dietary regimes with 0, 7.5, 15, and 22.5% or decreasing graded levels (22.5, 15, 7.5, and 0%) of EP canola meal over 4 growth phases to validate performance, carcass characteristics, and the NE system. Diets were formulated to equal NE:SID Lys for each growth phase (g/Mcal; 4.04, d 0 to 25; 3.63, d 26 to 50; 3.23, d 51 to 77; 2.83, d 78 to 90). At slaughter, carcass characteristics were measured for all pigs and jowl fat was sampled for 2 pigs per pen. For d 51 to 90, 22.5% EP canola meal was reduced to

18% due to decreased ADFI in phases 1 and 2. Overall (d 0 to 90), increasing dietary EP canola meal linearly decreased ($P < 0.001$) ADG and ADFI and linearly increased ($P < 0.01$) G:F. For 0 and 22.5/18% EP canola meal, respectively, ADG was 978 and 931 g/d, ADFI was 2.77 and 2.58 kg/d, and G:F was 0.366 and 0.378. Increasing dietary EP canola meal did not alter carcass backfat thickness, loin depth, or jowl fat fatty acid profile. Pigs fed 22.5/18% EP canola meal reached slaughter weight 3 d after ($P < 0.05$) pigs fed 0% EP canola meal. In conclusion, EP canola meal provided adequate energy and AA; however, ADG was reduced 3 g/d per each 1% of EP canola meal inclusion in diets formulated to equal NE and SID AA, likely due to high dietary glucosinolates. Thus, inclusion level of EP canola meal in swine diets should be targeted to an expected growth performance and carcass quality. Finally, the NE system did not accurately predict growth for diets with EP canola meal with a high content of ether extract and glucosinolates.

2.2 Introduction

With the increasing cost of feed energy, alternative energy-supplying feedstuffs should be explored. Canola meal has traditionally been fed as a protein source, but its low in available energy, partly due to efficient (95%) oil extraction using mostly solvents in crushing plants (Spragg and Mailer, 2007). In contrast, canola oil can be extracted using an expeller press without solvents, but oil removal is less efficient (75%). Hence, expeller-pressed (EP) canola meal

contains 10 to 15% oil (Leming and Lember, 2005) that may provide additional energy in swine diets, and might also be a valuable AA source.

Limited information exists about the nutritional value of EP canola meal (Leming and Lember, 2005). The ME content of EP canola meal is higher than that of solvent-extracted canola meal (Smulikowska, 1997, 2006). The EP canola meal was included at 10 to 18% in diets for individually-housed grower-finisher pigs without detrimental effects on growth performance and minor effects on carcass characteristics (Brand et al., 2001). These results must be validated in group-housed pigs. Feeding diets containing an unsaturated fat source can reduce pork fat quality (Whitney et al., 2006). Canola oil is rich in unsaturated fatty acids (Rowghani et al., 2007), and high dietary inclusion of EP canola meal may thus soften the fat.

The hypotheses were that EP canola meal contained valuable energy and AA and that feeding EP canola meal would result in equal growth performance if diets were formulated using NE and SID AA. Potential changes in carcass characteristics and fatty acid profile by feeding EP canola meal could be mitigated by feeding decreasing graded levels of EP canola meal. The objectives were to determine the DE and NE content and digestible AA profile of EP canola meal using ileal-cannulated pigs (Exp. 1); and to evaluate growth performance and carcass characteristics of grower-finisher pigs fed 0, 7.5, 15, and 22.5% and decreasing graded levels of EP canola meal (Exp. 2).

2.3 Materials and methods

Experimental Design and Diets

In Exp. 1, the EP canola meal diet contained 44% EP canola meal and the ratio of corn starch, sugar, and canola oil was identical to the N-free diet (Table 2.1) to measure energy digestibility of EP canola meal (Stein et al., 2006). In the EP canola meal diet, EP canola meal was the sole source of CP and AA. The N-free diet was used to estimate basal ileal endogenous losses of AA (Stein et al., 2006). Chromic oxide was included as an indigestible marker. Diets were formulated to meet or exceed vitamins and mineral requirements (NRC, 1998). One sample of EP canola meal was obtained from Associated Proteins, Ste. Agathe, Manitoba, Canada.

Table 2.1. Ingredient composition and nutrient content of diets used in Exp.1

Ingredient, %	EP canola meal	N-free
Cornstarch[1]	48.63	85.32
EP canola meal[2]	44.00	-
Sugar	2.85	5.00
Solka floc[3]	-	3.00
Canola oil	1.14	2.00
Limestone	1.50	1.00
Mono/di Ca phosphate	-	1.20
Salt	0.50	0.50
Mineral premix[4]	0.50	0.50
Vitamin premix[5]	0.50	0.50
Chromic oxide	0.38	0.38
K_2CO_3	-	0.50
MgO 58%Mg	-	0.10
Analyzed nutrient content (% of DM)		
Moisture	6.04	10.35
CP	17.21	0.57
Ether extract	7.10	0.66
Crude fiber	6.40	2.14
Ca	0.91	0.64
P	0.48	0.25
AA		
Ala	0.75	0.03

Arg	1.03	0.01
Asp	1.23	0.03
Cys	0.38	0.02
Glu	3.00	0.09
Gly	0.85	0.02
His	0.45	0.01
Leu	1.22	0.05
Lys	1.01	0.02
Met	0.32	-
Phe	0.68	0.01
Pro	0.98	0.06
Ser	0.66	0.02
Thr	0.71	0.01
Trp	0.22	0.02
Tyr	0.46	0.01
Val	0.87	0.01

[1]Melojel (National Starch and Chemical Co., New York, NY).

[2]EP canola meal is expeller-pressed canola meal.

[3]International Fiber Corp., New York, NY.

[4]Provided the following per kilogram of diet: Zn, 100 mg as $ZnSO_4$; Fe, 80 mg as $FeSO_4$; Cu, 50 mg as $CuSO_4$; Mn, 25 mg as $MnSO_4$; I, 0.5 mg as $Ca(IO_3)_2$; and Se, 0.1 mg as Na_2SeO_3.

[5]Provided the following per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine,1 mg; D-biotin, 0.2 mg; and vitamin B_{12}, 0.025 mg.

In Exp.2, the effect of including EP canola meal at 7.5, 15, or 22.5% was tested together with a control dietary regimen based on soybean meal (0% EP canola meal; Table 2.2 and 2.3). The Exp. was conducted over 4 growth phases. A fifth dietary regimen was formulated with gradually decreasing, graded levels of EP canola meal (22.5, 15, 7.5, and 0%) over the 4 phases. Within each phase, diets were formulated to be iso-caloric and iso-lysinic with a constant ratio of Thr, Met, Cys, and Trp to Lys. The main ingredients were corn, wheat, barley, distiller's dried grains with soluble (DDGS), EP canola meal, and soybean meal. Diets were fortified with premixes to meet the trace mineral and vitamin requirements (NRC, 1998).

Experimental Procedures

The animal protocols were approved by the University of Alberta Animal Care and Use Committee for Livestock, and followed guidelines established by the Canadian Council on Animal Care (CCAC, 1993). The digestibility experiment was conducted at the Swine Research and Technology Centre at the University of Alberta (Edmonton, Alberta, Canada). The growth performance study was conducted at Drumloche Research Farm (Lougheed, Alberta, Canada).

Exp. 1 Digestibility Study

Two diets were tested over 6 experimental periods using cannulated grower-finisher pigs. Six cross-bred barrows (Duroc sire x Large White /Landrace F_1; Genex Hybrid; Hypor, Regina, Saskatchewan, Canada; initial BW, 36.2 ± 1.9 kg;

Table 2.2. Ingredient composition and nutrient content of the phase 1 and 2 diets, Exp. 2[1]

	Phase 1, % EP canola meal[2]				Phase 2, % EP canola meal			
Ingredient, %	0	7.5	15	22.5	0	7.5	15	22.5
Wheat	34.60	30.82	26.92	23.03	34.72	30.94	27.04	22.48
Corn	30.00	30.00	30.00	30.00	35.00	35.00	35.00	35.00
EP canola meal	-	7.50	15.00	22.50	-	7.50	15.00	22.50
DDGS blend[3]	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Soybean meal	15.76	11.70	7.66	3.61	11.54	7.48	3.44	-
Limestone	1.30	1.32	1.40	1.48	1.26	1.27	1.35	1.43
Canola meal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tallow	1.03	1.40	1.81	2.21	0.30	0.67	1.07	1.55
Salt	0.44	0.43	0.43	0.43	0.48	0.48	0.48	0.48
L-Lys HCl	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.33
Mono/di Ca phosphate	0.34	0.31	0.28	0.25	0.18	0.15	0.12	0.09
Premix[4]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Thr	0.04	0.03	0.01	-	0.03	0.02	0.01	-

$CuSO_4$	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Calculated content, (as fed)								
SID Lys, %	0.97	0.97	0.97	0.97	0.87	0.87	0.87	0.87
NE, Mcal/kg	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
CP, %	20.27	20.62	20.96	21.31	18.75	19.10	19.44	19.96
Ether extract, %	3.84	4.99	6.17	6.64	3.26	4.41	5.59	6.83
Ca, %	0.70	0.74	0.80	0.86	0.55	0.61	0.67	0.69
P, %	0.56	0.61	0.66	0.71	0.48	0.53	0.58	0.60
Available P, %	0.30	0.30	0.30	0.30	0.21	0.21	0.21	0.21
SID Lys/NE, g/Mcal	4.04	4.04	4.04	4.04	3.63	3.63	3.63	3.63

[1]Phase 1 diet was fed from 23 kg BW to 53 kg BW and Phase 2 diet was fed from 54 kg BW to 80 kg BW.

[2]EP canola meal is expeller-pressed canola meal.

[3]The DDGS was co-fermented from wheat and corn (Husky Energy, Lloydminster, Saskatchewan, Canada).

[4]Provided the following per kilogram of diet: Zn, 125 mg as ZnO; Fe, 100 mg as $FeSO_4$; Cu, 14 mg as $CuSO_4$; Mn, 25 mg as MnO; I, 0.3 mg as $Ca(IO_3)_2$; and Se, 0.3 mg as Na_2SeO_3; vitamin A, 6000 IU; vitamin D, 1000 IU; vitamin E, 25 IU; niacin, 20 mg; D-pantothenic acid, 12 mg; riboflavin, 4 mg; menadione, 2 mg; folic acid, 0.5 mg; thiamine,1 mg; D-biotin, 0.1 mg; and vitamin B_{12}, 0.02 mg.

Table 2.3. Ingredient composition and nutrient content of the Phase 3 and Phase 4 diets, Exp.2[1]

	Phase 3, % EP canola meal[2]				Phase 4, % EP canola meal			
Ingredient, %	0	7.5	15	18	0	7.5	15	18
Wheat	31.35	37.91	33.03	24.32	-	6.09	12.07	5.00
Corn	20.00	20.00	28.13	31.47	20.00	20.00	24.12	26.64
EP canola meal	-	7.50	15.00	18.00	-	7.50	15.00	18.00
Barley	24.59	14.65	5.65	8.01	60.76	48.38	30.88	32.44
DDGS Blend[3]	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Soybean meal	5.83	1.71	-	-	1.08	-	-	-
Limestone	1.20	1.26	1.33	1.37	1.11	1.18	1.26	1.29
Canola meal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Salt	0.46	0.46	0.47	0.47	0.43	0.44	0.45	0.45
L-Lys HCl	0.35	0.35	0.29	0.26	0.35	0.26	0.15	0.11
Mono/di Ca phosphate	0.09	0.05	-	-	0.17	0.08	-	-
Premix[2]	0.10	0.10	0.10	0.10	0.07	0.07	0.07	0.07
L-Thr	0.03	0.01	-	-	0.03	-	-	-

Calculated content, (as fed)								
SID Lys, %	0.76	0.76	0.76	0.76	0.65	0.65	0.65	0.65
NE, Mcal/kg	2.35	2.35	2.35	2.35	2.31	2.30	2.30	2.30
CP, %	17.12	17.75	18.66	18.95	14.64	16.25	18.12	18.47
Ether extract, %	2.77	3.53	4.44	4.93	2.89	3.63	4.43	4.90
Ca, %	0.60	0.65	0.71	0.74	0.55	0.61	0.67	0.69
P, %	0.49	0.54	0.59	0.62	0.48	0.53	0.58	0.60
Available P, %	0.24	0.25	0.24	0.24	0.21	0.21	0.21	0.21
SID Lys/NE, g/Mcal	3.23	3.23	3.23	3.23	2.81	2.83	2.83	2.83

[1]Phase 3 diet was fed from 81 kg BW to 95 kg BW and Phase 4 diet was fed from 96 kg BW to 118 kg BW.

[2]EP canola meal is expeller-pressed canola meal.

[3]The DDGS was co-fermented from wheat and corn (Husky Energy, Lloydminster, Saskatchewan, Canada).

[4]Provided the following per kilogram of Phase 3 diet: Zn, 125 mg as ZnO; Fe, 100 mg as $FeSO_4$; Cu, 14 mg as $CuSO_4$; Mn, 25 mg as MnO; I, 0.3 mg as $Ca(IO_3)_2$; and Se, 0.3 mg as Na_2SeO_3; vitamin A, 6000 IU; vitamin D, 1000 IU; vitamin E, 25 IU; niacin, 20 mg; D-pantothenic acid, 12 mg; riboflavin, 4 mg; menadione, 2 mg; folic acid, 0.5 mg; thiamine, 1 mg; D-biotin, 0.1 mg; and vitamin B_{12}, 0.02 mg; or 70% thereof in the Phase 4 diet.

initial age, 91 ± 7 d) were surgically fitted with a T-cannula at the distal ileum. The pigs were fed the 2 diets in a cross-over design to provide 6 observations per diet. Pigs were housed in individual metabolism pens (1.2 x 1.2 m) that allowed freedom of movement. Pens had a plastic-coated, expanded metal floor, polyvinyl chloride walls (0.9 m high) fitted with plexiglass windows (0.3 x 0.3 m), a single-space dry feeder, and a nipple drinker. To ovoid orts, daily feed allowance was set at 3 times the estimated maintenance requirement for energy (3 × 110 kcal DE/kg $BW^{0.75}$; NRC, 1998), which was fed divided into 2 equal meals at 0800 and 1600. Diets were fed as a dry mash and pigs had free access to water throughout the experiment. The 10-d experimental periods consisted of a 5-d acclimation to the experimental diets, followed by a 2-d collection of feces, and a 3-d collection of ileal digesta.

Feces were collected continuously with bags replaced a minimum of 2 times per day at 0800 and 1600 h. The plastic bags were attached to a ring system glued to the skin around the anus (Van Kleef et al., 1994). Digesta was collected for 12 h each for 3 consecutive d using bags containing 5% formic acid attached to the open cannula barrel for 10 h. Bags were removed whenever full or at least every 30 min. Collected feces and digesta were pooled by pig and frozen at –20°C. Before analyses, feces and digesta were thawed, homogenized, sub-sampled, and freeze-dried.

Exp. 2 Performance Study

The growth component of the study was evaluated for 90 d. In total, 1,100 cross-bred pigs (550 barrows and 550 gilts; Duroc sire (Designed Genetics Inc, Lockport, Manitoba, Canada) x Large White / Landrace; Line 277; Fast Genetics; Saskatoon, Saskatchewan, Canada) with an initial age of 64 d were used. Per gender, 25 pens with 22 pigs each were used. Average BW at d 0 was 22.6 ± 1.27 kg. Pigs were randomly placed within gender to pens and pens were blocked by BW to diet. Experimental diets were randomly allocated to pens of the same gender within block. Hence, 5 BW blocks were created and each block contained all 5 treatments for barrows and gilts separately for a total of 10 observations per diet. Upon arrival, pigs were fed a pre-grower diet for 5 d and then switched to the phase-1 diets on d 0.

The dimensions of the pens were 6.15 x 2.39 m. The flooring of the pen was fully-slated concrete, and the siding was concrete panels with open slotting. Each pen was equipped with 1 nose to nose wet/dry feeder (Crystal Spring Hog Equipment, Winnipeg, Manitoba, Canada) that was located halfway along the dividing wall between pens. One bowl drinker was located at the back of the pen. The room was ventilated using negative pressure and was maintained within the thermo-neutral zone for the pigs, with a 12-h (light 0700 to 1900 h), 12-h dark cycle. Pigs had free access to diets as a dry mash and water. Pigs were injected intramuscularly with porcine circovirus vaccine (Circumvent; Intervet Canada Ltd, Whitby, Ontario, Canada) 1 wk before and 1 wk after weaning.

Four test diet regimens (Table 2.2 and 2.3) with increasing level of EP canola meal were fed in 4 phases with change-over from 1 phase to the next after a fixed budget of the previous diet was consumed. During phases 1 and 2, dietary levels of EP canola meal were 0, 7.5, 15, and 22.5%, but in phases 3 and 4, dietary levels of EP canola meal were 0, 7.5, 15, and 18%. Diets for the decreasing graded feeding regimen contained 22.5, 15, 7.5, and 0% EP canola meal for phases 1 to 4, respectively. Pigs were weighed at the initiation of feeding the experimental diets (d 0), d 34, 64, 76, and 90. Feed was delivered to each pen, and feed added was tracked using a robotic feed delivery system (Feed Logic; Feed Logic Co., Wilmar, MN). Feed remaining in the feeder was estimated on weigh days for each pen by measuring feed left to the top of the hopper of the feeder. Pen data were used to calculate pen ADG, ADFI, and G:F.

Pigs were slaughtered at a commercial slaughter facility (Britco Pork Inc., Langley, British Colombia, Canada). Pigs were fed Phase-4 diets until reaching the predetermined market weight (118 kg); the first pigs reached market weight on d 90. The warm pig carcasses were graded for back fat and loin depth using the light-reflectance Destron PG-100 grading probe (Destron Technologies, Markham, Ontario, Canada). The probe was inserted between the 3rd and 4th last ribs, 7 cm off the mid-line of the carcass. Jowl fat samples were obtained from 2 pigs per pen, returned frozen to Edmonton, and dissected free of skin and meat prior to grinding and homogenization for 10 pen samples per dietary regimen.

