THE EFFECTS OF FEEDING CANOLA MEAL FROM HIGH PROTEIN OR CONVENTIONAL VARIETIES OF CANOLA SEEDS ON PORK QUALITY

BY

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THESIS

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Abstract

Canola meal (CM) can be a valuable alternative to soybean meal (SBM) as a protein supplement for pigs. However, it has a lower crude protein content and about 3 times as much fiber as soybean meal, thus limiting the availability of essential amino acids and digestible energy in pig diets, and potentially decreasing carcass yield. Furthermore, the presence of glucosinolates in some varieties of canola caused hypothyroidism and enlarged thyroid glands in pigs, which lead to decreased animal growth. A new hybridized high protein variety of canola (*Brassica napus)* contains approximately 45% crude protein and may be a more desirable option as a SMB alternative than historic varieties of canola because of its higher protein and lower crude fiber content. Sinapine is another anti-nutritional component found in CM, which caused a "fishy" smell in the eggs of laying hens. While feeding CM to pigs did not have negative effects on sensory attributes of pork loins, effects on bacon sensory characteristics had not been evaluated. Furthermore, CM is high in polyunsaturated fatty acids (PUFA), which could lead to soft, thin bellies and complications during bacon processing. Research has been conducted at the University of Illinois to determine the effects of conventional (CM-CV) or high protein (CM-HP) canola meal diets for nursery pigs, although no research has been conducted on feeding CM-HP to growing and finishing pigs. Therefore, two experiments were conducted to evaluate the effects of CM-HP and CM-CV on pork quality of growing and finishing pigs. The objectives of the first experiment were to determine growth performance, carcass characteristics, and meat quality of growing and finishing pigs fed both types of CM. The objectives of the second experiment were to determine processing and sensory attributes of dry or conventionally cured bacon from pigs fed both types of CM. A 3-phase 91 d feeding program was used with grower diets fed from d 0 to d 35, finisher-1 diets fed from d 36 to d 63, and finisher-2 diets fed from d

64 to d 91. Seven diets were fed, which included a corn-SBM diet (control), 3 diets containing increasing inclusion rates of CM-HP, and 3 diets containing increasing inclusion rates of CM-CV. Canola meal replaced 33, 66, or 100% of the soybean meal in the diets. A total of 280 pigs were used in the study, with 70 pens and a total of 4 pigs per pen. One pig from each pen was randomly selected for a meat quality evaluation at the end of the feeding period. Therefore, 140 bellies (2 bellies from each of 70 pigs) were used for the second experiment. In the first experiment, overall ADFI was increased by about 6% for pigs fed 66% CM-CV when compared to pigs fed all levels of CM-HP and pigs fed the control. Furthermore, there was a linear increase in ADFI as CM-CV inclusion level increased. There were only a few differences in organ and viscera weights, however, there was a linear increase in liver percentage as CM-CV inclusion increased. There were no differences among treatments for any subjective evaluations (color, marbling, firmness), drip loss, proximate composition, cook loss, or shear force, however, there was a linear decrease in pH in pigs fed CM-HP. In study 2, there were no differences among dietary treatments for all fresh belly characteristics, most fatty acids, and calculated iodine value. However, there was a linear increase in total PUFA as CM-HP inclusion increased. Conventionally cured bacon and dry cured bacon were analyzed separately. There were no differences in either cure type for processing characteristics, bacon slice characteristics, and proximate composition. Furthermore, sensory panel evaluations of saltiness, flavor intensity, off flavor, and off odor were similar among dietary treatments in both types of bacon. Overall, CM-HP and CM-CV can replace soybean meal in growing-finishing pig diets without any detrimental effects on animal growth, carcass characteristics, meat quality, or bacon characteristics. Canola meal is a viable alternative to soybean meal as a protein supplement in pig diets.

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1.1 INTRODUCTION

Swine nutrition and feed formulation are very complex aspects of pork production. Feed is the greatest associated input cost in pork production, accounting for about 60% of all costs in farrow-to-finish systems (Meisinger, 2010). Although feed rations among hog operations will vary, it is assumed that a finished hog has consumed about 303 kg (11.9 bushels) of corn, 65 kg of soybean meal, and 15 kg of dried distiller grains (Lawrence and Ellis, 2008), which is approximately 2.5 kg of feed per day over their lifetime. This agrees with several studies where average daily feed intake of pigs was evaluated (Baidoo et al., 1987; De la Llata, 2001; Nyachoti et al., 2004). Current US corn prices are $4.7050/bushel and soybeans are at $14.0925/bushel (CargillAg, 2014). There are many factors that can affect grain prices. For example, an extreme drought that hit the Midwest in summer 2012 decreased supply and led to an overall price increase of corn and soybean meal (SBM) to record levels, with corn reaching $8.24 in August 2012 and soybeans at $16.05 in September 2012 (Good, 2013). Grain prices have continued to steadily increase for the past 20 years (Farmdoc, 2014). Formulating a diet that accounts for the complex nutrient requirements of swine and current feed prices can be a complicated process. With the continuous rise in feed costs, alternative feed sources are being explored, particularly alternative protein sources. Canola meal can be an alternative to SBM as a protein supplement for pigs (Bell, 1975; McKinnon and Bowland, 1977; Baidoo et al., 1987). A new hybridized high protein variety of canola is thought to have more digestible energy (DE) and metabolizable energy (ME) than conventional canola meal. Research has been done on the effects of including conventional or high protein canola meal diets for nursery pigs, although none has been

completed on feeding high protein canola meal to growing and finishing pigs. Therefore, one of the objectives of this study was to determine the performance and carcass characteristics of growing and finishing pigs fed diets containing high protein or conventional canola meal.

1.2 CANOLA MEAL

The continuous rise in feed costs is driving research for alternative feedstuffs. The use of alternative protein sources have the potential to reduce feed costs and increase profits for the swine producer. Previous evidence shows that canola meal can be a valuable alternative to SBM as a protein supplement for pigs (Bell, 1975; McKinnon and Bowland, 1977; Baidoo et al., 1987). Canola is a variety of rapeseed created through selective breeding which must have oil containing less than 2% erucic acid and meal containing less than 30 µmol/g of glucosinolates (Bell, 1993). Before these developments, rapeseed oil contained as much as 45% erucic acid, which is mildly toxic to animals, especially poultry (Bell, 1993; Bonnardeaux, 2007). Erucic acid can cause growth depression, reduction in feed intake, and reduce efficiency in growing broiler chickens. This type of rapeseed can also contain 50-100 µmol/g of glucosinolates (Bell, 1993), which break down into toxic aglucones (Canola Council of Canada, 2009). Glucosinolates can negatively affect growth rate, cause swelling of the thyroid gland, and make meal less palatable for livestock. Like many other high-oil seeds, canola seeds are subjected to a commercial crushing process and oil extraction (Sosulski and Sosulski, 1993), with approximately 57% of the seed resulting in canola meal and 43% resulting in canola oil (Canola Council of Canada, 2009). The canola oil can be used in human food or converted into biodiesel. The canola meal that is remaining after oil extraction can be used in the livestock industry or as a fertilizer for soil (Bonnardeaux, 2007). In order to be used as a feed source for livestock, the nutritional value of canola meal must be explored

1.2.1 Protein

Proteins are composed of amino acids, characterized as dietary essential or nonessential. An essential amino acid is one that cannot be synthesized by pigs at a rapid enough rate to meet the demands of normal metabolic processes. The primary ingredients in most swine diets are cereal grains, such as corn, sorghum, barley, and wheat, and they commonly provide 30-60% of the total amino acid requirements (National Research Council, 2012). Cereal grains are often deficient in some essential amino acids, and thus other sources of protein, such as soybean meal, or synthetic amino acids are added. This ensures that pigs meet their requirements for amino acids. Pigs do not have a specific crude protein requirement; however, amount of crude protein (CP) in swine diets is still a concern (Meisinger, 2010). Pigs fed low CP (12%) diets have fatter carcasses compared with pigs fed high CP (16%) diets. (Kerr et al., 1995; Chen et al., 1999). The decreased fatness in pigs fed CP levels beyond those needed for maintenance and growth may be partially due to more dietary energy being used for catabolization of excess dietary protein (Kerr et al., 2003). As dietary protein increases, the metabolic costs of amino acid deamination and excretion of urea are increased (Chen et al., 1999).

Canola meal nutrient composition may be influenced by such things as environmental conditions during the growing of the crop, harvest conditions, processing of the seed and meal, and the type of seed used. For example, the crude protein content of canola meal varies depending on the cultivar from which the meal is produced. Meal from cultivars of *B. campestris* contains around 35% crude protein, while meal from cultivars of *B. napus* contains approximately 38-40% crude protein. These two types can also be mixed to produce meal containing around 36-38% crude protein (Clandinin and Robblee, 1981; Canola Council of Canada, 2009; Thacker and Kirkwood, 1990). Because the protein content of canola meal is

lower than soybean meal (48%), greater rates of canola meal must be included in swine diets to provide the same level of dietary protein. Thacker and Kirkwood (1990) found that approximately 25% more canola meal must be used in the diet to achieve the equivalent amount of protein that soybean meal would supply.