Chemical Analyses

For Exp. 1, diets, EP canola meal, and freeze-dried digesta and feces were ground in a Retch mill (model ZMI, Brinkman Instruments, Rexdale, Ontario, Canada) over a 1-mm screen. The EP canola meal was analyzed for CP (method 984.13A-D; AOAC, 2006), ether extract (method 920.39A, AOAC, 2006), ADF (method 973.18*;* AOAC, 2006), NDF (Holst, 1973), total dietary fiber (method 985.29; AOAC, 2006), ash (method 942.05;AOAC, 2006), Ca (method 968.08; AOAC, 2006), P (method 946.06; AOAC, 2006), phytate (Method 986.11; AOAC, 2006), and available Lys (method 975.44; AOAC, 2006) at University of Missouri, Columbia, MO. Glucosinolate profile of EP canola meal was determined by GC analysis at POS Pilot Plant Corp, (Saskatoon, Saskatchewan, Canada) using the method of the Canadian Grain Commission developed by Heaney and Fenwick (1980) and modified by Daun and McGregor (1981). Diets, EP canola meal, and digesta were analyzed for AA content (method 982.30E; AOAC, 2006) and diets, EP canola meal, digesta, and feces were analyzed for DM (method 930.15; AOAC, 1990) at the University of Missouri, Columbia, MO. Chromic oxide in diets, digesta, and feces was determined using spectrophotometry (model 80-2097-62, KBUltraspec III; Pharmacia, Cambridge, UK) at 440 nm after ashing at 450°C overnight (Fenton and Fenton, 1979). The GE content of diets, EP canola meal, digesta, and feces was determined using an adiabatic bomb calorimeter (model 5003, IKA-Werke GMBH and Co KG, Staufen, Germany); benzoic acid was used as a standard. For Exp. 2, jowl fat was analyzed for fatty acid profile using GC (method 996.06; AOAC, 2006).

Calculations

For Exp. 1, the AID and apparent total tract digestibility values of the EP canola meal diet was calculated using the indicator method (equation 2; Stein et al., 2007; Appendix 1). For AA, the direct method was used, because EP canola meal was the sole ingredient contributing AA in the diet. Each pig while fed the N-free diet was used to calculate its own basal endogenous AA loss (equation 3; Stein et al., 2007). The SID for the AA in EP canola meal was calculated using the AID and the basal endogenous AA loss (equation 7; Stein et al., 2007). The SID AA content was calculated by multiplying the AA content in the ingredient by the corresponding SID. For energy, the difference method was used (Adeola, 2001) to calculate digestibility of EP canola meal using the ratio of corn starch, sugar, and canola oil in the N-free diet (Stein et al., 2006). The DE content was calculated using GE multiplied by its digestibility value. The NE content of EP canola meal was predicted using an equation (equation 4; Noblet et al., 1994), using analyzed nutrient and the determined DE content.

The lean yield of the carcass was calculated using the equation:

Lean % = 68.1863 - 0.7833 * Fat, mm + 0.0689 * Lean, mm + 0.0008 * Fat * Fat - 0.0002 * Lean * Lean + 0.0006 * Fat * Lean, developed by the Canadian Pork Council (CPC, 1994).

The iodine value of jowl fat was calculated using the equation (AOCS, 1998): C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723)

Feed cost and income over feed cost were calculated per pen and expressed per pig (Main et al., 2008). Pork value was CAD $1.30/kg dressed around the time the pigs were marketed.

Statistical Analyses

In Exp. 1, means and standard error were calculated using the Means procedure of SAS (SAS Inst. Inc., Cary, NC). In Exp. 2, data were analyzed using the MIXED procedure of SAS. Pen was considered the experimental unit. Block was the random effect in the model, and period was the repeated term solely for analyses of growth performance variables. Analysis of variance determined the differences among diets, gender, and the interaction between diet and gender and provided least squares means for each main effect for all dependent variables. Initial BW was only added to the model as a covariate to estimate BW. Linear and quadratic effects were tested by 2 contrast statements for diets with 0, 7.5, 15 and 22.5/18% EP canola meal, excluding the decreasing graded dietary regimen. Proc IML was used to create coefficients, because phases 3 and 4 had unequally-spaced inclusion of EP canola meal. Decreasing graded inclusions over the 4 growth periods were compared with the 0% EP canola meal (control) diet using a pre-planned contrast. Body weight at shipping was used as a covariate for analysis of carcass weight. Warm carcass weight was used as a covariate for analysis of carcass characteristics. To test the hypotheses, $P < 0.05$ was considered significant. If pertinent, trends ($0.05 < P < 0.10$) were reported.

2.4 Results

Chemical Characteristics and Nutrient Digestibility

The EP canola meal sample used for the present animal studies contained 38.5% CP, 13.3% ether extract, and 28.0% NDF (DM basis; Table 2.4). This sample contained 2.42% Lys and 2.16% available Lys or 96% availability. Total glucocinolate content was 23.2 µmol/g (DM basis).

The energy digestibility of the EP canola meal diet was 72.9% at the ileum and 85.1% for the total tract (Table 2.5). The AID of this diet was 72.1% for Lys.

The AID of energy of tested EP canola meal sample was 61.0% and the apparent total tract digestibility was 75.0% (Table 2.6). After the correction for basal endogenous losses, the SID was 73.2% for Lys.

The DE content of the EP canola meal was 3.77 Mcal/kg of DM. The calculated NE content was 2.55 Mcal/kg of DM (Table 2.7). The SID content was 1.77% for Lys, 1.04% for Thr, 0.52% for Met, and 0.39% for Trp (DM basis).

Table 2.4. Chemical content of expeller-pressed (EP) canola meal, Exp.1

Characteristic, % DM	EP canola meal
Moisture	4.4
GE, Mcal/kg	5.03
CP	38.5
Ether extract	13.3
Crude fiber	7.7
ADF	17.5
NDF	28.0
Total dietary fiber	27.0
Phytic acid	2.27
Ash	6.9
Ca	0.56
P	1.06
AA	
Ala	1.62
Arg	2.31
Asp	2.63
Cys	0.88
Glu	6.19
Gly	1.86
His	1.03
Ile	1.40

Leu	2.65
Lys	2.42
Met	0.62
Phe	1.51
Pro	2.20
Ser	1.41
Thr	1.54
Trp	0.47
Tyr	1.06
Val	1.90
Available Lys	2.16
Total glucosinolates, μmol/g[1]	23.2

[1]Contained the following glucosinolates (μmol/g of EP canola meal): 3-butenyl, 3.42; 4-pentenyl, 0.25; 2-OH-3-butenyl, 5.23; 2-OH-4-pentenyl, 0.08; CH_3-thiobutenyl, 0.16; phenylethyl, 0.21; CH_3-thiopentenyl, 0.08; 3-CH_3-indolyl, 0.39; 4-OH-3-CH_3-indolyl, 4.37; and total aliphatics, 8.99.

[2]EP canola meal is expeller-pressed canola meal.

Table 2.5. Apparent ileal and total tract digestibility of energy and apparent ileal digestibility of AA of the expeller-pressed (EP) canola meal diet in Exp.1

Chemical characteristic	EP canola meal diet	SEM
Energy digestibility, %		
Ileal	72.9	0.03
Total tract	85.1	0.02
AA digestibility, %		
Ala	70.4	0.04
Arg	81.8	0.03
Asp	70.7	0.06
Cys	71.8	0.07
Glu	83.7	0.02
Gly	60.3	0.09
His	80.9	0.02
Ile	73.4	0.04
Leu	78.0	0.03
Lys	72.1	0.03
Met	83.4	0.02
Phe	77.1	0.04
Pro	24.7	1.10

Ser	69.3	0.05
Thr	66.2	0.05
Trp	83.0	0.04
Tyr	74.1	0.05
Val	69.4	0.04

Table 2.6. Energy and standardized ileal AA digestibility of expeller-pressed (EP) canola meal

Chemical characteristic	EP canola meal	SEM
Energy digestibility, %		
Apparent ileal	61.0	0.16
Apparent total tract	75.0	0.02
Standardized ileal AA digestibility, %		
Ala	72.1	0.04
Arg	83.1	0.03
Asp	72.0	0.05
Cys	72.7	0.07
Glu	84.3	0.02
Gly	63.6	0.08
His	81.7	0.02
Ile	74.3	0.04
Leu	78.8	0.03
Lys	73.2	0.03
Met	83.9	0.02
Phe	78.0	0.04
Pro	35.2	0.80
Ser	70.6	0.04
Thr	67.6	0.05
Trp	83.9	0.04
Tyr	75.1	0.05
Val	70.5	0.04

Table 2.7. The DE, NE, and standardized ileal digestible (SID) AA content of the expeller-pressed (EP) canola meal

Chemical characteristic	EP canola meal
DE (Mcal/kg of DM)	3.77
NE (Mcal/kg of DM)	2.55
SID AA, % of DM	
Ala	1.17
Arg	1.92
Asp	1.89
Cys	0.64
Glu	5.22
Gly	1.18
His	0.84
Ile	1.04
Leu	2.09
Lys	1.77
Met	0.52
Phe	1.18
Pro	0.77
Ser	1.00
Thr	1.04
Trp	0.39
Tyr	0.80
Val	1.34

Growth Performance and Carcass Characteristics

During the experiment, 113 pigs were removed and excluded from analyses. Reasons were death (27%), lame (11%), twisted gut (7%), scours (6%), poor growth (6%), and tail biting (4%); removal appeared not related to dietary regimen.

Only the main factor dietary regime was described, because a dietary regimen by gender interaction on growth performance and carcass variables was not detected. Increasing the inclusion of EP canola meal linearly ($P < 0.001$) reduced pig BW at d 34, 64, 76, and 90 (Table 2.8). Pigs fed the highest inclusion of EP canola meal were 3.7 kg lighter at d 90. Pigs fed decreasing graded levels of EP

Table 2.8. Effect of feeding expeller-pressed (EP) canola meal on growth performance of grower-finisher pigs[1]

	EP canola meal, %						*P*-value		
Item	0	7.5	15	22.5/18[2]	Graded[3]	SEM	Linear	Quadratic	Graded vs. 0%
BW, kg									
d 34	54.5	53.8	53.6	53.0	53.6	0.27	<0.001	0.833	<0.001
d 64	83.8	82.3	80.6	79.4	80.7	0.67	<0.001	0.812	<0.001
d 76	97.2	95.5	93.7	93.2	94.3	0.61	<0.001	0.902	0.001
d 90	109.8	108.3	106.7	106.1	108.0	0.69	<0.001	0.980	0.901
ADG, kg/d									
d 0 to 34	0.931	0.906	0.909	0.866	0.898	0.01	<0.001	0.199	0.008
d 35 to 64	1.042	1.017	0.945	0.915	0.944	0.03	<0.001	0.867	0.002
d 65 to 76	0.952	0.932	0.907	0.958	0.961	0.02	0.475	0.099	0.715
d 77 to 90	0.988	0.998	0.972	0.983	0.975	0.02	0.327	0.684	0.281
d 0 to 90	0.978	0.963	0.934	0.931	0.945	0.01	<0.001	0.010	0.201

ADFI, kg/d									
d 0 to 34	1.949	1.856	1.833	1.769	1.795	0.03	<0.001	0.421	0.001
d 35 to 64	2.829	2.725	2.552	2.432	2.558	0.05	<0.001	0.796	0.001
d 65 to 76	3.130	3.188	2.873	3.021	3.085	0.05	0.001	0.298	0.447
d 77 to 90	3.163	3.149	3.159	3.092	3.260	0.05	0.430	0.584	0.162
d 0 to 90	2.768	2.724	2.598	2.579	2.671	0.02	0.001	0.282	0.481
G:F									
d 0 to 34	0.478	0.487	0.494	0.491	0.499	0.01	0.045	0.173	0.001
d 35 to 64	0.369	0.375	0.370	0.378	0.369	0.01	0.163	0.816	1.000
d 65 to 76	0.306	0.295	0.317	0.320	0.311	0.01	0.038	0.036	0.530
d 77 to 90	0.312	0.318	0.309	0.321	0.301	0.01	0.767	0.890	0.684
d 0 to 90	0.366	0.369	0.373	0.378	0.370	0.01	0.007	0.482	0.153

[1]Treatment means are based on 10 pen observations.

[2]For d 0 to 34 and d 35 to 64, 22.5% EP canola meal; for d 65 to 76 and d 77 to 90, 18% EP canola meal.

[3]For d 0 to 34, 35 to 64, 65 to 76, and 77 to 90, diets contained 22.5, 15, 7.5, and 0% EP canola meal, respectively.

canola meal also had a lower ($P < 0.001$) BW at d 34, 64, and 76 than pigs fed 0% EP canola meal; however, pigs BW was not different between these 2 diet regimens at d 90 (Table 2.9).

For the entire trial (d 0 to 90), d 0 to 34, and d 35 to 64, increasing the inclusion of EP canola meal linearly ($P < 0.001$) reduced ADG (Table 2.8). Inclusion of EP canola meal did not affect ADG for d 65 to 76 and d 77 to 90. Pigs fed decreasing graded levels of EP canola meal had a lower ($P < 0.01$) ADG for d 0 to 34 and 35 to 64 than pigs fed 0% EP canola meal, but ADG did not differ for d 65 to 76 and d 77 to 90 and overall (d 0 to 90).

For the entire trial (d 0 to 90), increasing the inclusion of EP canola meal quadratically reduced ($P = 0.01$) ADFI (Table 2.8). Inclusion of EP canola meal linearly ($P < 0.001$) reduced ADFI for d 0 to 34, d 35 to 64, and d 65 to 76, but did not affect ADFI for d 78 to 90. Pigs fed decreasing graded levels of EP canola meal had a lower ($P < 0.01$) ADFI for d 0 to 34 and 35 to 64 than pigs fed 0% EP canola meal, but ADFI did not differ for d 65 to 76, d 77 to 90, and overall (d 0 to 90).

For the entire trial (d 0 to 90), increasing the inclusion of EP canola meal linearly increased ($P < 0.001$) G:F (Table 2.8). Inclusion of EP canola meal linearly increased ($P < 0.05$) G:F for d 0 to 34 and overall (d 0 to 90) and quadratically increased ($P < 0.05$) G:F for d 65 to 76, but did not affect G:F for d 35 to 64 and 77 to 90. Pigs fed decreasing graded levels of EP canola meal had a lower ($P < 0.01$) G:F for d 0 to 34, but not for any other period or overall (d 0 to 90).

Table 2.9. Effect of feeding expeller-pressed (EP) canola meal on carcass characteristics and days following d 90 required for pigs to reach slaughter weight[1]

	EP canola meal, %						*P*–value		
Item	0	7.5	15	22.5/18[2]	Graded[3]	SEM	Linear	Quadratic	Graded vs. 0%
Carcass weight, kg	95.7	94.8	93.8	93.1	94.8	0.525	0.001	0.546	0.144
Back fat, mm	20.6	20.4	19.5	19.8	20.2	0.319	0.007	0.983	0.293
Loin depth, mm	63.5	63.2	63.1	62.3	63.0	0.448	0.109	0.535	0.431
Estimated lean, %	59.9	60.0	60.4	60.2	60.1	0.151	0.025	0.832	0.325
d 90 to slaughter, d[4]	26.5	28.1	29.3	29.6	28.1	0.773	<0.001	0.630	0.056

[1]Treatment means are based on 10 pen observations.

[2]For d 0 to 34 and d 35 to 64, 22.5% EP canola meal; for d 65 to 76 and d 77 to 90, 18% EP canola meal.

[3]For d 0 to 34, 35 to 64, 65 to 76, and 77 to 90, diets contained 22.5, 15, 7.5, and 0% EP canola meal, respectively.

[4]Pen average number of days from d 90 until slaughter.

Increasing the inclusion of EP canola meal linearly ($P < 0.001$) reduced carcass weight and backfat, and linearly increased ($P < 0.05$) lean yield and d to slaughter (Table 2.9). Pigs fed decreasing graded levels of EP canola meal did not have different carcass characteristics than pigs fed 0% EP canola meal, but tended to reach shipping weight 3 d later ($P < 0.10$).

Increasing the inclusion of EP canola meal did not affect jowl fat fatty acid profile and calculated iodine value (Table 2.10). Pigs fed graded levels of EP canola meal did not have a different jowl fat fatty acid profile and calculated iodine value than control pigs.

Increasing the inclusion of EP canola meal linearly reduced ($P < 0.001$) feed cost per kg of weight gained and linearly increased ($P = 0.01$) income over feed cost (Table 2.11). Feeding graded levels of EP canola meal reduced ($P = 0.01$) feed costs by 2 cent/kg gained and tended to increase ($P = 0.10$) income over feed costs by CAD$ 1.40/pig compared to feeding controls.

Table 2.10. Effect of feeding expeller-pressed (EP) canola meal on jowl fat fatty acid profile and iodine value[1]

	EP canola meal, %						*P*-value		
Variable	0	7.5	15	22/18[2]	Graded[3]	SEM	Linear	Quadratic	0% vs. Graded
Fatty acid, %									
10:0 Capric	0.10	0.09	0.08	0.08	0.08	0.008	0.410	0.750	0.660
12:0 Louric	0.09	0.09	0.08	0.08	0.08	0.042	0.703	0.865	0.421
14:0 Myristic	1.45	1.40	1.34	1.30	1.35	0.023	0.600	0.280	0.160
16:0 Palmitic	23.22	22.41	21.04	20.37	21.42	0.172	0.220	0.943	0.427
16:1 Palmitoleic	2.73	2.57	2.45	2.29	2.52	0.072	0.300	0.970	0.700
18:0 Stearic	9.78	9.36	8.38	8.27	8.85	0.200	0.625	0.801	0.817
18:1 Oleic	3.39	3.43	3.58	3.55	3.53	0.049	0.333	0.461	0.349
18:2 Linoleic	11.34	12.02	13.10	13.47	12.17	0.198	0.498	0.544	0.843
18:3 α-Linolenic	0.72	1.02	1.41	1.60	1.23	0.023	0.176	0.861	0.495
20:0 Arachidic	0.18	0.18	0.17	0.18	0.18	0.005	0.060	0.910	0.430

20:1 Gadoleic	0.98	0.98	1.05	1.07	1.01	0.019	0.120	0.480	0.290
20:2 Dihono-γ-linolenic	0.55	0.55	0.59	0.59	0.54	0.012	0.670	0.690	0.700
20:3 Podocarpic	0.08	0.08	0.08	0.08	0.08	0.002	0.530	0.020	0.500
20:4 Arachidonic	0.19	0.18	0.19	0.18	0.18	0.004	0.964	0.267	0.882
Iodine value	68.9	69.9	69.9	70.4	69.7	0.99	0.320	0.869	0.600

[1]Treatment means are based on 10 observations.

[2]For d 0 to 34 and d 35 to 64, 22.5% EP canola meal; for d 65 to 76 and d 77 to 90, 18% EP canola meal.

[3]For d 0 to 34, 35 to 64, 65 to 76, and 77 to 90, diets contained 22.5, 15, 7.5, and 0% EP canola meal, respectively.

Table 2.11. Effect of feeding expeller-pressed (EP) canola meal on feed cost and income over feed cost[1]

	EP canola meal, %						*P*–value		
Item	0	7.5	15	22.5/18[2]	Graded[3]	SEM	Linear	Quadratic	0% vs. Graded
Feed cost, CAD cents/kg gain[4]	0.67	0.65	0.63	0.62	0.65	0.01	<0.001	0.742	0.001
Income over feed cost, CAD $/pig	40.05	41.33	42.32	42.25	41.45	0.56	0.003	0.536	0.098

[1]Treatment means are based on 10 observations.