In addition to the amount of crude protein, amino acid content must be considered when using a protein replacement in swine diets. Lysine, threonine, methionine, and cysteine are especially important because these are the most limiting amino acids in swine diets composed predominantly of cereal grains (Sauer et al., 1982). Canola meal contains less lysine than soybean meal, and the availability of lysine is approximately ten percentage units less in canola meal than soybean meal (Sauer et al., 1982). The levels of threonine, tryptophan, methionine, and cysteine found in canola meal are similar to those found in soybean meal (Thacker and Kirkwood 1990; Stein et al., 1999; Canola Council of Canada, 2009). If canola meal completely replaces soybean in swine diets, the amount of canola meal fed must be increased relative to soybean meal in order to have the same supply of digestible lysine (Sauer et al., 1982). Synthetic lysine may also be used to account for the low availability of lysine in canola meal.

As previously mentioned, canola meal is typically high in crude protein (35-40%) and amino acids relative to most plant protein sources. It is also a good protein source for pig diets because the amino acid content is well suitable for pig digestion. However, canola meal is relatively high in fiber, reducing the digestible energy content. New varieties of *Brassica napus* have been hybridized, resulting in thinner seed hulls, less fiber, and more protein than conventional canola meal. The meal produced from these hybrids is known as high protein canola meal. It is thought to have greater energy digestibility and more DE and ME than conventional canola meal.

1.2.2 Fiber and Carbohydrates

Fiber is another important component of swine diets. The most widely accepted definition of fiber states that fiber is the sum of lignin and polysaccharides that are not digested by endogenous secretions of the digestive tract (Trowell, 1976). There are multiple items to consider when determining the role of fiber in swine nutrition, such as how much fiber to feed and the influence of fiber on nutrient absorption. In general, pigs will respond to high fiber (16-17% neutral detergent fiber; NDF) diets by increasing feed intake sufficient to meet their caloric requirements until gut capacity inhibits additional intake (Moore et al., 1986; Cheeke, 2005). If the crude fiber content of a swine diet exceeds 10-15%, caloric intake may be reduced because of excessive bulk or reduced palatability (National Research Council, 1998). A high fiber diet can increase the passage rate of nutrients and many will disappear into the hind gut rather than being digested in the small intestine. Weight, volume, and capacity of the hind gut increases with increasing dietary fiber (Coey and Robinson, 1954; Pond et al., 1989). In a study conducted by Just (1982), an increase in dietary fiber by 1% depressed the digestibility of gross energy by approximately 3.5% and depressed the efficiency of metabolizable energy by 0.7%. A large proportion of carbohydrates were fermented to volatile fatty acids in the hindgut by the microflora, which most likely lead to a lower metabolic rate efficiency than the glucose absorbed from the small intestine (Just, 1982). Fiber can also negatively affect carcass characteristics. Merkel et al. (1958) found that crude fiber was significantly ($P < 0.05$) correlated (-0.960 and -0.904, respectively) with dressing percentages and backfat thickness in pigs fed 7 different levels of crude fiber.

One of the main factors that tends to limit the nutritional value of canola meal is its relatively low digestible energy (Saben et al., 1971). The low level of digestible energy content

is a reflection of its high crude fiber content (Bell, 1993). Canola meal fiber content can vary depending on the type of seed used. Unlike in soybean meal, the hull of a canola seed stays with the meal and is a relatively high proportion of the canola seed (Canola Council of Canada, 2009). Additionally, Stringam et al. (1974) discovered that yellow hulls contained about 1/3 less crude fiber, more protein, and more oil than brown hulls. However, it was reported that the embryo part of the yellow seeds contained more fiber than brown seeds, thus off-setting the benefits of reduced fiber in the hull (Bell, 1993; Bell and Shires, 1982).

The carbohydrate matrix of canola meal is quite complex. The starch content of canola meal is around 5%, while sucrose is around 6% and cellulose at 4.5% (Canola Council of Canada, 2009). These sugars, when in free form, are readily digestible by monogastrics, but if protected by cell walls, their utilization may resemble that of the non-starch polysaccharides. It appears that these carbohydrates found in canola meal are protected and contribute very little to available energy (Canola Council of Canada, 2009).