[2]For d 0 to 34 and d 35 to 64, 22.5% EP canola meal; for d 65 to 76 and d 77 to 90, 18% EP canola meal.

[3]For d 0 to 34, 35 to 64, 65 to 76, and 77 to 90, diets contained 22.5, 15, 7.5, and 0% EP canola meal, respectively.

[4]Determined using the following feedstuff prices (CAD $/1,000 kg): wheat, 205; barley, 195; corn, 210; soybean meal, 420; EP canola meal, 210; solvent-extracted canola meal, 210; wheat:corn DDGS blend, 175; L-Lys HCl, 1900, tallow, 700.

2.5 Discussion

Canola is a major oilseed crop globally (Raymer, 2002). Canola oil has a reputation for excellent nutritional quality in the human diet (Gebauer et al., 2006), constitutes 40% of the seed, and is the most valuable seed component. Three processes to extract oil from the seed to produce raw canola oil for further refining and a protein meal as an alternative feedstuff have been developed over the years (Canola Council of Canada (CCC), 2009). Solvent-extracted canola meal, EP canola meal, and cold-pressed canola cake are the co-products of solvent extraction, expeller pressing, and cold pressing, respectively (Leming and Lember, 2005). Practically, inclusion of solvent-extracted canola meal is limited to 15% in diets for grower-finisher pigs, despite suggested maximum inclusion of 25% (CCC, 2009). The main reason is lower content of available energy and AA due to higher fiber and low CP compared to soybean meal (Bell, 1993). The lack of knowledge about the nutritional quality of EP canola meal and its effects on growth performance and carcass quality characteristics limits its application in swine feed formulation. In Exp. 1, the NE content of EP canola meal was established at 2.55 Mcal NE/kg of DM and 1.77% SID Lys in the DM indicating a valuable energy and AA content. In Exp. 2, feeding of EP canola meal, however, resulted in reduced ADG and ADFI compared to pigs fed a control diet based on soybean meal.

The nutritional value of EP canola meal varies among reports. The EP canola meal used in present study had a slightly higher CP (38.5 vs. 38.1%), a higher ether extract (13.3 vs. 10.3%), and a lower crude fiber content (7.7 vs. 12.1%)

(DM basis) compared to the Dutch data base for EP canola meal (CVB, 2003). Expeller-pressed canola meal contained 41.1% of CP, 5.9% of ether extract, and 23.8% of NDF in a recent Canadian study (Woyengo et al., 2009). The content of CP, GE, and ether extract of EP canola meal used in the present study were similar to EP canola meal produced in Western Australia (Spragg and Mailer, 2007). An Estonian study (Leming and Lember, 2005) reported a lower CP (36.1%) and ether extract (12.2%) content and higher GE (5.14 Mcal/kg) content (DM basis) than the EP canola meal in the present study. A Chinese EP canola meal contained 38.9% CP and 4.66 Mcal/kg of GE (DM basis; Li et al., 2002). Combined, these reports indicate that the macronutrient composition of EP canola meal differs among samples globally. The greatest differences are observed in content of energy-yielding substrates residual oil and CP and therefore GE. Differences are most likely caused by the efficacy of oil extraction among expeller pressing plants using various equipment and conditions, thereby altering content of remaining macronutrients (Leming and Lember, 2005). The macronutrient composition of EP canola meal may also be affected by cultivar of canola seed, soil type, and growing conditions (Bell, 1993).

The measured DE content of 3.77 Mcal/kg (DM basis) in the present study was 0.57 Mcal/kg higher than the DE content of 3.20 Mcal/kg (DM basis) included in the North American feedstuff tables (NRC, 1998) for solvent-extracted canola meal, but the DE content was 0.15 Mcal/kg lower than the DE content of 3.92 Mcal/kg (DM basis) for soybean meal. Previously, a DE content of 3.70 Mcal/kg (DM basis) was reported for EP canola meal (Mullan et al.,

2000). Furthermore, a DE content of 4.11 Mcal/kg was reported for EP canola meal (Woyengo et al., 2009). The NE content of EP canola meal used in present study was predicted using the equation using the measured DE content and macronutrient composition of EP canola meal (Equation 4; Noblet et al., 1994). The NE content of 2.55 Mcal/kg (DM basis) in EP canola meal was 0.81 and 0.34 Mcal/kg higher, respectively, than the NE content of 1.74 and 2.21 Mcal/kg (DM basis) for solvent-extracted canola meal and soybean meal (Sauvant et al., 2004). These values indicate that EP canola meal has a higher energy value than solvent-extracted canola meal and soybean meal mainly due to a higher residual oil content, because energy digestibility of EP canola meal is identical to the value reported for soybean meal (Sauvant et al., 2004).

The EP canola meal is a good supplemental protein feedstuff. In the present study, CP digestibility of EP canola meal was 75.0%, similar to the 75.0% in the Dutch feedstuff tables (CVB, 2003). The SID Lys content of 1.77% (DM basis) in EP canola meal was 0.03 and 1.06% lower, respectively, than the SID Lys content of solvent-extracted canola meal and soybean meal (NRC, 1998). In canola meal, the CP content is negatively correlated with residual oil content (Spragg and Mailer, 2007). Thus, SID Lys content is lower in EP canola meal due to its higher residual oil content. The SID Lys content of EP canola meal used in the present study was 0.32% (DM basis) higher than previously reported (Woyengo et al., 2009). Interestingly, 96% of Lys in EP canola meal was analyzed as available and thus assumed chemically intact, indicating that steam conditioning followed by expelling does not result in heat damage to the Lys (van Barneveld, 1994).

Formulating swine diets using the NE and SID AA systems reduces the risk of introducing co-products as alternative feedstuffs in swine diets (Zijlstra and Payne, 2007). In the present study, increasing the inclusion of EP canola meal reduced ADFI, leading to a reduced ADG coinciding with a slightly increased G:F. The reduced ADFI reduces the NE and other nutrient intake. The reduced ADFI could be due to differences in energy content, dietary macronutrient profile, or residual anti-nutritional factors (Nyachoti et al., 2004) such as glucosinolates in EP canola meal. Dietary energy content was maintained across diets; therefore, dietary macronutrient profile and glucosinolates may explain the reduced ADFI. The content of ether extract was 2.8% (as fed) higher for the diets containing 22.5 than 0% EP canola meal for d 0 to 34. Increased dietary fat may reduce ADFI of pigs (Azain, 2001) in part because pigs eat to meet their energy requirement (NRC, 1998). Extra fat may also reduce feed intake directly (Rayner and Miller, 1993), although 6% added rapeseed oil did not reduce ADFI (Lauridsen et al., 1999).

Glucosinolates are another factor in canola co-products that may reduce performance (Lee et al., 1984). Feeding higher levels of glucosinolates may reduce ADFI, enlarge the thyroid, reduce plasma thyroid hormones, and may cause liver and kidney abnormalities and mortality (Bunting, 1981; Van Etten and Tookey, 1983; Schone et al., 1997b). Depending on the nature of glucosinolates and the reaction conditions, isothiocynates, oxazolidine-2-thiones, thiocynates, or nitriles may be formed (Pusztai, 1989) that can impair growth performance. Although canola contains less glucosinolates than older rapeseed varieties,

sufficient quantities of glucosinolates may remain after processing to cause reduced ADFI and ADG if fed to pigs for long periods and (or) at high inclusion levels (Mullan et al., 2000). Pigs fed diets containing canola meal may have reduced growth performance (Bell et al., 1991) although uncertainty exists whether improper feed formulation (not NE and SID AA), presence of glucosinolates, taste, or other factors in the diet, such as fiber, reduced ADG (Bell, 1993). Combined, the ether extract and glucosinolate data relative to the existing body of knowledge indicate that glucosinolates and likely not dietary fat was the main cause for reduced ADFI. Specifically, the content of total glucosinolates was 5.2 µmol/g higher in the diet containing 22.5% EP canola meal than the control diet, whereas pigs tolerate 2.5 µmol/g of dietary glucosinolates (Bell, 1993; Schone et al., 1997a, b).

Pigs in the present study reached a high plane of growth performance. The ADG for d 0 to 90 was 0.931 kg/d with diets containing 22.5/18% EP canola meal, whereas ADG was 0.757 kg/d in an Australian study with 20% EP canola meal (Mullan et al., 2000). In the latter study, inclusion of 20% EP canola meal reduced ADG by 4.5% via reduced ADFI and G:F (Mullan et al., 2000), whereas reduced ADFI was the main cause for reduced ADG in the present study. In the present study, carcass weight was reduced with an identical BW at slaughter, providing further evidence that diets containing co-products high in fiber reduce dressing percentage. Thus, up to a 3-kg heavier market BW should thus be considered to mitigate the lower dressing percentage with the feeding of EP canola meal.

Feeding high fat diets to finisher pigs may reduce carcass lean and increase carcass fat (Verland et al., 1999). The decreasing graded feeding regimen that gradually reduced inclusion of EP canola meal from 22.5 to 0% over the 4 growth periods provided more dietary fat during the energy-dependant stage of growth and less fat during the energy-independent stage to counteract potential negative effects of feeding high fat diets on carcass and pork quality. None of these carcass characteristics were different between the graded feeding and soybean control regimens indicating that feeding EP canola meal at a high initial inclusion but then gradually decreasing the level did not hamper carcass quality. The continued inclusion of EP canola meal throughout the study, however, reduced carcass weight, indicating that increased EP canola meal inclusion reduced carcass value. Iodine value of fat has been used as a measure of pork fat quality. Feeding diets containing an unsaturated fat source can reduce the degree of saturation in pork fat (Whitney et al., 2006). Adequately firm pork fat should have an iodine number below 70 (Lea et al., 1970), although more recently a threshold iodine value of 74 for North American pork was suggested (Boyd, 1997). Iodine value of jowl fat from all feeding regimen was below 70 in the present study, indicating that feeding of EP canola meal did not hamper fat quality.

In swine diets, energy is the most expensive component and therefore energy content of feed ingredients should be considered in feed formulation (Zijlstra and Beltranena, 2007). Feeding pigs is the single most expensive cost of pork production accounting for as much as 70% of variable costs (Payne and Zijlstra, 2007). In present study, inclusion of EP canola meal reduced feed cost per unit of

gain and thereby increased income over feed cost with increasing EP canola meal inclusion. Practically, however, the increase in net income can only be achieved in barns with sufficient space to overcome the reduced facility utilization due to reduced ADG.

In summary, EP canola meal is a good source of energy and AA. The EP canola meal can be included in swine diets to reduce feed costs per unit of gain without impacting carcass and fat quality. However, 1% inclusion of EP canola meal reduced ADG by 3 g/d. Therefore, inclusion of EP canola meal should be targeted to ensure an expected growth rate and to meet marketing strategy targets. Diets formulated to equal NE may still result in unequal ADG due to differences in ADFI most likely caused by excessive glucosinolates intake. In conclusion, EP canola meal is a valuable feedstuff to consider in swine feed formulation. The inclusion level of EP canola meal in swine diets should be determined not only by targeting expected growth performance, but also by considering animal flow and barn turnover rate of a particular farm.

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Chapter 3. Effect of processing conditions on the nutrient digestibility of cold-pressed canola cake for grower pigs

3.1 Abstract

Cold-pressed canola cake contains more residual oil than expeller-pressed and solvent-extracted canola meal and might be an attractive feedstuff for swine. The nutritional quality of cold-pressed canola cake is not well-described and can vary with processing conditions. The cold-pressed canola cake was processed at 4 different processing conditions; non-heated and heated conditions at slow and fast barrel speed. In total, 7 ileal-cannulated barrows (26 kg BW) were fed twice daily at 2.8 x maintenance either 44% of one of the 4 cold-pressed canola cake or an N-free diet. Diets with EP canola meal with or without whole canola seeds were used as comparison in a 7 × 7 Latin square to measure energy and AA digestibility and to calculate standardized ileal digestible (SID) AA and NE content. In 9-d periods with sequentially a 5-d diet adaptation and a 2-d feces and 2-d digesta collection, 7 observations per diet were obtained. On average, cold-pressed canola cake contained 41.0% CP, 16.2% ether extract (in DM), and 7.04 μmol/g total glucosinolates (as fed). Both AID and total tract energy digestibility of energy in cold-pressed canola cake was 36% higher ($P < 0.05$) in heated vs. non-heated conditions and 8% higher ($P < 0.05$) in fast vs. slow conditions, without interaction. The AID of energy of cold-pressed canola cake was 13 and 118% higher ($P < 0.05$) than EP canola meal and canola seed, respectively. Heat and speed interacted ($P < 0.05$) for SID of AA of ingredients, but effects were not

consistent among AA. The DE and NE content of cold-pressed canola cake was 0.73 and 0.52 Mcal/kg of DM higher ($P < 0.05$), respectively, than EP canola meal, and did not differ from canola seed. On average, cold-pressed canola cake contained 4.17 Mcal/kg DE, 2.84 Mcal/kg NE, 0.87% SID Lys, 0.46% SID Met, and 0.79% SID Thr in the DM. In conclusion, the content of ether extract was an important determinant of the energy value of cold-pressed canola cake: higher residual oil in the cake increased the DE and NE content. Processing conditions greatly impacted the digestible nutrient content of cold-pressed canola cake that should be validated using a growth study in pigs.

3.2 Introduction

With the increasing cost of feed energy, alternative energy-supplying feedstuffs should be explored, including canola co-products. For small-scale oil extraction, oil is extracted mechanically by expeller and cold pressing that produce expeller-pressed canola meal (EP canola meal) and cold-pressed canola cake, respectively, instead of solvent-extracted canola meal (Leming and Lamber, 2005). Higher content of residual oil in these co-products may provide more dietary energy. The EP canola meal is a valuable AA source (Seneviratne et al., 2009), but the AA value is unknown for and cold-pressed canola cake.

In expeller-pressing, seed is heated up to 110ºC, but direct heat is not applied in cold-pressing (Leming and Lamber, 2005; Spragg and Mailer, 2007). In expeller pressing, materials may double- or triple-press seed to reach > 75% oil extraction (Spragg and Mailer, 2007), while oil extraction is lower in single pass

cold pressing [Canola Info (CI), 2007]. Residual oil content in canola meals, thus, depends on processing conditions that also impact glucosinolates content and AA quality due to heat application (van Barneveld, 2008). Nutritional quality information for cold-pressed canola cake is scarce, while some information is available for EP canola meal (Seneviratne et al., 2009; Woyengo et al., 2009). Moreover, the effects of processing conditions on the chemical characteristics and nutritional quality of cold-pressed canola cake are unknown, and require description to gauge the feeding opportunity of this co-product for swine.

In the present study, we hypothesized that energy and AA digestibility of cold-pressed canola cake would differ depending on processing conditions and would be different from EP canola meal and canola seed. The objectives of this study were to characterize the effect of processing condition on AA and energy digestibility and SID AA and NE content of cold-pressed canola cake and to compare cold-pressed canola cake to canola seed and EP canola meal.

3.3 Materials and Methods

Experimental Design and Diets

In a pilot project, cold-pressed canola cake samples were collected across the western Canada and analyzed for proximate composition. Based on the results (Appendix 2), cold pressed-canola cake was produced under 4 processing conditions using a cold press at Canadian International Grain Institute (Biopress 200; Winnipeg, Manitoba, Canada) to have representative cold-pressed canola cake samples for the present study. The cold press operated with 2 barrel speeds

(slow and fast) and barrel temperatures (heated and non-heated) in a 2 × 2 factorial arrangement. Whole canola seeds were obtained from a local canola grower (Bentley, Alberta, Canada) and were in off grade quality with more than 5% dockage, discolored, 5% heated and moldy [Official Grain Grading Guide (OGGG), 2009]. One sample of EP canola meal was obtained directly from Associated Proteins, Ste. Agathe, Manitoba, Canada. The other ingredients were obtained via commercial supply and were of unknown origin.

The cold pressed-canola cake and EP canola meal diets contained 44% canola meal and the ratio of corn starch, sugar, and canola oil was identical to the N-free diet (Table 3.1) to measure energy digestibility of cold-pressed canola cake and EP canola meal (Stein et al., 2006). To avoid problem with feeding, 20% ground canola seed was combined with EP canola meal. Canola meal and seed were the sole source of CP and AA in diets. The N-free diet containing 84.32% corn starch was used to estimate the basal ileal endogenous losses of CP and AA (Stein et al., 2006). Chromic oxide was included as an indigestible marker. Diets were formulated to meet or exceed vitamins and mineral requirements (NRC, 1998).

Experimental Procedures

The animal protocol was approved by the University of Alberta Animal Care and Use Committee for Livestock, and followed guidelines established by the Canadian Council on Animal Care (CCAC, 1993). The study was conducted at the Swine Research and Technology Centre at the University of Alberta (Edmonton, Alberta, Canada).

Table 3.1. Ingredient composition and nutrient content of test diets[1]

	Cold-pressed canola cake				Seeds+ EP	EP	
	Non-heated		Heated		canola	canola	N
Ingredient, %	Slow	Fast	Slow	Fast	meal	meal	free[2]
Cornstarch –Melojel	48.63	48.64	48.64	48.64	40.37	48.64	85.32
CP canola cake	44.00	44.00	44.00	44.00	-	-	-
Canola seed	-	-	-	-	20.00	-	-
EP canola meal	-	-	-	-	33.00	44.00	-
Sugar	2.85	2.85	2.85	2.85	2.33	2.85	5.00
Canola oil	1.14	1.14	1.14	1.14	0.93	1.14	2.00
Limestone	1.50	1.50	1.50	1.50	1.50	1.50	1.00
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[3]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Trace mineral premix[4]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Cr_2O_3	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Analyzed nutrient content (in DM)							
CP	18.64	17.80	18.22	19.85	19.35	18.60	0.47
Ether extract	8.10	9.73	7.37	5.25	13.16	6.40	3.73

[1] EP canola meal is expeller-pressed canola meal; CP canola cake is cold-pressed canola cake

[2]The N-free diet also contained 3.00% solka floc, 1.20% mono/dical phosphate, 0.50% KCO_3, and 0.10% MgO.

[3]Provided the following per kilogram of diet: vitamin A, 8,250 IU; vitamin D3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg ; menadione, 4 mg; folic acid, 2 mg; thiamine,1 mg; D-biotin, 0.2 mg; and vitamin B12, 0.025 mg.

[4]Provided the following per kilogram of diet: Zn, 100 mg as $ZnSO_4$; Fe, 80 mg as $FeSO_4$; Cu, 50 mg as $CuSO_4$; Mn, 25 mg as $MnSO_4$; I, 0.5 mg as $Ca(IO_3)_2$; and Se, 0.1 mg as Na_2SeO_3.