1.2.3 Fat and Energy

Dietary fatty acid composition directly affects the fatty acid composition of pork. Pigs consuming unsaturated fat will deposit fat that is also unsaturated (Ellis and Isbell, 1926; White et al., 2009; Xu et al., 2010). As pigs mature and deposit more fat, though, the proportion of fatty acids tends to shift towards saturated (SFA) and monounsaturated fatty acids (MUFA) (Wood et al., 2008). This can be attributed to the increase in *de novo* synthesis of SFA and MUFA, specifically myristic acid (C14:0), palmitic acid (C16:0), palmitoleic acid (C16:1), stearic acid (C18:0), and oleic acid (C18:1) (Kloareg et al., 2007; Wood et al., 2008). Kouba et al. (2003) found that total polyunsaturated fatty acids (PUFA) decreased ($P < 0.01$) by about

40% over time, while total SFA increased ($P < 0.01$) over time by about 10% in pigs fed either a control diet or a linseed diet containing 6% of whole crushed linseed, which is high (> 15%) in C18:3n-3. Alpha-linolenic acid (C18:3n-3) is the precursor fatty acid for the synthesis of EPA (C20:5n-3) and DHA (C22:6n-3), which play a major role in human health (Conquer and Holub, 1998). However, compared with the control diet, feeding linseed led to an increase in the PUFA:SFA ratio and a decrease in the ω6:ω3 ratio, with a corresponding increase ($P < 0.05$) in the proportion of most n-3 PUFA (Kouba et al., 2003). These results can be desirable from a human health standpoint. Omega-6:omega-3 ratios are thought to be too high in most American diets (15:1 – 16.7:1; Simopoulos, 2008). A ratio of around 4:1 to 1:1 is desirable based on research suggesting that humans evolved on a diet with a 1:1 ratio (Simopoulos, 2008). High amounts of omega-6 fatty acids can lead to many diseases, including cardiovascular disease, cancer, and inflammatory diseases (Simopoulos, 2008). Simopoulos (2008) found that a ω6:ω3 ratio of 4:1 was associated with a 70% decrease in mortality of rate due to cardiovascular disease compared to the normal American ratio of around 15:1. Producing pork which has a high amount of PUFA, but still has a low ω6:ω3 ratio can be desirable for human health. However, pork fat with high levels of PUFA can present challenges with further processing, such as fat smearing, bacon sliceability and bacon slice defects, and with reduced shelf life (Leick et al., 2010; National Research Council, 2012).

The oil from a canola seed is low (7%) in saturated fatty acids (SFA) and high in monounsaturated fatty acids (61%) (MUFA) and polyunsaturated fatty acids (32%) (PUFA) (canolainfo.org, 2007). It is also very high in linolenic acid (21%), which is a ω3 fatty acid (canolainfo.org, 2007). As previously mentioned, a high proportion of ω3 fatty acids is desirable in pork fat for the potential human health benefits, but may be detrimental to bacon production

because of fat smearing and decreased slice yield (National Research Council, 2012). The oil content of canola meal may vary according to the efficiency of the extraction process and whether or not the gums from oil refining are added to the meal. Gums are rich in oil and will increase the energy content of the meal. Smaller oilseed plants typically use expeller processing due to lower capital costs (Canola Council of Canada, 2009). This type of extraction removes about 75% of the oil (Seneviratne et al., 2010). Solvent-extraction is much more efficient, removing about 95% of the oil (Seneviratne et al., 2010).

1.2.4 Vitamins and minerals

Canola meal is also a good source of essential minerals, such as potassium (1.24%), sulfur (0.86%), calcium (0.64%), and iron (162 mg/kg), and an especially good source of selenium (1.1 mg/kg) and phosphorus (1.03%) (Bell and Keith, 1991; Canola Council of Canada, 2009). It is comparable to soybean meal which has 1.96 % potassium, 0.39% sulfer, 0.35% calcium, and 225 mg/kg iron, 0.32 mg/kg selenium, and 0.64% phosphorus (Cromwell, 2012). Similar to other vegetable sources where phosphorous is present as phytate, the bioavailability is estimated to be 30-50% of the total phosphorous level (Bell and Keith, 1991). Canola meal also appears to be rich in choline (6500 mg/kg), biotin (0.96 mg/kg), folic acid (0.8 mg/kg), riboflavin (5.7 mg/kg), and thiamin (5.1 mg/kg) (Canola Council of Canada, 2009), compared with soybean meal which has 2790 mg/kg choline, 0.27 mg/kg biotin, 1.37 mg/kg folic acid, 2.9 mg/kg riboglavin, and 4.5 mg/kg thiamin (Cromwell, 2010).

1.2.5 Anti-nutritional factors

One of the undesirable components of canola meal is glucosinolates. Glucosinolates are bitter, sulfur-containing glycosides. Canola glucosinolates are composed of two main types,

aliphatic and indolyl. Aliphatic glucosinolates comprise approximately 85% of the glucosinolates present in canola meal while indolyl glucosinolates account for the other 15% (Newkirk et al., 2003). The breakdown of glucosinolates is thought to be mainly responsible for animal growth inhibition, and results in the production of many compounds that can inhibit thyroid hormone (TH) production or cause liver hemorrhage, depending on the type (Busato et al., 1991; Canola Council of Canada, 2009). Thyroid hormone regulates the basal metabolic rate, and the underproduction of TH is known as hypothyroidism. This condition reduces insulin-stimulated glucose uptake in muscle and adipose tissue (Dimitriadis et al., 2013), negatively affecting protein accumulation and inhibiting animal growth (Jepson et al., 1988; Busato et al., 1991). With the development of the low glucosinolate varieties of rapeseed in the early 1970's, a significant breakthrough was achieved in meal quality. There are many breeds of canola that now contain less than 30 µmol/g of glucosinolates, compared with rapeseed which could have 50-150 µmol/g, depending on the variety (Bell, 1993). The development of low glucosinolate canola meal now means that the relatively low available energy in canola meal is the first limiting factor in most feed formulations (Bell, 1993).

Some other anti-nutritional factors of canola meal are sinapine, tannins, and phytic acid, which collectively may comprise up to 10% of the canola meal (Bell, 1993). Sinapine has a bitter flavor and may affect palatability of feed. It also causes the development of a "fishy" smell in the eggs of layer hens (Canola Council of Canada, 2009). The "fishy" smell is due to the interference of sinapine with the hen's ability to convert trimethylamine, found in yolk, to N-oxide, thus, not as concerning in pig diets (Pearson et al., 1980). Furthermore, Melton (1990) reported that replacing soybean meal with canola meal in pig diets did not affect pork loin flavor. Tannins exist mainly in the seed hull and are more abundant in dark seeds than in yellow seeds.

They can interfere with digestive enzymes, especially those involved in protein hydrolysis. Phytic acid is involved in binding phosphorous and other essential minerals, making them more unavailable to monogastrics (Bell, 1993).

1.3 FAT QUALITY

Attention to the quality of pork fat has increased in the United States over the last decade (Leick et al., 2010; Boler et al., 2012; Kyle et al., 2014; Tavarez et al., 2014), partly because of an increase in bacon consumption (Person et al., 2005; Annual Meat Trade Review, 2012). Fat quality affects both further processing characteristics and the ability of pork producers to meet export specifications. Problems that arise with bacon containing low quality fat can include slices sticking together, an oily appearance, and separation of fat from lean during slicing (Carr et al., 2005). Good quality fat has been described as firm and white, while poorer quality fat has been described as soft, oily, wet, grey, and floppy (Hugo and Roodt, 2007). The quality of fat is best determined by the composition of the fatty acids and their physical characteristics. Individual fatty acids, as well as combinations and ratios, are used to predict fat quality. In pork fat, fatty acids are classified as saturated, monounsaturated (MUFA), or polyunsaturated (PUFA) (Hugo and Roodt, 2007). The saturated fatty acids (C12:0—C18:0) have a positive influence on firmness and cohesiveness of the carcass fat tissue, while unsaturated fatty acids, characterized as having double bonds and lower melting points, have a negative influence on firmness and cohesiveness of the carcass fat tissue.

Iodine value (IV) is currently used as a standard measurement of pork fat quality in the United States. It is defined as the amount of iodine (in g) bound by 100 g of fat (Madsen et al., 1992). Iodine will bind to unsaturated or double bonds in fatty acids; thus, a greater amount of

iodine will bind to a sample that has a greater amount of unsaturated fatty acids (AOCS, 1998). There are several equations that can be used to determine IV, but the most published equation is from the American Oil Chemists' Society (AOCS, 1998) (IV = [C16:1] x 0.95 + [C18:1] x 0.86 + [C18:2] x 1.732 + [C18:3] x 2.616 + [C20:1] x 0.785 + [C22:1] x 0.723). However, that equation does not account for the long chain polyunsaturated fatty acids found in canola meal. So, another equation that can be used is: IV = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.795) + C20:2 (1.57) + C20:3 (2.38) + C20:4 (3.19) + C20:5 (4.01) + C22:4 (2.93) + C22:6 (4.64) (Meadus et al., 2010). This equation probably more closely represents the true fat quality from pigs fed canola meal than the original AOCS equation. Even so, it is important to remember, iodine values are often highly variable because they can be affected by numerous factors including genetics, age, sex, breed, diet, fat thickness, body weight, and various fat depots. Iodine value provides an estimate of the proportion of unsaturated fatty acids, therefore giving an indication of percentage of unsaturated fatty acids, softness of fat, and rancidity (Bergstrom et al., 2010; Benz et al., 2011). Having a greater proportion of unsaturated fatty acids in pork belly fat can lead to soft bellies, causing problems in bacon production, such as decreased processing yields, poor sliceability, and decreased shelf life (Larsen et al., 2009). Acceptable IV ranges from 70 (Barton-Gade, 1987; Madsen et al., 1992) to 75g/100g (Boyd et al., 1997). Although, Eggert et al. (2001) considered an IV above 65 to be unacceptable by some industry standards. However, Leick et al. (2010) reported that feeding up to 15% DDGS resulted in an IV of 83.7 and did not have adverse effects on bacon processing. Leick et al. (2010) also reported that pigs fed 30, 45 and 60% DDGS had IV of 87.6, 90.4, and 93.4, respectively, and had decreased belly quality which would lead to difficulty in bacon slicing. Kyle et al. (2014)

found IV to have a relatively low correlation (r = -0.15) with slice yield, but this is currently one of the better methods processors have to predict slice yield.