In total, 7 diets were tested over seven experimental periods as a 7 × 7 Latin square design using ileal-cannulated grower-finisher pigs to provide 7 observations per diet. Seven crossbred barrows (Duroc sire x Large White /Landrace F1; Genex Hybrid; Hypor, Regina, SK; initial BW, 26.1 ± 0.9 kg; initial age, 66 ± 2 d) were surgically fitted with a T–cannula at the distal ileum. Diets were randomly allocated to pigs for the first period. Pigs were housed individually in metabolism pens measuring 1.2 m wide x 1.5 m length x 0.95 m height (1.8 m^2) raised 0.4 m. Pens had a plastic-coated, expanded metal floor and polyvinyl chloride walls fitted with plexiglass windows (0.3 x 0.3 m), a single-space dry feeder, and a nipple drinker.

Pigs were weighed at the start of each period. To ovoid orts, the daily feed allowance was set at 2.8 × the estimated maintenance requirement for energy (2.8 x 110 kcal DE/kg $BW^{0.75}$; NRC, 1998) that was fed in 2 equal meals at 0800 and 1600 h. Diets were fed as a dry mash and pigs had free access to water throughout the experiment. The 9-d experimental periods consisted of a 5-d acclimation to the experimental diets, followed by 2-d collection of feces, and a 2-d collection of ileal digesta.

Feces were collected continuously with bags replaced a minimum of 2 times per day at 0800 and 1600 h. Feces were collected using plastic bags attached to a ring system glued to the skin around the anus (Van Kleef et al., 1994). Digesta was collected for 10 h each for 2 consecutive d using bags containing 5% formic acid attached to the open cannula barrel. Bags were removed whenever they filled with digesta or at least every 30 min. Collected feces and digesta were pooled by

pig and frozen at –20°C. Prior to analyses, feces and digesta were thawed, homogenized, sub-sampled, and freeze-dried.

Chemical Analyses

At the end of the experiment, feces and digesta specimens were thawed pooled within animal and subsample were taken for chemical analysis. Each diet and test feedstuffs were sub sampled as well. Diet, test feedstuffs, digesta, and feces samples were ground in a Retch mill (model ZMI, Brinkman Instruments, Rexdale, Ontario, Canada) over a 1-mm screen.

The cold-pressed canola cake, EP canola meal and canola seed were analyzed for CP (method 984.13A-D; AOAC, 2006), ether extract (method 920.39A, AOAC, 2006), crude fiber (Method 978.10; AOAC, 2006), ADF (method 973.18; AOAC, 2006), NDF (Holst, 1973), ash (method 942.05; AOAC, 2006), Ca (method 968.08; AOAC, 2006), and P (method 946.06; AOAC, 2006) at University of Missouri, Columbia, MO. Glucosinolates profile was determined by GC analysis using the method of the Canadian Grain Commission method developed by Heaney and Fenwick (1980) and modified by Daun and McGregor (1981) at POS Pilot Plant Corp, Saskatoon, SK, Canada.

Diet, digesta, and feces were analyzed for DM (method 930.15; AOAC, 1990) and gross energy using an adiabatic bomb calorimeter (model 5003, Ika-Werke GMBH and Co KG, Staufen, Germany); benzoic acid was used as a standard. Chromic oxide in diets, digesta, and feces was determined by spectrophotometry (model 80-2097-62, KBUltraspec III; Pharmacia, Cambridge, UK) at 440 nm

after ashing at 450°C overnight (Fenton and Fenton, 1979). Diets, digesta, and feces were analyzed for AA (Sedgwick et al., 1991) at University of Alberta (Edmonton, Alberta, Canada). Diets were analyzed for CP (method 984.13A-D; AOAC, 2006) and crude fat [Method 920.39 (A), AOAC, 2006].

Calculations

The AID for energy and AA and total tract energy digestibility in cold-pressed canola cake diets, EP canola meal diet, and EP canola meal and canola seed diets was calculated using the indicator method (equation 2; Stein et al., 2007; Appendix 1). The AID AA values also represent the digestibility values of cold-pressed canola cake and EP canola meal itself, because cold-pressed canola cake and EP canola meal was the sole ingredient contributing AA in the diet. Pigs fed the N free diet was used to calculate its own basal endogenous loss (equation 3; Stein et al., 2007). The SID AA for ingredients was calculated using AID and basal endogenous N loss (equation 7; Stein et al., 2007). The SID AA of canola seed was calculated using difference method (Adeola, 2001). The SID content of AA was calculated by multiplying the SID of a AA by AA content of the same AA in the ingredient. The AID and apparent total tract energy (ATTD) of ingredients was calculated using the difference method (Adeola, 2001). Digestible energy content of a ingredient was calculated by multiplying its GE and total tract digestibility. The NE content was calculated using the determined DE content and chemical characteristics (Equation 4; Noblet et al., 1994).

Statistical Analyses

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) in a 7 × 7 Latin square. Pig was considered the experimental unit and period and pen were the random terms for the model. Cold-pressed canola cake means were analyzed as 2 × 2 factorial design having 2 speeds and 2 levels of heat application and their interaction (Milliken and Johnson, 1984). Treatment means were separated by the probability of difference by using LSMEANS and PDIFF statements in case an interaction between the main factors occurred. The EP canola meal and combination of EP canola meal and canola seed control diets were compared to the group of 4 cold-pressed canola cake diets using pre-planned contrasts. To test the hypotheses, $P < 0.05$ was considered significant.

3.4 Results

The cold-pressed canola cake samples processed with heated barrel had a 7.75% (in DM) lower CP and 46.9% (in DM) higher ether extract content than with non-heated barrel (Table 3.2). The EP canola meal used in the present study contained 6.53% and 14.66% (in DM) less CP and ether extract, respectively, than cold-pressed canola cake. Canola seeds used in the study contained 19.45% CP but, canola seeds and EP canola meal mixture contained 35.51% CP (DM basis; results not shown). The cold-pressed canola cake samples processed with heated barrel conditions had a 20.45% (DM basis) lower Lys than with non-heated barrel. Total Lys:CP was 0.04 for cold-pressed canola cake at non-heated barrel

Table 3.2. Chemical characteristics of test ingredients (DM basis)[1]

Item	Cold-pressed canola cake				Canola Seed	EP canola meal
	Non-heated		Heated			
	Slow	Fast	Slow	Fast		
Moisture	9.60	7.63	6.35	8.70	5.58	6.09
GE, Mcal/kg	5.12	5.45	5.88	5.24	6.86	5.20
CP	44.98	40.39	36.37	42.38	19.45	38.35
Ether extract	9.63	16.55	24.18	14.28	50.20	13.79
Crude fiber	7.28	6.46	6.78	6.67	6.28	7.89
ADF	18.79	17.15	18.54	17.29	23.40	18.54
NDF	31.46	29.06	39.41	36.42	37.44	22.01
Ash	8.10	6.85	6.67	7.67	3.33	6.92
Ca	0.91	0.84	0.79	0.90	0.37	0.58
P	1.56	1.43	1.28	1.47	0.59	1.12
AA						
Ala	1.49	1.51	1.35	1.47	0.57	1.51
Arg	1.76	1.60	1.42	1.83	0.92	1.80
Asp	2.24	2.75	2.10	2.86	0.57	2.38
Cys	1.16	1.04	0.97	1.09	0.57	1.07
Glu	6.11	7.83	5.72	8.06	0.42	6.51
Gly	1.97	2.12	1.67	2.16	0.35	1.95
His	0.69	0.58	0.57	0.66	0.25	0.60
Ile	2.38	2.59	2.07	2.47	0.40	2.55

Leu	1.79	1.93	1.55	1.86	0.64	1.94
Lys	1.58	1.55	1.16	1.33	0.57	1.64
Met	0.60	0.54	0.50	0.58	0.19	0.56
Phe	1.43	1.54	1.28	1.47	0.45	1.53
Ser	0.78	0.91	0.75	1.16	0.21	0.80
Thr	1.11	1.25	0.96	1.37	0.41	1.25
Tyr	0.82	0.80	0.70	0.78	0.31	0.83
Val	2.08	2.28	1.89	1.05	0.56	2.27

[1]EP canola meal is expeller-pressed canola meal

condition while 0.03 for heated barrel condition. The EP canola meal contained 16.72% more Lys (in DM) than the cold-pressed canola cake.

The cold-pressed canola cake samples processed with heated barrel had 2.44% (as fed) higher total glucosinolates than with non-heated barrel (Table 3.3). Total glucosinolates content of EP canola meal was 2.7 times higher than cold-pressed canola cake.

The AID and ATTD of energy in cold-press canola cake diets was, respectively, 20 and 8% higher ($P < 0.05$) in heated vs. non-heated barrel and 22 and 7% higher ($P < 0.05$) in fast vs. slow barrel speed, without interaction (Table 3.4). The AID and ATTD of energy of cold-pressed canola cake diets did not differ from diets containing the EP canola meal with or without canola seed.

Table 3.3. Composition of glucosinolates of test ingredients (as is basis)[1]

	Cold-pressed canola cake				Seed	EP
	Non-heated		Heated			canola
Item, µmol/g	Slow	Fast	Slow	Fast		meal
Allyl	-	-	-	-	-	0.05
CH3-thiobutenyl	-	0.06	0.05	-	-	0.17
CH3-thiopentenyl	-	-	-	-	-	0.07
Phenylethyl	0.20	0.14	0.17	0.14	-	0.15
2-OH-3-butenyl	1.50	1.27	1.89	1.02	1.01	4.39
2-OH-4-pentenyl	-	-	-	-	-	0.07
3-butenyl	1.07	0.83	1.23	0.74	1.38	3.10
3-CH3-indolyl	0.24	0.17	0.27	0.15	0.05	0.23
4-OH-3-CH3-indolyl	1.81	1.39	2.09	1.06	0.71	2.61
4-pentenyl	0.19	0.07	0.20	0.06	-	0.22
Total aliphatics	2.78	2.18	3.34	1.83	1.44	7.79
Total glucosinolates	7.79	6.11	9.24	5.00	4.59	18.85

[1]EP canola meal is expeller-pressed canola meal

Table 3.4. Apparent ileal (AID) and total tract digestibility (ATTD) of energy and apparent ileal digestibility of AA of test diets[1]

	Cold-pressed canola cake				Seed + EP canola meal	EP canola meal		*P*-value				
	Non-heated		Heated					Speed	Heat	Speed × Heat	CPCC vs. EP meal + seed	CPCC vs. EP canola meal
Item	Slow	Fast	Slow	Fast			SEM					
AID energy	62.07	74.45	73.42	90.71	71.26	71.86	4.57	0.012	0.015	0.628	0.426	0.491
ATTD energy	83.00	86.71	87.67	95.28	86.14	85.86	1.29	0.002	0.001	0.224	0.162	0.112
AID AA												
Ala	63.78	61.70	86.99	87.29	67.75	71.16	1.24	0.365	<0.001	0.236	0.004	0.200
Arg	69.14	69.74	86.85	86.77	72.81	80.52	1.59	0.860	<0.001	0.820	0.030	0.161
Asp	58.91[c]	54.17[c]	82.32[b]	87.78[a]	62.23	67.97	1.65	0.828	<0.001	0.012	0.009	0.351
Cys	66.83	70.15	89.00	89.46	79.59	67.17	0.98	0.044	<0.001	0.116	0.652	<0.001

Glu	67.59	71.71	88.71	91.24	76.11	80.85	2.04	0.132	<0.001	0.755	0.457	0.693
Gly	40.12	33.81	76.73	79.40	46.95	53.18	3.21	0.429	<0.001	0.128	0.052	0.429
His	48.84	53.20	84.53	85.23	69.87	82.34	2.51	0.314	<0.001	0.498	<0.001	0.279
Ile	66.85	69.66	87.68	89.80	71.85	78.18	0.94	0.006	<0.001	0.637	0.035	0.966
Leu	64.15	66.04	86.48	88.65	67.89	70.10	1.28	0.134	<0.001	0.909	0.019	0.012
Lys	40.85[c]	48.88[b]	80.29[a]	82.77[a]	67.56	77.27	1.05	0.001	<0.001	0.025	0.001	<.0001
Met	81.90[b]	76.17[c]	81.94[b]	91.78[a]	85.16	80.06	1.22	0.103	<0.001	<0.001	0.249	0.253
Phe	72.29	71.80	89.59	90.51	73.41	76.28	1.00	0.815	<0.001	0.454	0.008	0.015
Ser	35.96	46.33	80.10	80.18	54.28	73.11	2.81	0.067	<0.001	0.072	0.101	0.001
Thr	49.33	49.60	87.55	81.44	49.14	69.01	2.08	0.187	<0.001	0.154	0.001	0.347
Tyr	60.53	55.11	83.48	81.05	65.45	74.12	1.54	0.021	<0.001	0.486	0.294	0.041
Val	61.75	66.12	85.71	88.88	68.58	66.49	1.57	0.035	<0.001	0.701	0.092	0.001

[a–c]Means within the same raw with the same superscript letter are not different ($P > 0.05$).

[1]CPCC is cold-pressed canola cake; EP canola meal is expeller-pressed canola meal.

Barrel heating and speed interacted ($P < 0.05$) for AID of Asp, Lys, and Met (Table 3.4). The AID Lys of cold-pressed canola cake diets was 20% higher ($P < 0.05$) in non-heated-fast vs. non-heated-slow conditions. The AID Met of cold-pressed canola cake diets was 7% lower ($P < 0.05$) in fast vs. slow barrel speed for non-heated barrel while 12% higher ($P < 0.05$) in fast vs. slow barrel speed for heated barrel. The AID of Lys of cold-pressed canola cake diets was lower ($P < 0.05$) than diets containing the EP canola meal with or without canola seed.

The AID and total tract energy digestibility of energy in cold-press canola cake were both 36% higher ($P < 0.05$) in heated vs. non-heated barrel and tended both to be 8% higher ($P < 0.10$) for fast vs. slow barrel speed, without interaction (Table 3.5). The AID energy of cold-pressed canola cake was 13% and 118% higher ($P < 0.05$) than EP canola meal and canola seed, respectively.

Barrel heating and speed interacted ($P < 0.05$) for SID Lys and Met content of cold-pressed canola cake (Table 3.6). An increase in barrel speed at non-heated barrel increased ($P < 0.05$) SID Lys content by 21% while barrel speed did not affect SID Lys content under heated conditions. The SID Lys content of cold-pressed canola cake was lower ($P < 0.05$) from EP canola meal and canola seed. Fast barrel speed at non-heated barrel condition reduced ($P < 0.05$) SID Met content by 6.46% while fast barrel speed at heated barrel condition increased ($P < 0.05$) SID Met content by 12%. The SID Met content of cold-pressed canola cake did not differ from EP canola meal and canola seed.

Barrel heat and speed interacted ($P < 0.05$) for DE and predicted NE content of the test ingredients (Table 3.6). An increase in barrel speed at non-heated barrel

Table 3.5. Apparent ileal (AID) and total tract digestibility (ATTD) of energy and standardized ileal digestibility of AA of test ingredients[1]

`	Cold-pressed canola cake				EP			*P*-value				
	Non-heated		Heated			canola		Speed	Heat	Speed ×	CPCC vs.	CPCC vs. EP canola
Item	Slow	Fast	Slow	Fast	Seed	meal	SEM			Heat	seed	meal
AID energy	59.67	67.78	84.66	88.20	34.40	64.72	5.59	0.084	0.001	0.432	<0.001	0.003
ATTD energy												
	60.70	68.15	85.52	89.60	57.58	66.06	5.79	0.096	0.001	0.468	0.001	0.009
SID AA												
Ala	64.14	62.80	88.09	87.94	81.53	71.77	1.45	0.540	<0.001	0.623	0.083	0.156
Arg	69.89	70.65	87.07	87.41	52.68	81.17	1.75	0.754	<0.001	0.907	<0.001	0.391
Asp	59.24	55.82	82.56	88.14	89.35	68.05	1.89	0.583	<0.001	0.052	0.001	0.372
Cys	67.87	71.30	89.33	90.00	81.27	67.25	1.15	0.071	<0.001	0.179	0.608	0.001

Glu	67.67	72.48	88.80	91.46	47.32	80.89	2.31	0.129	<0.001	0.631	0.337	0.744
Gly	40.62	36.89	78.07	81.29	76.31	53.29	3.54	0.944	<.0001	0.355	0.337	0.274
His	49.72	56.06	84.58	85.31	65.09	82.91	2.68	0.227	<0.001	0.326	0.511	0.001
Ile	67.66	70.43	88.08	90.13	86.48	78.36	1.43	0.024	<0.001	0.670	<0.001	0.015
Leu	65.16	66.98	86.81	88.90	94.96	70.17	1.07	0.206	<0.001	0.925	0.020	0.995
Lys	41.41[c]	50.00[b]	80.70[a]	83.02[a]	78.27	77.52	1.22	0.004	<0.001	0.040	0.001	<0.001
Met	82.07[b]	76.77[c]	82.06[b]	91.85[a]	86.87	79.95	1.45	0.139	0.001	0.001	0.365	0.174
Phe	73.05	72.60	89.89	90.80	73.34	76.27	1.13	0.833	<0.001	0.529	0.187	0.140
Ser	37.19	46.16	80.61	80.81	70.22	73.46	3.31	0.192	<0.001	0.205	<0.001	0.002
Thr	50.94	50.29	88.69	82.05	65.19	69.11	2.40	0.172	<0.001	0.249	0.758	0.646
Tyr	60.80	55.81	83.69	81.53	74.45	74.55	1.78	0.076	<0.001	0.407	<0.001	0.028
Val	63.05	67.25	86.31	89.13	62.08	66.65	1.75	0.087	<0.001	0.701	0.007	0.003

[a–c]Means within the same raw with the same superscript letter are not different ($P > 0.05$).

[1]CPCC is cold-pressed canola cake; EP canola meal is expeller-pressed canola meal.