The softness of fat is directly proportional to the amount of unsaturated fatty acids in the fat depot. Wood et al. (1989) found a correlation of -0.75 between objective fat firmness and C18:2n-6 (linoleic acid) proportions. This area is receiving increasing attention because of changes in the genetics of pigs and in feed ingredients used to formulate swine rations. Soft fat problems are relatively greater in leaner pigs, which have a greater proportion of the fatty acids in the carcass fat derived from the diet and a smaller proportion from de novo synthesis of fatty acids by the animal (Person et al., 2005; National Research Council, 2012). Fat deposition is the difference between synthesis and mobilization, and depends on the energy intake and intake of essential nutrients. In the pig, lipid synthesis primarily occurs in adipose tissue and glucose is the major precursor (Madsen et al., 1992). When the diet contains high (6%) amounts of fat, synthesis by the pig itself (de novo synthesis) is decreased and more dietary fatty acids are deposited in adipose tissue (Jakobsen and Thorbeck, 1991; De la Llata et al., 2001). Fat deposition is low at birth but increases rapidly as the pigs mature. According to Nurnberg et al. (1998), the potential for dietary manipulation of the fatty acid composition of monogastric animals (like pigs) are much greater than for ruminants because fatty acids from the diet pass through the digestive system, absorbed into the blood stream and are deposited unchanged in the different depots. Subcutaneous fat, like that found in bacon, is more affected by diet than intramuscular fat (Hugo and Roodt, 2007). Verbeke et al. (1999) stated that dietary mono-unsaturated fatty acid incorporation in pork fat is less pronounced because MUFA are the predominant fatty acids in pigs, and therefore, those coming from endogenous origin play an

important role. Polyunsaturated fatty acids in pork fat are exclusively of dietary origin and the effects are reflected more in the adipose tissue of the pig.

Oleic acid (18:1) comprises the majority of lipids in pig adipose tissue, usually exceeding 40% of the total, however, the concentration is poorly related (r = 0.06) to the firmness of the tissue (Cameron et al., 1990). Studies have shown that stearic acid (18:0) and linoleic acid (18:2) are particularly important contributors to fat tissue firmness. As fatty acid composition was manipulated with different diets, genetics, sex, or fatness, these two showed the greatest (18:0, r = 0.36; 18:2, r = -0.54) correlation with firmness. The ratio of 18:0:18:2 was found by Whittington et al. (1986) to provide the best correlation (r = 0.78) of firmness. Hugo and Roodt (2007) indicated that C18:0 content was the best predictor of firmness.

1.4 BACON PRODUCTION IN THE UNITED STATES

In the U.S., the term "bacon" describes the cured belly of a swine carcass. Most bacon made in the U.S. is cut in long narrow slices, crosswise on the belly, and is known as "streaky" bacon. Several steps are involved in the production of sliced bacon. First, each pork belly is skinned and trimmed in order to meet a certain specification. Bellies may then be cured, thermally processed, chilled, and sliced. Bellies are often pressed before slicing.

1.4.1 Curing

Curing is the addition of salt, sugar, and nitrate or nitrite to meats for the purpose of preservation, flavor, enhancement, or color development (Savell and Smith, 2009). There are two primary methods of curing bacon: pumping and dry curing. Pumping, or wet curing, involves injecting the curing ingredients directly into the meat. Bellies are then left for approximately 1.5 to 24 hours before being heated. Dry cured bacon has a premeasured amount

a cure mixture applied or rubbed onto the surface of the belly. Additional cure may be applied over a number of days. Dry cured bellies typically experience about 2.54 cm of sodium migration per week (Toldra, 2002). After the curing phase, bacon may be left to hang for up to 2 weeks in order for the moisture to be drawn out. Less time is needed if it is going to be smoked, because this thermal processing will contribute to moisture loss (Pearson and Gillett, 1996).