Table 3.6. DE, NE, and SID AA content of test ingredients in DM basis[1]

	Cold-pressed canola cake					EP		*P*-value				
	Non-heated		Heated			canola		Speed	Heat	Heat ×	CPCC vs.	CPCC vs. EP canola
Item	Slow	Fast	Slow	Fast	Seed	meal	SEM			Speed	Seed	meal
DE, Mcal/kg	3.15[c]	3.76[b]	5.08[a]	4.68[a]	3.93	3.44	0.20	0.515	<0.001	0.001	0.355	0.001
NE, Mcal/kg	2.06[d]	2.56[c]	3.55[a]	3.19[b]	2.99	2.32	0.14	0.568	<0.001	0.002	0.412	0.001
SID AA												
Ala	0.95[c]	0.95[c]	1.19[b]	1.29[a]	0.46	1.08	0.02	0.018	<0.001	0.011	<0.001	0.612
Arg	1.23[b]	1.13[c]	1.24[b]	1.60[a]	0.48	1.46	0.03	0.003	0.001	0.001	<0.001	0.001
Asp	1.33[d]	1.54[c]	1.73[b]	2.52[a]	0.51	1.62	0.05	<0.001	<0.001	0.001	<0.001	0.016
Cys	0.79[c]	0.74[d]	0.87[b]	0.98[a]	0.46	0.72	0.01	0.013	<0.001	0.001	<0.001	0.001
Glu	4.13[d]	5.68[b]	5.08[c]	7.37[a]	0.20	5.27	0.14	<0.001	<0.001	0.027	<0.001	0.057
Gly	0.80[c]	0.78[c]	1.30[b]	1.76[a]	0.27	1.04	0.07	0.020	<0.001	0.015	<0.001	0.163

His	0.34[c]	0.32[c]	0.48[b]	0.56[a]	0.16	0.50	0.02	0.102	<0.001	0.019	<0.001	0.001
Ile	1.55[c]	1.74[b]	1.80[b]	2.20[a]	0.35	2.00	0.03	0.001	<0.001	0.018	<0.001	0.673
Leu	1.21[c]	1.35[b]	1.36[b]	1.68[a]	0.61	1.36	0.02	<0.001	<0.001	0.002	<0.001	0.003
Lys	0.65[d]	0.77[c]	0.94[b]	1.11[a]	0.45	1.27	0.02	0.001	<0.001	0.001	<0.001	<0.001
Met	0.49[b]	0.41[c]	0.41[c]	0.53[a]	0.17	0.45	0.01	0.015	0.039	<0.001	<0.001	0.166
Phe	1.04[c]	1.12[b]	1.15[b]	1.34[a]	0.33	1.17	0.02	0.001	<0.001	0.009	<0.001	0.956
Ser	0.29[d]	0.42[c]	0.60[b]	0.94[a]	0.15	0.59	0.03	0.001	<0.001	0.007	<0.001	0.893
Thr	0.57[c]	0.63[c]	0.85[b]	1.12[a]	0.27	0.86	0.03	0.001	<0.001	0.009	<0.001	0.029
Tyr	0.50[c]	0.45[d]	0.59[b]	0.64[a]	0.23	0.62	0.01	0.995	0.001	0.009	<0.001	0.350
Val	1.31[b]	1.53[a]	1.63[a]	0.94[c]	0.35	1.51	0.04	0.001	0.009	<0.001	<.0001	0.057

[a–d]Means within the same raw with the same superscript letter are not different ($P > 0.05$).

[1]CPCC is cold-pressed canola cake; EP canola meal is expeller-pressed canola meal.

condition increased ($P < 0.05$) DE content of cold-pressed canola cake by 19% while barrel speed did not affect at heated barrel condition. Fast barrel speed at non-heated barrel condition increased ($P < 0.05$) the NE content of cold-pressed canola cake by 24% while fast barrel speed at heated barrel condition reduced ($P < 0.05$) NE by 10%. Both the DE and NE content of cold-pressed canola cake did not differ ($P < 0.05$) from canola seed but, was lower ($P < 0.05$) for EP canola meal. Heating and speed of the barrel interacted ($P < 0.05$) for SID AA content of test ingredients and effects of interaction were not consistent among AA.

3.5 Discussion

Cold-pressing of canola seed to extract crude canola oil is practiced in on-farm biodiesel production facilities. During cold-pressing, seed is subjected to mechanical pressing without heat application (Klein-Hessling, 2007). However, temperature of the seed might be increased up to 65°C due to the friction build up in the press (Spragg and Mailer, 2007) or the barrel might be heated directly, depending on the equipment model. In cold-pressing, oil recovery is low compared to solvent extraction and thus, resulted cake may contain 18% residual oil (Leming and Lember, 2005). Such a high residual oil content will increase the DE content relative to solvent-extracted canola meal (van Barneveld, 2008), and may thus facilitate a path to utilize on-farm produced cold-pressed canola cake in swine diets as not only a supplementary protein source, but also an energy-supplying feedstuff.

Processing conditions vary greatly among oil extraction plants; therefore, quality and nutritional value of cold-pressed canola cake varies greatly (Leming and Lember, 2005; Appendix 2). In the present study, cold-pressed canola cake samples from different plants were analyzed for proximate composition and 4 processing conditions were selected to produce a range of cold-pressed canola cake samples. The lack of knowledge about the content of digestible nutrients and anti-nutritional factors in cold-pressed canola cake and the effects of processing conditions on nutritional quality have limited the use of cold-pressed canola cake in swine diets. In the present study, application of heat to the barrel of the press during oil extraction increased the digestible nutrient content of cold-pressed canola cake while the effect of barrel speed was not consistent.

Cold-pressed canola cake has not been intensively studied in animal models but its chemical content was characterized in a few studies. Processing conditions during oil extraction greatly affects the nutritional and chemical content of press cake (Weigal, 1991; Glencross et al., 2004). A cold press with an output of 8 to 9 kg/h produced a canola cake with 19.4% ether extract in an Estonian study (Leming and Lamber, 2005). In Australia, cold-pressed canola cake contained 30% of canola seed oil as residual oil (Spragg and Mailer, 2007). With cold pressing, residual oil content is 60 to 70% (Mustafa et al., 2000). A high efficiency cold press designed to press 200 kg/h produced a canola cake with 27% ether extract (Thacker and Petri, 2009). Canola seed with more than 20% distinctly green seeds processed into a canola cake with 16% ether extract by the same cold press. The 11% lower ether extract content could be due to less residual

oil in the meal because green seeds have a thin seed (OGGG, 2009) that may enable more efficient oil extraction. Another possible reason is that green canola seeds are immature (OGGG, 2009) compared to regular canola seeds and might have less oil deposition (Fowler and Downey, 1970). In the present study, the cold press produced 0.8, 2.5, 1.7, and 4.8 kg/h of cold-pressed canola cake for non-heated slow, non-heated fast, heated slow, and heated fast barrel conditions, respectively, and contained 10, 17, 24, and 14% ether extract. Barrel speed and heat interacted for ether extract content of pressed-cake and effects were not consistent. Increasing barrel speed at non-heated condition increased the ether extract content of pressed-cake by 7% likely because canola seeds have less time to get crushed and pressed though the screw thereby increasing residual oil in the cake. In contrast, heated barrel together with increased barrel speed might more easily disrupt the cell walls of the seed and facilitated removal of oil that is encapsulated by cell walls (Armstrong, 1993) thereby reducing residual oil in the cake. Stir-frying condition had a remarkable effect on dropping the residual oil in pressed-cake (Kunjie et al., 2004). Thus, residual oil content of cold-pressed canola cake varied with processing conditions and quality of seed. In the present study, one sample of off-grade canola seed was processed into cold-press canola cake; thus, variation in residual oil content was solely due to changes in processing conditions.

Composition of cold-pressed canola cake primarily related to the efficiency of oil removal. In the present study, ether extract content of cold-pressed canola cake was correlated with GE content. The highest GE was reported for cold-pressed

canola cake with the highest ether extract content and vice versa. The CP and crude fiber content of pressed-cake was concentrated when more oil was extracted. On average, cold-pressed canola cake in the present study contained 30% more CP and 44% less crude fiber (DM basis) than in the Estonian study (Leming and Lember, 2005). In Alaska, for cold-pressed canola cake had a CP content of 28.3% of DM (Geier, 2004). In the United States, cold-pressed canola cake processed on-farm had a CP content of 36.9% of DM (Lardy, 2008). In Canada, cold-pressed canola cake contained 32% CP, 26% NDF, and 20% ADF on DM basis (Thacker and Petri, 2009). The EP canola meal used in the present study had 7% lower CP and 16% higher crude fiber than the cold-pressed canola cake on DM basis. The cold-pressed canola cake used in the present study had 111 and 8% higher CP and crude fiber respectively, than the parent whole canola seed in DM basis. Overall, the higher levels of CP and crude fiber in cold-pressed canola cake and EP canola meal than in whole canola seed could be attributed to the increased concentration of components due to oil extraction.

Processing conditions of cold pressing may affect digestibility of energy, likely due to altering densities of macronutrients. The AID and ATTD of energy of cold-pressed canola cake was lower for slow vs. fast barrel speed, perhaps in part due to a higher fiber content at slow barrel speed that may have reduced nutrient digestibility (Widyaratne and Zijlstra, 2007). Furthermore, AID and ATTD of energy of cold-pressed canola cake was higher with a heated than non-heated barrel. This difference could be due to increased in fat digestibility of pressed-cake due to heat application (Dänicke et al., 1998; Mujahid et al., 2003).

Fats and oil are rich in energy value (Jørgensen et al., 2000; Duran-Montagé et al., 2007) and highly digestible if provided in free form in the diet (Noblet and Shi, 1994). Canola oil as a supplementary fat source was very digestible with ileal digestibility above 90% (Jørgensen et al., 2000). Canola meal with 14% fat and 5.52 Mcal/kg GE had 17.7% higher energy digestibility than canola meal with 2.2% fat and 4.68 GE Mcal/kg for red seabream (Glencross et al, 2004). Therefore, the high energy digestibility for heated barrel conditions might be due to high ether extract content and improved fat digestibility.

The DE content is a function of GE content and energy digestibility. The measured DE content of cold-pressed canola cake varied from 3.15 to 5.08 Mcal/kg (DM basis) in the present study. A higher content of ether extract resulted in with a higher DE content for cold-pressed canola cake indicating that residual oil content is directly related with the DE content of the meal (van Barneveld, 2008). The average DE content of cold-pressed canola cake was 0.97 and 0.25 Mcal/kg higher than the DE content of 3.20 and 3.92 Mcal/kg (DM basis) included in the North American feedstuff tables (converted value NRC, 1998) for solvent-extracted canola meal and soybean meal. The DE content of cold-pressed canola cake was 21 and 24% (in DM) higher than EP canola meal and canola seed respectively. The NE content of cold-pressed canola cake used in present study was predicted using an equation that includes the measured DE content and macronutrient composition of cold-pressed canola cake (equation 4; Noblet et al, 1994). The NE content of cold-pressed canola cake was 22% higher and 15% lower (in DM) than EP canola meal and canola seed respectively. These

values indicate that cold-pressed canola cake has a higher energy value than EP canola meal mainly due to extra residual ether extract in the cold-pressed canola cake.

Except for Met and Lys, the SID of AA contents were affected independently by heat and barrel speed. The barrel heating might inactivate the myrosinase which is a heat –labile anti nutritive factor (Maheshwari et al., 1980) present in the cake which in turn increased the digestibility of AA. Furthermore the crude fiber content of cold-pressed canola cake was 2.2% higher for non-heated than heated. Increased fiber content may reduce the digestibility of AA. Nutrient digestion, especially for protein, AA, and minerals, is usually reduced when fiber is added to the diet (Eggum, 1995). This primarily indicates that higher SID AA contents are not due to high CP but increased digestibility of AA and crude fiber that affected by processing condition.

Barrel heating and speed interacted for SID Lys content. When the speed of the barrel increased from slow to fast, SID Lys content was increased for non-heated barrel but, had no effect for heated barrel. The EP canola meal had more SID Lys content than the cold-pressed canola cake. In expeller pressing, temperature of meal could increase up to 110ºC (Spragg and Mailer, 2007). Lysine is susceptible to heat damage (Klein-Hassling, 2007; Spragg and Mailer, 2007). The total Lys of EP canola meal was 17% higher than cold-pressed canola cake. Therefore, higher SID Lys content may be due to higher total Lys content present in the EP canola meal. Total Lys: CP of cold-pressed canola cake was 0.03 while that of EP canola meal was 0.04 indicating that SID Lys content

differences are not directly due to the processing condition, but CP content that affected by processing conditions. The source of canola seed for cold-pressed canola cake and EP canola meal was different. Therefore, the reason behind having more SID Lys content in EP canola meal than cold-pressed canola cake is likely due to high CP content of EP canola meal and differences in parent canola seed.

In summary, cold-pressed canola cake is a source of digestible energy and AA. On average, cold-pressed canola cake contained 4.17 Mcal/kg of DE, 2.84 Mcal/kg of NE, 0.87% SID Lys, 0.46% SID Met, and 0.79% SID Thr (in DM). The nutritional quality of cold-pressed canola cake varied with the processing conditions used during the oil extraction. The DE and SID AA content of cold-pressed canola cake were higher than EP canola meal and canola seed. The macronutrient profile of cold-pressed canola cake should be analyzed prior to swine diet formulation. In conclusion, the content of ether extract was an important determinant of energy value of cold-pressed canola cake; higher residual oil in the cake increased the DE and NE content. Processing conditions greatly impacted the digestible nutrient content of cold pressed- canola cake and should be validated using a growth study in pigs.

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Chapter 4. Effect of crude glycerol combined with solvent-extracted or expeller-pressed canola meal inclusion on growth performance and diet nutrient digestibility of weaned pigs

4.1 Abstract

Co-products from the canola and biodiesel industry may be alternative feedstuffs to reduce feed costs for swine. Solvent-extracted canola meal contains little residual oil and thus has low energy content. Combining canola meal with crude glycerol may be a strategy for increasing energy content of canola meal. Expeller-pressed canola meal might also be combined with crude glycerol. In total, 5 diets were formulated: a soybean meal control diet and 4 canola co-product diets were fed in a 2 x 2 factorial arrangement, with the 2 types of canola meal (solvent-extracted and expeller-pressed) partially replacing soybean meal and 2 levels of crude glycerol (0 and 5%). In total, 240 weaned pigs (6.3 kg BW; 27 d initial age) were housed in pens of 4 pigs and fed for 28 d. Pen feed disappearance and individual BW were measured weekly and feces were collected on d 17 and 18. The solvent-extracted and expeller-pressed canola meal contained 43.7 and 40.4% CP, 2.4 and 10.2% ether extract, and 11.4 and 9.9 % crude fiber (in DM), respectively. Glycerol contained 49.6 % of ether extract (in DM). For d 0 to 28, ADG, and G:F did not differ between the 2 types of canola meal and 2 levels of glycerol, and did not differ between canola co-product diets and the control diet. For d 0 to 7, ADFI was 10% higher ($P < 0.05$) for solvent-extracted than expeller-pressed canola meal diets. For d 0 to 28, ADFI was 6% higher ($P <$

0.05) for the control than canola co-product diets. Glycerol inclusion increased ($P < 0.05$) G:F for the solvent-extracted but not for expeller-pressed canola meal diet for d 8 to 14. Canola meal type interacted ($P < 0.05$) with glycerol inclusion for apparent total tract energy and CP digestibility, and DE content of diets. Glycerol increased ($P < 0.05$) energy digestibility by 1% and DE content by 0.14 Mcal/kg of DM for the solvent-extracted canola meal diet. In contrast, glycerol reduced ($P < 0.05$) CP digestibility and increased ($P < 0.05$) DE content by 0.04 Mcal/kg of DM for the expeller-pressed canola meal diet. The CP and energy digestibility of canola co-product diets was lower ($P < 0.05$) than that of the control diet, while the DE content did not differ. In conclusion, 15% of either solvent-extracted or expeller-pressed canola meal or in combination with 5% glycerol can partially replace soybean meal in diets formulated to equal NE and SID AA content fed to weaned pigs from 1 to 5 wk after weaning without affecting growth performance.

4.2 Introduction

Feed costs are the highest variable cost of pork production (Payne and Zijlstra, 2007). Feeding canola co-products may provide opportunities to reduce feed costs. Crude glycerol is a primary co-product of biodiesel production (Groesbeck et al., 2008). Currently, sufficient crude glycerol might be produced for inclusion in swine diets. A major limitation for inclusion of solvent-extracted canola meal in swine diets is the available energy content [Canola Council of Canada (CCC), 2009) and adding an energy source such as crude glycerol (Lammers et al., 2007)

may provide a solution. Mixing of glycerol into expeller-pressed canola meal might also create an opportunity for a new alternative feedstuff for swine.

Crude glycerol has been evaluated in swine diets (Bernal et al., 1978; Kijora et al., 1995; Simon et al., 1996; Zijlstra et al., 2009). These studies replaced cereal grain with crude glycerol that is absorbed by the monogastric gastrointestinal tract (Tao et al., 1983). Adding crude glycerol may have positive effects on ADFI (Groesbeck et al., 2008; Zijlstra et al., 2009) and increased energy digestibility (Zijlstra et al., 2009). Crude glycerol is a reasonably source of energy containing 3.21 Mcal/kg of ME for growing pigs (Lammers et al., 2007). However, research determining the value of glycerol as an energy supplement and the effect of glycerol on growth performance of weaned pigs are limited. Furthermore, research combining crude glycerol with solvent-extracted canola meal to increase energy for weaned pigs has not been conducted.

The hypothesis was canola co-products can be fed in diets formulated to be equal in NE and SID AA content to weaned pigs without impacting growth performance. The objectives were to measure growth performance and apparent total tract digestibility (ATTD) of energy and CP in weaned pigs fed 4 diets containing either solvent-extracted or expeller-pressed canola meal with or without crude glycerol in comparison to a soybean meal control diet.

4.3 Materials and methods

Experimental Design and Diets

The experimental design was a randomized complete block design with 60 pens divided into 12 blocks according to the ventilation gradient of the room. In total, 5 diets were formulated including a soybean meal control diet (Table 4.1). The 4 diets were in a 2 x 2 factorial arrangement with 2 types of canola meal (15% solvent-extracted or expeller-pressed) and 2 levels of crude glycerol (0 or 5%). Diets were formulated to be equal in NE and SID Lys contents (2.26 Mcal/kg of NE and 1.07% of SID Lys, as fed basis) and to meet or exceed vitamins and mineral requirements (NRC, 1998). Acid-insoluble ash (Celite 281, World Minerals, Santa Barbara, CA) was included as an indigestible marker. Diets were mixed and steam pelleted (70 hp; CPM, Crawfordsville, IN). Expeller-pressed canola meal and crude glycerol were sourced from Associated Proteins, Ste. Agathe, Manitoba, Canada and Milligan Bio-Tech, Foam Lake, Saskatoon, Canada respectively. Solvent extracted canola meal was sourced from University of Alberta feed mill from unknown origin.

Experimental Procedures

The animal protocol was approved by the University of Alberta Animal Care and Use Committee for Livestock, and followed guidelines established by the Canadian Council on Animal Care (CCAC, 1993). The study was conducted at the Swine Research and Technology Centre at the University of Alberta

Table 4.1. Ingredient composition of diets (as fed basis)[1]

		Canola meal			
	Soybean meal	Solvent-extracted		Expeller-pressed	
Ingredient, %	Control	- Glycerol	+ Glycerol	- Glycerol	+ Glycerol
Wheat	62.83	53.05	48.99	56.58	52.52
Soybean meal	15.00	7.50	7.50	7.50	7.50
Canola meal					
Solvent-extracted	-	15.00	15.00	-	-
Expeller-pressed	-	-	-	15.00	15.00
Lactose	10.00	10.00	10.00	10.00	10.00
Crude glycerol	-	-	5.00	-	5.00
Soy protein concentrate	2.50	2.50	2.50	2.50	2.50
Herring meal	2.50	2.50	2.50	2.50	2.50
Canola oil	2.00	4.50	3.50	1.00	-

Limestone	1.13	1.00	1.00	1.04	1.02
Mono/dical phosphate	1.10	1.05	1.08	1.00	1.05
Salt	0.50	0.50	0.50	0.50	0.50
L-Lys HCl	0.35	0.35	0.36	0.34	0.35
L-Thr	0.16	0.14	0.15	0.14	0.15
DL-Met	0.09	0.06	0.07	0.06	0.07
L-Trp	0.01	0.02	0.02	0.01	0.01
Vitamin premix[1]	0.50	0.50	0.50	0.50	0.50
Trace mineral premix[2]	0.50	0.50	0.50	0.50	0.50
Choline chloride 60%	0.03	0.03	0.03	0.03	0.03
Celite	0.80	0.80	0.80	0.80	0.80

[1]Vitamin premix provided per kg of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; and vitamin B_{12}, 0.025 mg.
[2]Mineral premix provided per kg of diet: Zn, 100 mg as $ZnSO_4$; Fe, 80 mg as $FeSO_4$; Cu, 50 mg as $CuSO_4$; Mn, 25 mg as $MnSO_4$; I, 0.5 mg as $Ca(IO_3)_2$; and Se, 100 mg as Na_2SeO_3.

(Edmonton, Alberta, Canada). In total, 240 weaned pigs (Duroc x Large White /Landrace F_1; Genex Hybrid; Hypor, Regina, Saskatchewan, Canada) with an initial BW of 6.3 ± 0.94 kg and initial age of 27 ± 2 d) were used. Pigs were weaned at approximately 20 d. The study was conducted in 3 rooms that were equipped with floor level pens (1.1 x 1.5 m) with plastic flooring and plastic solid partitions at the front and between pens. One adjustable height nipple drinker was attached to the back wall of the pen. A multiple-space self-feeder was attached to a side pen partition. Each room had 20 pens that were blocked across the ventilation gradient to provide 4 blocks per room that each contained the 5 diets, for a total of 12 observations per diet. Two gilts and 2 barrows were randomly selected from light and heavy BW groups and randomly assigned to each pen. Experimental diets were randomly assigned to pen within block. Pigs had ad libitum access to feed and water throughout the study. Individual animal was the sampling unit for weekly BW measurements. Feed disappearance was measured weekly and fecal grab samples were obtained on d 17 and 18. Average daily gain, ADFI, and G:F were calculated weekly and for the entire trial (overall d 0 to 28).

Chemical Analyses

Diets, ingredients, and freeze-dried feces were ground in a Retch mill (model ZMI, Brinkman Instruments, Rexdale, Ontario, Canada) over a 1-mm screen. Diets, ingredients, and feces were analyzed for DM (method 930.15; AOAC, 1990), CP by combustion analysis (method 990.03; AOAC, 2006), ether extract (method 920.39A; AOAC, 2006), and crude ash (method 942.05; AOAC, 2006).

Diets and feces were analyzed for acid insoluble ash (Atkinson, 1984) and GE using an adiabatic bomb calorimeter (model 5003, Ika-Werke GMBH & Co KG, Staufen, Germany); benzoic acid was used as a standard. Canola meals and diets were analyzed for crude fiber (method 978.10; AOAC, 2006), ADF (method 973.18; AOAC, 2006), and NDF (Holst, 1973). Diets were analyzed for AA (method 982.30E; AOAC 1990) and available Lys (method 975.44; AOAC 2006) at University of Missouri, Columbia, MO. Glycerol was analyzed for Na and K (method 956.01; AOAC 2006) and Cl (method 9.15.01, 943.01; AOAC 2006). Total glucosinolates content was determined by GC analysis using the method of the Canadian Grain Commission method developed by Heaney and Fenwick (1980) and modified by Daun and McGregor (1981) at POS Pilot Plant Corp, Saskatoon, SK, Canada.

Statistical analysis

Pen was the experimental unit. Data was analyzed using PROC Mixed in SAS (SAS Inst. Inc., Cary, NC). Initial BW was used as a covariate for ADG, ADFI and G: F. Diet was the fixed effect in the model and block was the random effect. For the whole study, data were analyzed as repeated measures analysis and week was the repeated term. Bayesian information criterion was used to determine the best variance covariance structure for the repeated measures (Wang and Goonewardene, 2004). Canola co-product means were analyzed as 2 x 2 factorial design having 2 canola meal types and 2 levels of glycerol and their interaction. Soybean meal control diet was compared to the 4 canola co-products diets as a

group with a pre-planned contrast. Treatment means were separated by the probability of difference by using LSMEANS and PDIFF statements in case an interaction between the main factors occurred. Differences were considered significant if $P < 0.05$.

4.4 Results

Solvent-extracted canola meal contained 3.27% more CP, 1.52% more crude fiber, and 7.81% less ether extract than EP canola meal (Table 4.2). Crude glycerol contained 49.58% ether extract (DM basis).

Table 4.2. Analyzed nutrient composition of canola co-products (DM basis)[1]

	Canola meal		Crude
Nutrient, %	Solvent-extracted	Expeller-pressed	glycerol
CP	43.71	40.44	0.85
Ether extract	2.43	10.24	49.58
Crude fiber	11.38	9.86	-
Crude ash[1]	8.02	7.25	10.76
ADF	20.55	16.65	-
NDF	32.89	25.68	-
Total glucosinolates, µmol/g	2.69	7.79	-

[1]Crude glycerol contained 0.02% Na, 3.36% K, and Cl was not detected.

The CP and AA content was consistent among canola meal diets, with a lower CP and total Lys content for the soybean meal control diet (Table 4.3). The ether extract content was higher for diets with than without glycerol, and higher for solvent-extracted than EP canola meal diets, and was lowest for the soybean meal control diet.

Table 4.3. Analyzed nutrient composition of diets (DM basis)[1]

		Canola meal			
	Soybean meal	Solvent-extracted		Expeller-pressed	
Nutrient, %	Control	- Glycerol	+ Glycerol	- Glycerol	+ Glycerol
Moisture	10.45	11.15	10.25	9.95	10.34
GE, Mcal/kg	4.36	4.54	4.65	4.42	4.50
CP	21.86	22.26	22.03	23.00	22.71
Ether extract	3.81	6.45	8.07	4.26	5.60
Crude fiber	2.32	3.70	3.51	3.25	3.44
Crude ash	6.59	6.74	6.83	6.53	6.87
ADF	4.03	6.42	6.17	6.19	6.05
NDF	14.45	20.46	22.30	25.00	17.96
AA					
Ala	0.86	0.93	0.91	0.90	0.93
Arg	1.26	1.31	1.30	1.28	1.33
Asp	1.73	1.67	1.68	1.64	1.72

Cys	0.31	0.38	0.38	0.39	0.42
Glu	4.40	4.49	4.29	4.43	4.45
Gly	0.92	1.02	1.01	1.00	1.03
His	0.50	0.54	0.53	0.53	0.55
lle	0.86	0.89	0.85	0.89	0.91
Leu	1.51	1.59	1.56	1.54	1.61
Lys	1.32	1.42	1.42	1.34	1.41
Met	0.31	0.37	0.37	0.36	0.38
Phe	0.97	0.98	0.96	0.97	0.99
Pro	1.36	1.44	1.40	1.42	1.43
Ser	0.84	0.90	0.95	0.87	0.91
Thr	0.83	0.90	0.95	0.87	0.93
Trp	0.31	0.29	0.29	0.31	0.30
Tyr	0.60	0.62	0.60	0.60	0.60
Val	0.98	1.07	1.04	1.05	1.09
Total	19.98	21.01	20.72	20.60	21.19
Available Lys	1.26	1.33	1.34	1.28	1.34

Canola meal and glycerol did not interact for ADG during any period of the study (Table 4.4). Canola meal type and glycerol did not affect ADG. The ADG of pigs fed canola co-product diets did not differ from pigs fed the soybean meal control diet.

For d 0 to 28, canola meal and glycerol did not affect ADFI or interact for ADFI (Table 4.4), similar for d 15 to 21 and d 22 to 28. Pigs fed canola co-products diets had a 6% lower ($P < 0.05$) ADFI than pigs fed soybean meal control diet. For d 0 to 7, ADFI was 10% higher ($P < 0.05$) for pig fed solvent-extracted than EP canola meal diets. For d 8 to 14, canola meal and glycerol interacted ($P < 0.05$) for ADFI. Glycerol in the solvent-extracted canola meal diet reduced ($P < 0.05$) ADFI by 12% while inclusion of glycerol in the expeller-pressed canola meal diet did not affect ADFI.

For d 0 to 28, canola meal and glycerol did not affect G:F or interact for G:F (Table 4.4), and G:F of pigs fed canola co-product diets did not differ from pigs fed the soybean meal control diet, similar for d 0 to 7, 15 to 21, and 22 to 28. For d 8 to 14, canola meal and glycerol interacted ($P < 0.05$) for G:F. Glycerol in solvent-extracted diets increased ($P < 0.05$) G:F by 21% while inclusion of glycerol in the EP canola meal diet did not affect G:F.

Canola meal and glycerol interacted for energy and CP digestibility and DE content (Table 4.5). Specifically, glycerol reduced ($P < 0.05$) CP digestibility by 3% for the EP canola meal diet, but increased ($P < 0.05$) energy digestibility by 1% for solvent-extracted canola meal. Glycerol increased DE content by 0.14 and 0.04 Mcal/kg of DM for solvent-extracted and EP canola meal diets, respectively.

Table 4.4. Effect of canola meal and glycerol on growth performance of weaned pigs[1]

	Soybean	Canola meal					*P*-value			
	meal	Solvent-extracted		Expeller-pressed			Control	Canola	Glycerol	Meal x
Item	Control	- Glycerol	+ Glycerol	- Glycerol	+ Glycerol	SEM	vs. Rest	meal		Glycerol
ADG										
d 0 to 7	0.270	0.272	0.252	0.268	0.256	0.025	0.759	0.999	0.494	0.866
d 8 to 14	0.419	0.400	0.427	0.391	0.380	0.023	0.453	0.236	0.751	0.455
d 15 to 21	0.528	0.512	0.475	0.471	0.503	0.026	0.174	0.800	0.940	0.228
d 22 to 28	0.650	0.595	0.638	0.651	0.635	0.021	0.361	0.227	0.540	0.205
d 0 to 28	0.469	0.445	0.448	0.445	0.443	0.013	0.156	0.870	0.956	0.860
ADFI										
d 0 to 7	0.286	0.303	0.295	0.285	0.257	0.011	0.896	0.016	0.108	0.394
d 8 to 14	0.555	0.535[a]	0.470[b]	0.510[a,b]	0.540[a]	0.021	0.056	0.267	0.371	0.035

d 15 to 21	0.757	0.743	0.741	0.710	0.699	0.032	0.292	0.209	0.829	0.887
d 22 to 28	1.022	0.931	0.961	0.950	0.986	0.026	0.017	0.450	0.251	0.930
d 0 to 28	0.655	0.624	0.606	0.616	0.619	0.017	0.037	0.909	0.642	0.573
G:F										
d 0 to 7	0.945	0.914	0.878	0.945	1.006	0.087	0.912	0.315	0.868	0.579
d 8 to 14	0.758	0.752[b]	0.909[a]	0.765[b]	0.706[b]	0.041	0.598	0.027	0.233	0.018
d 15 to 21	0.704	0.695	0.650	0.658	0.731	0.031	0.502	0.466	0.654	0.074
d 22 to 28	0.637	0.644	0.664	0.688	0.644	0.020	0.215	0.543	0.583	0.134
d 0 to 28	0.711	0.713	0.741	0.720	0.718	0.008	0.182	0.323	0.115	0.094

[a–c]Means within the same item with the same superscript letter are not different ($P > 0.05$).

[1]Twelve pen observations per diet. Treatment means are reported as least squares means.

Table 4.5. Apparent total tract (ATTD) CP and energy digestibility and DE content (Mcal/kg; DM basis) of diets[1]

	Soybean	Canola meal					*P*-value			
	meal	Solvent-extracted		Expeller-pressed			Control	Canola	Glycerol	Meal x
Item	Control	- Glycerol	+ Glycerol	- Glycerol	+ Glycerol	SEM	vs. Rest	meal		Glycerol
Digestibility, %										
CP	77.87	73.92[b]	76.18[a,b]	76.82[a]	73.72[b]	1.07	0.007	0.818	0.662	0.009
Energy	84.05	80.95[b]	81.90[a]	80.96[b]	80.54[b]	0.41	<0.001	0.019	0.339	0.020
DE content	3.66	3.67[b]	3.81[a]	3.58[d]	3.62[c]	0.02	0.523	<0.001	<0.001	0.002

[a–d]Means within the same raw with the same superscript letter are not different ($P > 0.05$).

[1]Twelve pen of 4 pigs per diet. Treatment means are reported as least squares means.

Digestibility of CP and energy of the soybean meal control diet was 3.5% higher ($P < 0.05$) than the canola co-product diets; however, the DE content of the soybean meal control diet did not differ from canola co-product diets.

4.5 Discussion

In western Canada, canola is a major cash crop. Following processing for oil extraction and subsequent biodiesel production, an array of canola co-products will be available for incorporation into swine diets. The capacity for oil extraction is increasing in western Canada and biodiesel production from renewable energy sources has experienced explosive growth (Kerr et al., 2007) to reduce the dependence on petroleum-based fuel products and reduce their environmental footprint (Hill et al., 2006). Canola co-products have been used in swine diets with varying success. Canola meal may reduce growth performance in young pigs (McIntosh et al., 1986), in part due to feed intake responses or by feeding diets formulated using DE that did not rank canola meal properly to other feedstuffs. Grower-finisher pigs fed expeller-pressed canola meal can maintain G:F (Seneviratne et al., 2009), but excess may reduce ADFI and thereby ADG. Crude glycerol is a principal canola co-product of biodiesel production (Ma and Hanna, 1999; Van Gerpen, 2005; Thompson and He, 2006), with 79 g of crude glycerol generated for every 1 L of biodiesel produced (Thompson and He, 2006). The increasing capacity of canola crushing and biodiesel production in Canada will provide ample opportunities to use canola co-products in swine diets.

The use of solvent-extracted canola meal is limited in swine diets due to its lower content of available energy and AA than soybean meal. The energy content of crude glycerol is higher than canola meal, and crude glycerol, as energy source, may play an important role in meeting the energy needs of pigs (Lammers et al., 2007). Therefore, adding glycerol to solvent-extracted canola meal may create a feedstuff combination for use in swine diets, although some oil still needs to be added to meet the energy needs of the young pig. Combining crude glycerol and expeller-pressed canola meal may also be possible, if the expeller and biofuel processing plants are co-located. In the present study, ADG and G:F of weaned pigs fed with combinations canola co-products and soybean meal control diets did not differ, indicating that the feeding of canola co-products is a worthwhile pursuit.

Crude glycerol is not a purified feedstuff and may contain variable amounts of other components. The crude glycerol in the present study contained 1.24 %-units less Na and 3.35%-units more K than glycerol from other studies (e.g., Lammers et al., 2007), indicating that different salts are used during the biodiesel production process. Furthermore, the used in the present study contained 49.6% ether extract, crude glycerol in previous research contained 13.1% (Thompson and He, 2006), and more purified glycerol contained 0.12% ether extract (Lammers et al., 2007), indicating that composition of crude glycerol may vary widely. Thus, knowing the composition of the specific batch of crude glycerol prior to feed formulation is important to ensure predictable growth performance.

In the present study, ADG for the total study period was lower than achieved in other recent studies. For example, in corn and soybean meal-based diets, ADG was 0.570 kg/d (Groesbeck et al., 2008). In a recent study in the same facility, ADG was 520 to 560 g/d using wheat-based diets. Combined, these results indicate that growth performance of pigs in the present study was 10% below expectation; reduced animal health was not observed.

In the present study, ADG and G:F was similar for the soybean meal control and canola co-product diets for d 0 to 28. Pigs fed canola co-products diets ate 6% less than pigs fed soybean meal control diet. Several explanations are possible. First, canola co-product diets contained 60% more ether extract than the control diet. Increased dietary fat may reduce ADFI of pigs (Azain, 2001) in part because pigs eat to meet their energy requirement (NRC, 1998). Second, the presence of glucosinolates in the diet may reduce feed intake due to its bitter taste (Fenwick et al., 1982). Glucosinolates content of solvent-extracted and EP canola meal diets used in the present study was 2.7 and 7.8 µmol/g, respectively (Table 4.2). These levels were above the 2.5 µmol/g of tolerance level of glucosinolates (Bell, 1993; Schone et al., 1997a, b).

The addition of canola meal in the diets considerably increased fiber content compared to the soybean meal diet. Fiber is known to reduce digestibility of CP (Eggum, 1995) and AA (Grieshop et al., 2001). Thus reduced CP and energy digestibility could be due to increased fiber content in canola co-products. Degradation of fiber in the swine intestine depends on source of fiber, other available nutrients, and microbial population residing in the hindgut (Varen and

Yen, 1997) and VFA produced by microbial population can supply about 30% of the maintenance requirement of the pig (Rérat et al., 1987). However, the efficiency of utilization of dietary energy decreases with more fiber in the diet (Noblet et al., 1994). The increased content of fat and therefore DE content in canola co-product diets counteracted the negative fiber effects on energy and AA utilization to some extent.

Overall, feed intake did not differ between the 2 types of canola meal; however, ADFI was 9% higher for d 0 to 7 for pigs fed solvent-extracted canola meal than pigs fed expeller-pressed canola meal diets. Negative effects of glucosinolates on animals are relative to its dietary concentration (Tripathi and Mishra, 2007). Based on feedstuff analyses (Table 4.2), residual glucocinolates in the solvent extracted canola meal diets was lower than in the expeller-pressed canola meal diets (0.40 vs.1.17 μmol/g). The reduced feed intake of diets containing glucosinolates is due to the presence of sinigrin and progoitrin, as both glucosinolates are associated with bitter taste (Fenwick et al., 1982). Expeller-pressed canola meal diets contained less ether extract and less free canola oil as a specific feedstuff than the solvent-extracted canola meal diet, but contained more residual canola oil still bound inside the feedstuff. Perhaps, pigs may eat more of free canola oil than oil bound to the meal. The higher DE content for the solvent-extracted than expeller-pressed canola meal diets indicated that the extra GE added as canola oil to the solvent-extracted canola meal was digested well. Pigs do not use the oil in canola seed as effectively as they used free canola oil (Thacker, 1998).

In the present study, adding 5% glycerol by replacing wheat as an energy source did not affect growth performance. Crude glycerol in swine diets did not or marginally affected growth performance in a range of swine studies (Mourot et al., 1994; Kijora et al., 1995, 1997; Kijora and Kupsch, 2006). Adding crude glycerol may have positive effects on ADFI (Groesbeck et al., 2008; Zijlstra et al., 2009). Even up to 10% glycerol did not have negative effects on growth performance of grower finisher pigs (Lammers et al., 2007) indicating that crude glycerol can serve as energy source for pigs within existing logistical and feed processing constraints.