There are several ingredients included in a cure solution, the most important being salt, sugar, and nitrite. Salt, usually in the form of sodium chloride, inhibits the growth of microorganisms and contributes a characteristic flavor to the product. Salt acts by dehydration and altering of the osmotic pressure so that it inhibits bacterial growth and subsequent spoilage (Pearson and Gillett, 1996). Sugar, usually in the form of sucrose, counteracts the harshness of salt and assists in lowering the acidity of the cure (Pearson and Gillett, 1996). Nitrite contributes the characteristic cured-pink color (nitroshemoglobin) to the product, provides a bacteriostatic safeguard, and slows the development of rancidity during storage (Savell and Smith, 2009). FSIS (Food Safety and Inspection Service) regulations permit the use of nitrite ($NaNO_2$ or KNO_2), but not nitrate, in bacon such that, with pumping, ingoing nitrite levels cannot exceed 120 ppm and must be accompanied by 550 ppm of a cure accelerator. Residual nitrite in bacon cannot exceed 40 ppm.

Proper color development in rapidly cured meats is largely a function of time. Thus, the use of cure accelerators has been implemented. Ascorbic acid, sodium ascorbate, and sodium erythorbate speed up color development by reducing the time it takes for nitrous acid (HONO) to be reduced to nitric oxide (NO) which leads to faster development of nitroshemoglobin, and therefore, reducing residual nitrite levels (Savell and Smith, 2009).

Alkaline phosphates are added to meat to decrease shrinkage during curing and smoking and to decrease moisture loss. The phosphate groups in alkaline phosphates increase the water holding capacity of muscle proteins and thereby decrease shrinkage of the product during processing. They can be used to increase the brine retention in the belly, which will lead to an increased yield. Phosphates are limited by the USDA to 0.5% in finished products (Savell and Smith, 2009).

Water is also considered a curing ingredient. Water disperses the curing ingredients throughout the meat and can increase the juiciness by partially replacing water lost during heating, smoking, or cooking.

1.4.2 Smoking

Smoking is the next step in bacon production. Originally, smoking, like curing, was employed as a means of preservation, and the intent was to dry out the product. However, meats presently undergo much shorter smoking cycles in order to obtain a mild smoked flavor while maintaining tenderness and juiciness of the product. Improvements in processing and refrigeration make it much less important to smoke meat as a means of preservation. Mass-produced bacon is heat processed in large convection ovens. It is much faster to mass produce bacon using a convection oven into which smoke is applied (as little as 6 hours) than by traditional smoking (many days; Pearson and Gillett, 1996). The purpose of smoking meat in modern commercial plants is to develop a distinctive flavor, aroma, and appearance that is pleasing to the consumer. These attributes can be achieved using natural smoke obtained by smoldering wood chips or by spraying bacon with a liquid smoke extract (Savell and Smith,

2009). After heat processing, the bacon must be chilled to below 40 ˚F before is it sliced. Most bacon is then pressed and sliced before packaging.

1.4.3 Bacon Quality

The demand for bacon has recently seen an extensive growth, thus increasing the demand for and value of fresh pork bellies. The 1992 Pork Chain Quality Audit found that 10% of bellies were too thin for bacon production and an additional 2% were too soft/oily to be used in bacon manufacturing (Cannon et al., 1996). Stetzer and McKeith (2003) found that thin bellies resulted in unrealized revenue of $97 million for pork packers in the U.S. Using bellies that are too thin can result in losses in profitability further down the chain at the processor level because of reduced processing yields and a greater percentage of inferior products when sliced.

Although there is not a specific grading system used for bacon, several commercial producers and researchers have cited Person et al. (2005) as a way to classify differences in quality of bacon slices. Person et al. (2005) classified bacon slices based on their characteristics for secondary lean (cutaneous trunci) and slice thickness. The most valuable slices were #1 slices and had the cutaneous trunci greater than 50% of the width of the slice and a profile thickness no less than 1.9 cm at any point. Less valuable were the #2 slices, which had a cutaneous trunci less than 50% of the width of the slice or a profile thickness less than 1.9 cm wide. Slices classified as #3 were slices that did not meet any of the previously mentioned characteristics. Pieces falling into this category generally came from either end of the belly and are classified as “ends and pieces” (Person et al. 2005).

Thinner bellies tend to be the result of less fat in the belly. Mandigo (2002) reported that bellies from current market pigs contain approximately 29% less fat compared with bellies from

40 years ago, which can cause problems in bacon processing. However, processors must realize that some consumers may prefer leaner bacon, which is often derived from thinner bellies that contain less fat. It is important for bacon processors to understand the relationship between belly thickness, processing yields, and consumer preferences so they can develop raw materials that maintain processing efficiency without compromising customer satisfaction of the finished product.