Adding crude glycerol by replacing wheat enhanced energy digestibility of the solvent-extracted canola meal diet. This diet contained 1.62% more ether extract with glycerol than without (DM basis). Solvent-extraction of canola oil is practiced using a solvent (hexane) to maximize oil recovery from the seed (Leming and Lamber, 2005). Therefore, residual oil content is very low and by adding a more available energy source as glycerol (Kerr et al., 2007), the energy content of diets containing solvent-extracted canola meal can be enhanced to partially counteract the low energy content, making canola meal a more attractive feedstuff in feed formulation for swine. Inclusion of crude glycerol increased the DE content of the solvent-extracted canola meal diet, with a smaller effect for the expeller-pressed canola meal diet. In the solvent-extracted canola meal diet, adding of 5% glycerol provided extra DE, because extra GE was provided and energy digestibility was increased. In contrast, DE content was slightly increased energy digestibility was not altered for the expeller-pressed canola meal diet.

Adding crude glycerol reduced CP digestibility for EP canola meal in the present study. The EP canola meal diet with glycerol contained 6% more crude fiber than without glycerol. The inverse relation between fiber content and digestibility of CP has been well established (Grieshop et al., 2001). For example, increasing either soluble or insoluble non-starch polysaccharide by 3% reduced the apparent total tract apparent digestibility of CP (Bach-Knudsen and Hansen, 1991). Furthermore, glycerol may stabilize protein and thereby make protein more resistant for denaturing (Feng and Yan, 2007). Therefore, reduced CP digestibility might be due to the protein stabilizing effect of glycerol.

In summary, canola co-product diets resulted in ADG and G:F as similar to soybean meal control diet for ADG and G:F, even though ADFI was 6% lower for pigs fed canola co-products diets. For the solvent-extracted canola meal diet, adding 5% glycerol provided extra DE and increased energy and CP digestibility. Crude glycerol can thus be added to solvent-extracted canola meal to enhance the energy content. In conclusion, 15% of either solvent-extracted or expeller-pressed canola meal, or in combination with 5% glycerol can partially replace conventional soybean meal in diets formulated to be equal in NE and SID AA content fed to weaned pigs from 1 to 5 wk after weaning without affecting growth performance.

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Chapter 5. General Discussion

In an effort to reduce dependence on petroleum-based fuel products and reduce their negative impact on the environment (Hill et al., 2006), production of biodiesel from renewable energy sources has experienced explosive growth (Kerr et al., 2007). The canola crushing industry in western Canada is expanding and will produce more co-products that will be marketed to the livestock industry. Furthermore, the biodiesel industry in Canada was promoted by the Canadian federal and provincial governments with the objectives of reducing dependence on petroleum-based fuel and green house gas emission, improving rural development and enhancing and stabilizing farm income, and thus represents an additional economic opportunity for agriculture (Racz, 2007). The biodiesel industry based on canola complements the existing canola crushing capacity for canola oil for human consumption. The main co-products of canola crushing for the biodiesel industry are canola meal and glycerol (BBI Biofuels Canada and Saville, 2006). These co-products are of high interest as potential alternative feedstuffs for swine to increase global feed competitiveness. Therefore, the canola and biodiesel industries open up opportunities for the livestock industry to use canola co-products to develop cost-effective feeding programs. Characterization of the nutritional quality of co-products followed by validation utilizing growth performance experiments is required for use in swine diet formulation. The animal work conducted in this thesis is specifically focused to address this knowledge gap.

In Chapter 2, the EP canola meal was nutritionally characterized; then inclusion of increasing levels of EP canola meal was investigated in grower-finisher pigs in diets formulated using NE and SID AA determined previously. The EP canola meal contained dietary energy partly in the form of residual oil and also contained AA that were digestible, resulting in an interesting digestible energy and AA profile. Therefore, the thesis hypothesis that EP canola meal contains valuable energy and AA was accepted. In a validation study, 1,100 pigs were housed in 50 pens and fed 5 dietary regimes with increasing and gradually reduced levels of EP canola to measure growth and carcass characteristics and to validate that the use of the NE system predict performance and the NE value of EP canola meal. Overall, increasing dietary EP canola meal linearly decreased the ADG and ADFI and linearly increased the G: F. The reduced ADFI indicated that even though diets were formulated to equal NE content, growth performance may differ because a reduced feed intake due to factors other than energy in the diet, such as residual anti-nutritional factors. Dietary glucosinolates caused metabolic disorders such as gastro intestinal tract and liver hypotrophy that in turn increased the maintenance energy requirement of the pig that may reduce growth performance. Therefore, the hypothesis that feeding EP canola resulted in equal performance was rejected, although carcass characteristics were not different. The reduction in ADFI for the EP canola meal diets can perhaps be compensated by using increased dietary AA to ensure that AA intake is maintained. In conclusion, EP canola meal is a valuable feedstuff to consider in swine feed formulation, but there are risks to use this alternative feedstuff that should be managed carefully.

In Chapter 3, the effect of processing conditions on the nutrient digestibility of cold-pressed canola cake was investigated using EP canola meal and canola seed as comparisons. On-farm, canola oil extraction is mostly done by cold pressing and cake quality is greatly affected by processing conditions (Van Barneveld, 2008). To have representative samples of cold-pressed canola cake, 4 processing conditions were applied using 2 speeds of the press and with or without external heat applied. Cold-pressed canola cake contains more residual oil than EP canola meal and solvent-extracted canola meal, and ether extract content of cold-pressed canola cake varied from 12 to 27% among processing conditions. The application of heat and speed during oil extraction interacted for nutrient digestibility, indicating that friction and heat affect energy digestibility using different mechanisms. Cold-pressed canola cake is a good source of dietary energy having a content of NE in the range of 1.82 to 3.28 Mcal/kg (DM basis) and SID Lys in the range of 0.65 to1.10 % (in DM) depending on the processing conditions used. Therefore, the thesis hypothesis that cold-press canola cake is an acceptable feedstuff was accepted.

In Chapter 4, combinations of canola co-products were studied in comparison to soybean meal fed to weaned pigs. Solvent-extracted canola meal contained less residual oil than EP canola meal and cold-pressed canola cake. A major limitation of the value and inclusion of solvent-extracted canola meal in swine diets is the available energy content (CCC, 2009). The addition of crude glycerol was beneficial. Interestingly, growth performance did not differ among the canola co-product diets and not even in comparison with the soybean meal control;

indicating that canola co-product may play a more significant role in the feeding of young pigs compared to current practice. The hypothesis that diets containing canola co-products can be fed in diets formulated to equal NE and SID AA content to weaned pigs without effects on growth performance was thus accepted. Overall, growth performance was not excellent. Test diets contained 15% canola meal where only 5% is recommended for weaned pigs (CCC, 2009) but other reasons must have played a role as well, because performance was not different from pigs fed the soybean meal control.

In summary, the present thesis fills some of the existing gaps in the lack of knowledge about the nutritional quality of canola co-products for swine. For the canola industry and associated biodiesel industry. The work conducted is of importance because the pork and feed industry have been identified as an important market for the increasing volumes of co-products produced. The new technical information in this thesis will support decisions for risk management, feed formulation, and placing an economic value on the co-products. For the pork industry, the detailed characterization of the nutritional value of co-products from the canola and biodiesel industry creates large opportunity to use these co-products as alternative feedstuffs to enhance the competitiveness of this industry.

In general, 3 studies were conducted in well; however, limitations were identified. Diets of the highest inclusion level of EP canola meal were formulated to 22.5% EP canola meal; however, inclusion level for this regime had to be reduced to 18% to counter the lower feed intake for this regimen during phase 1. This resulted in unequal spacing by having 18, 15, 7.5 and 0 % EP canola meal in

the test feeding regimens that had to be corrected for. Nutritional characterizations of alternative feedstuffs are first carried out in individually-housed pigs. However, the nutritional values should be validated in group-housed pigs with free access to feed. This is an important component of research to the use of alternative feedstuffs. Another important control for the study would be a sample of solvent-extracted canola meal. We could only analyze for jowl fat sample, because we could not reduce economic value of the carcass. However, analysis of fatty acid profile of belly fat might have given the better understanding of impact of high inclusion of EP canola meal on processed meat products. For Chapter 3, the processing of cold-pressed canola cake was time demanding. Specifically, processing condition at speed 2 and without heat application only produced 0.4 kg/hr of cold-pressed canola cake. Parent canola seeds of cold-pressed canola cake and EP canola meal were different and thus reasons for differences in some variables could not be fully explained. Effect of interaction of barrel heating and speed on oil removal was not fully explained with current data, but electronic microscopy images might help. In Chapter 4, the crude glycerol was obtained from the producer and was not analyzed for its composition prior to feed formulation. We assumed that the composition was similar to previous batches from the same producer that we have used. The energy value of glycerol found in the literature was used in feed formulation; however, the energy value of glycerol may vary drastically with changes in composition. Residual compounds such as methanol, ethanol, Na, and K; the most important soap content in crude glycerol may also affect growth performance, and these were not considered during feed

formulation. The seed used to produce cold-pressed canola cake of the present study was heated and moldy that indicated that farmers could use off-grade canola seeds for cold-pressing and still the cake would be an acceptable feedstuff. To have more efficient oil extraction, heating of seeds at farm level and different screw configuration are suggested.

In future studies, cold-pressed canola cake could be included in diets for grower-finisher pigs to validate its suitability in swine diet formulation. Very few studies have been conducted to evaluate the composition of cold-pressed canola cake; therefore, the effect of cold-pressed canola cake on growth performance and carcass characteristics should be investigated. Furthermore, a representative sample of cold-pressed canola cake could be studied for impact of high fat and fiber diets on carcass and pork quality. Expanded analyses on NSP of EP canola meal and cold-pressed canola meal is suggested because, the various types of polysaccharides in canola which individually or collectively could influence the nutritive value of the meal (Slominski and Campbell, 1990).

Few data on the chemical composition of crude glycerol have been published. Furthermore, limited work has been completed on feeding crude glycerol as an energy-supplying feed ingredient in pig diets. All seem to indicate that logistical and not biological limitations will be the main constraints for inclusion into feed. Crude glycerol is not currently an approved feed ingredient in Canada. The quality of crude glycerol is highly dependent on facility and therefore, quality of crude glycerol should be assessed in any future research experiment. Methanol is poisonous at low concentrations and may cause metabolic disorders and

blindness. Future research to ensure the safety of feeding crude glycerol and identification of specific analyses may facilitate approval as feedstuff before recommending crude glycerol as a competitive energy supplying feed ingredient for swine in Canada.

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Appendix 1

Equation for digestibility and Explanation of DE and NE content calculations

The AID AA was determined by quantifying the nutrient intake in feed and digesta at terminal ileum. Digesta collection was restricted for 10 h and thus indigestible marker was included in the feed. Therefore marker concentration in feed and digesta was determined and values were substituted for the following equation.

$AID = [1- (AA_d / AA_f) \times (Cr_f / Cr_d)] \times 100\%$ [Eq. (2) of Stein et al., 2007]

where AID is the apparent ileal digestibility of an AA (%), AA_d and AA_f are the concentration of that AA in ileal digesta and feed (g/kg of DM), respectively, and Cr_d and Cr_f are the Cr_2O_3 concentration in the ileal digesta and feed (g/kg of DM), respectively.

The IAA_{end} of each AA was determined based on the AA values of ileal digesta of pigs fed with N–free diet and was calculated using following equation.

$IAA_{end} = [AA_d \times (Cr_f / Cr_d)]$ [Eq. (3) of Stein et al., 2007).

where IAA_{end} is the basal ileal endogenous loss of an AA (g/kg of DMI).

By correcting the AID that was calculated for each AA of each test diet for IAA_{end}, the standardized ileal digestibility (SID) values were calculated using following equation.

$SID = [AID + (IAA_{end} / AA_f) \times 100]$, [Eq. (7) of Stein et al., 2007).

where SID is the standardized ileal digestibility of an AA (%).

SID AA content in the ingredient was calculated as follows;

AA content in the ingredient x SID % = SID AA content in the ingredient

AID and total tract energy digestibility of experimental diets were calculated using equation Eq. 3 of Stein et al (2007) substituting energy values instead AA.

AID and total tract digestibility of a nutrient was corrected for other ingredients that contribute same nutrient and was calculated using following equation.

AID, % of nutrient = $((T_t \times D_{nt}) - P_s \times D_{ns} / (P_t))$

where T_t is the sum of percentage of the sources contributing to the nutrient in the test diet, D_{nt} is the calculated digestibility of the nutrient in the test diets, P_s is the percentage of the other contributing sources for the nutrient of concern, D_{ns} is the digestibility percentage of the nutrient in other sources and P_t is the percentage of the ingredient in the test diet.

DE content in the ingredient was calculated as follows;

GE content in the ingredient x ATTD = DE content of the ingredient

NE content in the ingredient was calculated as follows;

NE = 0.703 x DE – 0.0041 x CP + 0.0066 x EE – 0.0041 x CF + 0.0015 x ST (Noblet et al., 1994).

where, EE is ether extract, CF is crude fiber and ST is starch content of the ingredient

Appendix 2

Composition of cold-pressed canola meal samples in DM basis

Plant[1]	Condition	Moist	CP	Crude fat	Crude fiber	Ash	NDF	Ca	P
CIGI	cold / speed1	9.51	33.31	15.27	8.08	5.53	18.72	0.54	0.86
	cold/ speed2	9.11	32.10	17.11	7.65	5.49	18.70	0.54	0.84
	cold / speed3	9.01	31.13	18.67	7.79	5.35	17.37	0.53	0.83
	cold / speed4	8.80	36.80	20.39	7.51	5.21	17.44	0.51	0.79
	cold / speed5	8.59	31.01	21.28	6.39	5.19	17.72	0.51	0.81
	cold/ speed6	8.36	30.32	21.64	5.91	5.23	17.61	0.52	0.82
	heat/ speed1	5.84	29.34	26.01	6.16	5.08	20.25	0.49	0.75
	heat / speed2	6.20	30.46	23.89	7.51	5.22	19.39	0.51	0.80
	heat/speed3	6.51	30.62	22.69	7.81	5.28	18.05	0.53	0.82
	heat /speed4	6.79	30.68	22.08	8.07	5.28	19.41	0.52	0.82

	heat/speed5	7.09	31.14	21.48	7.90	5.34	18.04	0.51	0.82
GFC		6.18	32.93	12.32	8.57	6.27	27.24	0.64	0.99
Ecoseeds	Cold press extruder (comet type),								
	One time through	6.28	25.90	32.42	7.18	4.38	15.70	0.42	0.65
Wineglassranch	With about 6 mm die opening								
	No. 1 canola seeds	8.72	26.6	27.72	5.93	5.31	17.83	0.48	0.77
	Cold press extruder (comet type),								
	One time through with about								
	6 mm die opening, off grade canola	6.1	30.42	21.25	7.13	5.58	38.54	0.52	0.92
	5 tons cold screw press (Chinese)								
	off grade canola seeds	8.65	31.10	15.12	6.87	5.69	32.64	0.53	0.90
	Camelina meal	7.89	32.45	18.16	8.75	4.48	31.31	0.30	0.74
Associated									
Protein		4.67	36.42	12.51	9.05	6.64	21.39	0.54	1.01

Wineglassranch	No 1 canola seeds	6.93	19.51	45.92	4.86	3.85	20.49	0.34	0.56
	Off grade canola seeds	4.69	18.15	49.22	6.75	3.42	30.05	0.29	0.50
	Camelina seeds	6.25	23.56	38.28	7.27	3.26	32.11	0.209	0.527
Bifrostbio		13.52	37.42	20.18	7.09	6.26	17.65	0.57	1.10

[1]CIGI- Canadian International Grain Institute- Rex Newkirk – rnewkirk@cigi.ca ;GFC- Gowans Feed Consultancy – Malacky Young – malackyy@telus.net; Ecoseeds - Adam LaLiberte - ecoseeds@telusplanet.net; Wineglassranch - Parker , CO - Judy Bowcott /Ken Herlinveaux - wineglassranch@abnorth.com ; Associated Protein - Manitoba - Robert Teffaine - TP: (204) 882-2565 ext 225; Bifrostbio - Manitoba - Roy Eyjolfson - info@bifrostbio.com - TP: 204-376-3075.

Appendix 3

Final Presentation

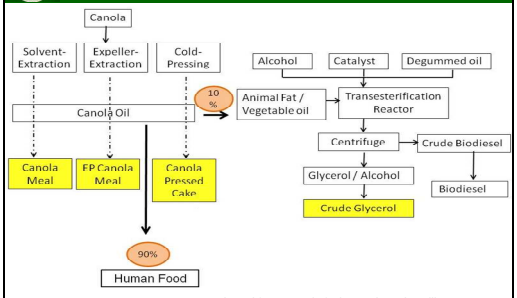
Nutritional Characterization of Canola Co-products for Swine

Ruwani Seneviratne

Introduction

- Canola – major oil seed crop in Canada (CCC, 2009)
  - 9 million tonnes/yr
  - 50% crushing in Canada
- Increased canola crushing capacity
  - Oil - Human food, feedstock for biodiesel
  - Canola meal – livestock feed
- Different processing technology

Flow Chart of Canola Crushing and Biodiesel Processing



Adapted from BBI Bio fuel Canada and Saville, 2006

Introduction

- Co-products Availability
  - 2.4 million tonnes/yr canola meal
  - 0.24 million tonnes/yr EP canola meal
- Necessity for alternative markets
- Feed costs are the highest variable cost of pork production (Payne and Zijlstra, 2007)
- Co-products: potential alternative feedstuffs

Gap in Knowledge

- Co-products characterization
  - Nutritional quality
  - Economic value
- Validation
  - Growth performance study

Thesis - Hypotheses

- EP canola meal (Study 1)
  - Good source of energy and AA
  - No detrimental effects on growth and carcass quality
- CPCC (Study 2)
  - Good source of energy and AA
  - Nutritional quality varied with processing conditions
- Canola co-products + Glycerol (Study 3)
  - No detrimental effects on growth of weaned pigs

Study 1

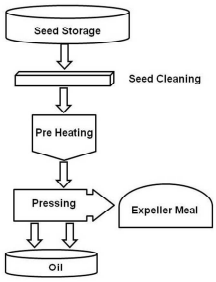
Nutritional Value of Expeller-Pressed Canola Meal for Grower-Finisher Pigs

Journal of Animal Science (Submitted)

Introduction

- EP canola meal
  - Oil and energy content
  - Protein source
- At 12 to 18% in grower-finisher pig diets (Brand et al., 2001)
- Higher ME than solvent-extracted canola meal (Smulikowska et al. 1997, 2006)
- Residual canola oil unsaturated (Rowghani et al., 2007)

Flow Chart of Expeller Pressing



(Adapted from Leming and Lember, 1999)

Gap in Knowledge

- Limited info about nutritional value of EPCM
- EPCM - not intensively studied in swine

Hypotheses

- EPCM had a valuable energy and digestible AA content
- Feeding EPCM would reduced feed cost, and resulted in equal growth performance if diets formulated using NE and SID AA
- Potential changes in carcass and fat quality characteristics could be mitigated by feeding decreasing graded levels of EPCM

Objectives

- To determine the DE content and digestible AA profile of EPCM sample (Exp. A)
- To evaluate the growth performance and carcass characteristics (Exp. B)

Materials and Methods

Exp. A - Digestibility Study

- 6 ileal-cannulated barrows (36 kg)
- N free diet and EPCM diet
- EPCM - sole source of CP and AA
- N–free diet
  - Estimate basal ileal endogenous losses of CP and AA (Stein et al., 2006)
  - Control for energy digestibility
- Chromic oxide as an indigestible marker

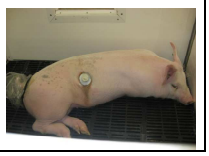
Ingredient Composition of Diets (Exp. A)

Ingredient, %	EPCM diet	N-free diet
Cornstarch	48.63	85.32
EPCM	44.00	-
Sugar	2.85	5.00
Solka floc	-	3.00
Canola oil	1.14	2.00
Limestone	1.50	1.00
Mono/dical phosphate	-	1.20
Salt	0.50	0.50
Mineral & Vitamin premix	1.00	1.00
Chromic oxide	0.38	0.38
KCO_3	-	0.50
MgO 58%Mg	-	0.10

Materials and Methods

Exp. A Digestibility Study

- Two equal meals at 0800 and 1600
- Free access to water
- 5-d acclimation to experimental diets
- 2-d collection of feces
- 3-d collection of ileal digesta



Chemical Characteristics of EPCM (Exp. A; DM Basis)

Item	EPCM	Canola Meal[1]
GE (Mcal/kg)	5.03	4.61
CP	38.5	39.6
Ether extract	13.3	3.9
Crude fiber	7.7	14.0
Total Glucosinolate (µmol/g)	23.2	7.2

[1]NRC, 1998; Sauvant et al., 2004

DE and NE Content and SID Content of AA (DM basis)

Item	EPCM	Canola Meal[1]	SBM[1]
DE (Mcal/kg)	3.77	3.20	3.92
NE (Mcal/kg)	2.55	1.79	2.17
SID Lys (%)	1.77	1.80	2.83
Available Lys (%)[2]	1.52	-	-

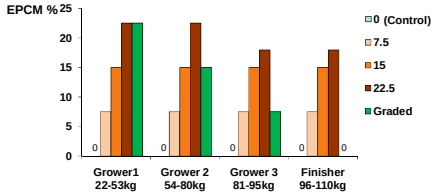
[1]NRC,1998
[2]AOAC Official Method 975.44, 2006

Exp. B - Performance Study

- At Drumloche Research Farm (Alberta, Canada)
- 1100 pigs (22.6kg; Duroc x Landrace/Large white)
- 50 pens (in 5 blocks of 10); 22 pigs per pen

Exp. B - Performance Study

- 5 feeding regimens 0,7.5,15, 22.5% and decreasing graded levels of EPCM
- 4 phases – Grower 1, 2, 3, and Finisher



Grower 1 and 2 Diets (Exp. B)

	Grower 1 , % EPCM				Grower 2, % EPCM			
Ingredient, %	0	7.5	15	22.5	0	7.5	15	22.5
Wheat	34.6	30.8	26.9	25.4	34.7	30.9	27.0	22.5
Corn	30.0	30.0	30.0	30.0	35.0	35.0	35.0	35.0
EPCM	-	7.5	15.0	22.5	-	7.5	15.0	22.5
Wheat:corn DDGS	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Soybean meal	15.8	11.7	7.7	6.0	11.5	7.5	3.4	-
Tallow	1.0	1.4	1.8	2.0	0.3	0.7	1.1	1.6
Calculated nutrients								
NE Mcal / kg	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
SID Lys,%	0.97	0.97	0.97	0.97	0.87	0.87	0.87	0.87

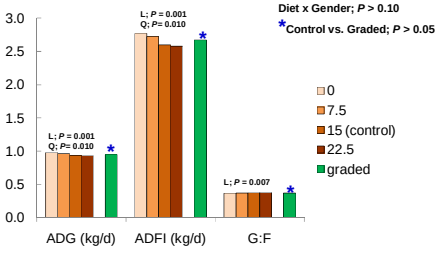
Grower 3 and Finisher Diets (Exp. B)

	Grower 3, % EPCM				Finisher, %EPCM			
Ingredient, %	0	7.5	15	18	0	7.5	15	18
Wheat	31.4	37.9	33.0	24.3	-	6.1	12.1	5.0
Corn	20.0	20.0	28.1	31.5	20.0	20.0	24.1	26.6
EPCM	-	7.5	15.0	18.0	-	7.5	15.0	18.0
Barley	24.6	14.6	5.6	8.0	60.8	48.4	30.9	32.4
Wheat: corn DDGS	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Soybean Meal	5.8	1.7	-	-	1.1	-	-	-
Calculated nutrients								
NE Mcal/kg	2.35	2.35	2.35	2.35	2.30	2.30	2.30	2.30
SID Lys,%	0.76	0.76	0.76	0.76	0.65	0.65	0.65	0.65

Exp. B Performance Study

- Feed disappearance and BW gain
- ADG, ADFI, G:F
- Carcass measurements
- Jowl fat sample
  - Fatty acid profile (Method: gas chromatography)
  - Iodine value (AOCS, 1998)
- Mixed model in SAS
- Pen as exp. unit

Growth Performance



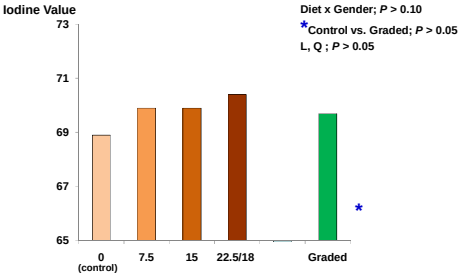
Increased dietary fat =➔ Reduced ADFI (Rayner and Miller, 1993; Azain, 2001)
Glucosinolates =➔ Reduced ADFI (Van Etten and Tookey, 1983; Schone et al., 1997)

Carcass Characteristics

	EPCM, %						*P*- value	
Item	0	7.5	15	22.5/18	Graded[1]	SEM	L	Q
Carcass weight, kg	95.7	94.8	93.8	93.1	94.8	0.87	0.02	0.01
Backfat, mm	20.4	20.3	19.6	20.1	20.1	0.55	0.43	0.30
Loin depth, mm	62.8	63.0	63.4	63.0	62.8	0.71	0.94	0.27
Lean, %	60.0	60.0	60.3	60.1	60.1	0.26	0.44	0.33

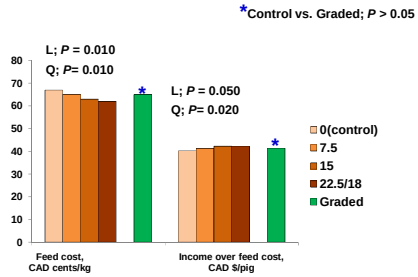
[1] Control vs. graded ; *P* > 0.05

Jowl Fat Iodine Value



Threshold iodine value for North American pork = 74 (Boyd, 1997)

Feed Cost



Conclusions and Implications

- EPCM
  - Good energy and AA source
  - Reduced feed costs
  - Did not impact carcass and fat quality
- ADG 3 g/d lower per 1% inclusion of EPCM
  - Residual glucosinolates
  - Inclusion of EPCM should be targeted to ensure an expected growth and to meet marketing strategy targets
- Diets formulated to equal NE may still result in unequal ADG due to feed intake differences

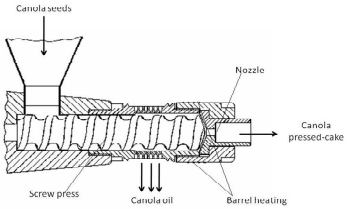
Study 2

Effect of Processing Conditions on the Nutrient Digestibility of Cold-Pressed Canola Cake for Grower Pigs

Introduction

- On-farm oil extraction
- No heat treatment (Spragg and Mailer, 2007)
- Different in chemical composition (Leming and Lamber, 2005)

Flow Chart of Cold-pressing



(Adapted from Leming and Lamber, 2005)

Gap in Knowledge

- Limited research
  - with swine
  - effect of processing conditions
- Limited info on nutritional quality

Hypotheses

- CPCC – good source of energy and AA
- Energy and AA digestibility of CPCC would differ depending on processing conditions
- Energy and AA digestibility of CPCC would be different from EP canola meal and canola seed

Objectives

- To characterize the effect of processing condition on AA and energy digestibility
- To calculate SID AA and NE content of CPCC
- To compare CPCC to canola seed and EP canola meal

Materials and Methods

- A pilot project
  - 22 canola meal samples
  - Chemical contents
  - 12-27% EE
- 4 processing conditions
  - 2 barrel speeds (slow, fast)
  - 2 barrel temperature (heated , non-heated)

Materials and Methods

- 7 ileal-cannulated barrows (26 kg)
- CPCC, EPCM, EPCM+ Seed, and N free diet

  sole source of CP and AA
- N–free diet
  - Estimate basal ileal endogenous losses of CP and AA (Stein et al., 2006)
  - Control for energy digestibility
- Chromic oxide as an indigestible marker

Ingredient Composition of Diets

Ingredient, %	CPCC diet	EPCM diet	Seeds	N-free diet*
Cornstarch	48.64	48.64	40.37	85.32
Pressed cake	44.00	-	-	-
Canola seed	-	-	20.00	-
EPCM	-	44.00	33.00	-
Sugar	2.85	2.85	2.33	5.00
Canola oil	1.14	1.14	0.93	2.00
Limestone	1.50	1.50	1.50	1.00
Chromic oxide	0.38	0.38	0.38	0.38
Salt	0.50	0.50	0.50	0.50
Vitamin premix	0.50	0.50	0.50	0.50
Mineral premix	0.50	0.50	0.50	0.50

*The N-free diet also contained 3.00% solka floc, 1.20% mono/dical phosphate, 0.50% KCO_3, and 0.10% MgO.

Materials and Methods

- Two equal meals at 0800 and 1600 h
- Free access to water
- 5-d acclimation to experimental diets
- 2-d collection of feces
- 2-d collection of ileal digesta

Materials and Methods

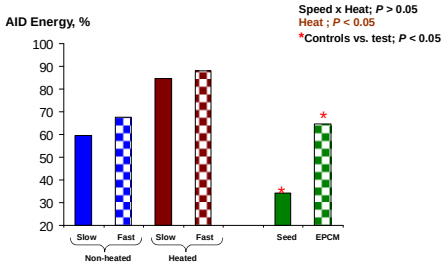
- AID , ATTD energy
- AID and SID AA digestibility
- DE and NE content
- Mixed model in SAS
- Pig as exp. unit
- 2 x 2 treatment structure
- 2 controls

Results

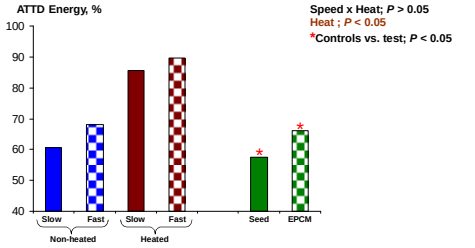
Chemical contents of test ingredients on DM basis

	Cold-pressed canola cake				Canola	EP
	Non-heated		Heated		Seed	canola
Item	Slow	Fast	Slow	Fast		meal
GE, Mcal/kg	5.12	5.45	5.88	5.24	6.86	5.20
CP	44.98	40.39	36.37	42.38	19.45	38.35
Ether extract	9.63	16.55	24.18	14.28	50.20	13.79
Glucosinolates	7.79	6.11	9.24	5.00	4.59	18.85

AID Energy of Test Ingredients

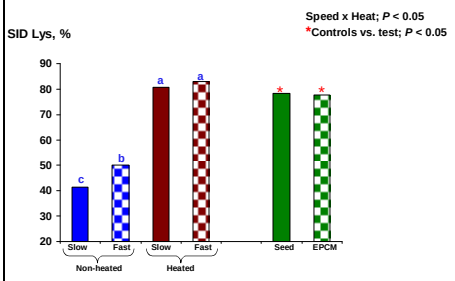


ATTD Energy Test Ingredients

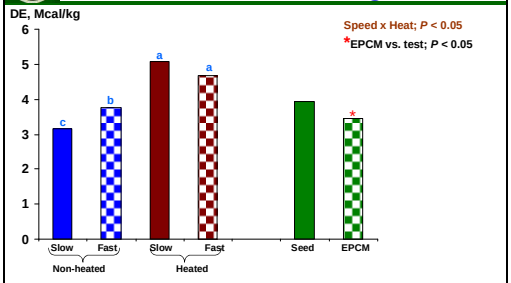


Fat digestibility could be increased by heat application (Dänicke et al., 1998; Mujahid et al., 2003)

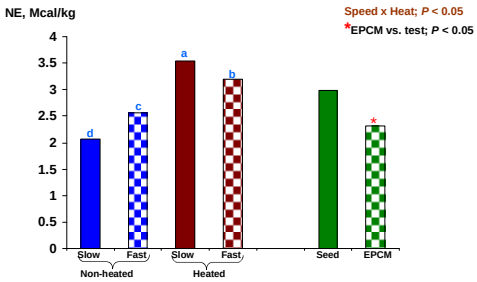
SID Lys of Test Ingredients



DE Contents of Test Ingredients



NE Contents of Test Ingredients



Summary

- CPCC
  - Good source of digestible energy and AA
- CPCC contained
  - 4.17 Mcal/kg of DE
  - 2.84 Mcal/kg of NE
  - 0.87% SID Lys
- CPCC quality
  - Processing condition

Conclusion

- EE – important determinant of energy
- Higher the residual oil ==➔higher DE, NE
- Impact of processing conditions

Study 3

Effect of Crude Glycerol Combined with Solvent-extracted or Expeller-pressed Canola Meal on Growth Performance and Nutrient Digestibility of Weaned Pigs

Introduction

- Solvent extracted canola meal – low in energy (CCC,2009)
- Crude glycerol – energy source (Lammers et al., 2007)
- EP canola meal – more energy than canola meal

Gap in Knowledge

- Limited research evaluating glycerol as an energy supplement
- Limited info about effect of glycerol on growth performance
- No research combining crude glycerol with canola meal to increase energy

Hypothesis

- Canola co-products diets formulated to equal NE and SID AA content could be fed to weaned pigs without reducing growth performance

Objectives

- To measure
  - growth performance
  - total tract digestibility of energy
  - total tract digestibility CP

Materials and Methods

- At SRTC
- 240 weanlings (120 barrows and 120 gilts)
- 2 gilts and 2 barrows per pen
- 60 pens , 12 blocks
- Test feed at 27 d
- 5 diets

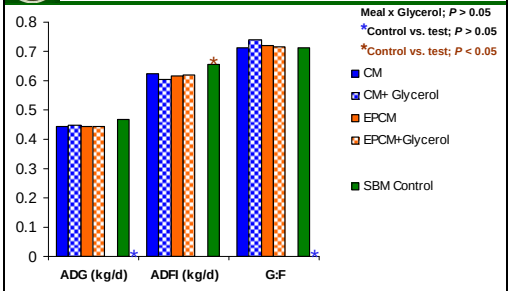
Main Ingredient Composition of Diets

		Canola meal			
	Soybean meal	Solvent-extracted		Expeller-pressed	
Ingredient, %	Control	- Glycerol	+ Glycerol	- Glycerol	+ Glycerol
Wheat	62.8	53.0	49.0	56.6	52.5
Soybean meal	15.0	7.5	7.5	7.5	7.5
Canola meal					
Solvent-extracted	-	15.0	15.0	-	-
Expeller-pressed	-	-	-	15.0	15.0
Lactose	10.0	10.0	10.0	10.0	10.0
Crude glycerol	-	-	5.0	-	5.0
Soy protein concentrate	2.5	2.5	2.5	2.5	2.5
Herring meal	2.5	2.5	2.5	2.5	2.5
Canola oil	2.0	4.5	3.5	1.0	-
Celite	0.8	0.8	0.8	0.8	0.8

Materials and Methods

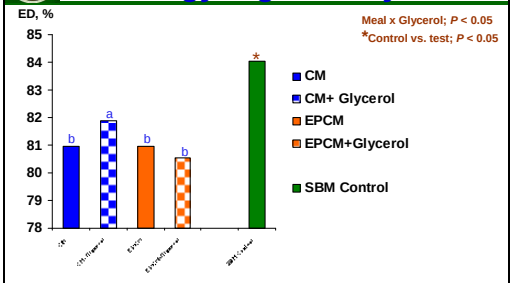
- Ad libitum feeding
- BW & feed disappearance - weekly
- Fecal grabs on 17d and 18d
- Pen – Exp. Unit
- Mixed model in SAS

Growth Performance



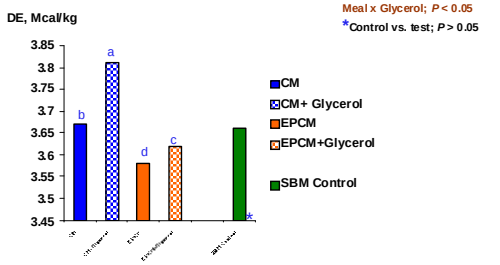
Increased dietary fat may reduce ADFI of pigs (Azain, 2001)

Energy Digestibility

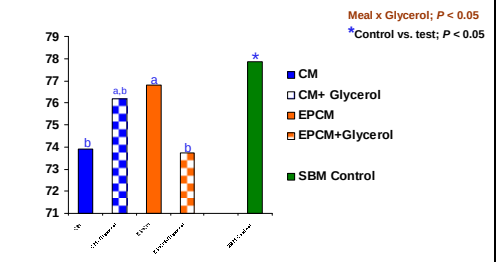


Efficiency of utilization of dietary energy decreases with more fiber (Noblet et al., 1994).

DE Content



CP Digestibility



Fiber is known to reduce CP (Eggum, 1995) and AA digestibility (Grieshop et al., 2001)

Summary

- Similar ADG and G:F for Canola co-product diets and SBM control diet
- Glycerol in Canola meal
  - Extra DE
  - Increased energy digestibility
  - Increased CP digestibility

Conclusion

- 15% canola co-product with or without glycerol ==➔ Partially replaced SBM

Thesis - Conclusion

- Fills gap in knowledge
  - Nutritional quality of canola co-product
- Have importance to canola and associated biodiesel industry
- Provide technical info
  - Risk management
  - Feed formulation
  - Placing economic value

Thesis - Implication

- Creates an opportunity to use canola co-products as alternative feedstuffs

Acknowledgement

- Funding for the project
  - Alberta Canola Producers Commission (Edmonton, AB)
  - Canadian International Grains Institute (Winnipeg, MB)
  - Saskatchewan Canola Development Commission (Saskatoon, SK)
- Supply of expeller-pressed canola meal
  - Associated Proteins (Ste. Agathe, MB)
- Supply of crude glycerol
  - Milligan Bio-Tech (Foam Lake, SK)