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Chapter 2:

Effects of feeding canola meal from high protein or conventional varieties of canola seeds on pork carcass characteristics and cutability

2.1 ABSTRACT

The objectives of this study were to determine growth performance, carcass characteristics, visceral mass differences, and meat quality of growing and finishing pigs fed diets containing high protein (CM-HP) or conventional (CM-CV) canola meal. Seven diets were fed to test the effects of increasing inclusion rates of CM-HP and CM-CV compared with no canola meal (control). Inclusion rates were 33, 66, or 100% replacement of soybean meal with canola meal for both CM-HP and CM-CV. Overall ADG was increased ($P = 0.01$) in pigs fed CM-CV compared with CM-HP. ADFI was also increased ($P < 0.01$) in pigs fed CM-CV compared with pigs fed CM-HP. Furthermore, there was a linear increase ($P = 0.03$) in ADFI as CM-CV inclusion level increased. There were no differences ($P \geq 0.25$) among all treatments for ending live weight, HCW, carcass yield, loineye area, backfat thickness, and estimated carcass lean. Liver weights, as a percentage of live weight, were greater ($P \leq 0.04$) in pigs fed 100% CM-CV compared with pigs fed control and pigs fed 33% and 100% CM-HP and 33% and 66% CM-CV. There was also a linear increase ($P < 0.01$) in liver weights as CM-CV inclusion increased. There were no differences ($P \geq 0.40$) among treatments for any subjective evaluations (color, marbling, firmness). Cook loss, shear force, and drip loss were not different ($P \geq 0.22$) among treatment groups. There was a linear increase ($P = 0.01$) in pigs fed CM-HP. There were no differences ($P \geq 0.19$) for loin proximate composition (moisture and fat percentage). Pigs fed CM-HP had increased ($P \leq 0.04$) whole shoulder, Canadian back, and light butt weights and decreased whole belly weights, as a percentage of chilled side weight compared with pigs fed

CM-CV, however there were no other cutability differences. High protein canola meal and CM-CV are viable alternatives to soybean meal as protein supplements in growing-finishing pig diets.

2.2 INTRODUCTION

Soybean meal (SBM) is the most used protein supplement in finishing swine diets in the United States (Cromwell, 1998; AllAboutFeed, 2013), and SBM demand has steadily increased over the past 30 years (USDA, 2013). As the demand for SBM increases with the increase in livestock, poultry, and aquaculture production, protein alternatives for SBM are being researched (Goldsmith, 2008). Canola meal can be an alternative to SBM as a protein supplement for pigs (Bell, 1975; McKinnon and Bowland, 1977; Baidoo et al., 1987). Conventional canola meal, however, has about 20-25% less CP and about 3 times as much fiber as SBM. This limits the availability of essential AA and digestible energy in pig diets (Thacker and Kirkwood, 1990). Additionally, increased fiber can decrease carcass yield, and additional digestible energy is required to make up for lost nutrient availability. Furthermore, the presence of glucosinolates in meal from some varieties of canola caused hypothyroidism and enlarged thyroid glands in pigs, which can lead to muscle growth inhibition (Busato et al., 1991; Canola Council of Canada, 2009). A new hybridized high protein variety of canola (*Brassic napus)* may result in meal with more digestible energy (DE) and metabolizable energy (ME) than conventional CM. This variety of canola contains approximately 45% crude protein (CP) and may be a more desirable option as a SMB alternative than historic varieties of canola. Research has been conducted at the University of Illinois to determine the effects of conventional (CM-CV) or high protein (CM-HP) canola meal diets for nursery pigs, but no research has been conducted on feeding high protein canola meal to growing and finishing pigs. Therefore, the objectives of this study were to determine

growth performance, carcass characteristics, visceral mass differences, and meat quality of growing and finishing pigs fed diets containing high protein or conventional canola meal as a replacement of SBM.

2.3 MATERIALS AND METHODS

The study was conducted at the Swine Research Center of the University of Illinois and the experimental protocol for the study was approved by the University of Illinois Institutional Animal Care and Use Committee.

2.3.1 Experimental Design and Treatments

A 3-phase 91 d feeding program was used in this study with grower diets fed from d 0 to d 35 (Table 2.1), finisher-1 diets fed from d 36 to d 63 (Table 2.2), and finisher-2 diets fed from d 64 to d 91 (Table 2.3). Seven dietary treatments were used. Dietary treatments included a corn-soybean meal diet (control), 3 diets containing increasing inclusion rates of high-protein canola meal (CM-HP), and 3 diets containing increasing inclusion rates of conventional canola meal (CM-CV). Canola meal replaced 33, 66, or 100% of the soybean meal in the diets. All diets were formulated to meet current estimates for nutrient requirements for growing and finishing pigs (NRC, 2012). Soybean meal was sourced from the University of Illinois feed mill, and CM-HP and CM-CV were provided by DOW AgroSciences LLC, Indianapolis, IN.

A total of 280 barrows and gilts (initial body weight: 27.4 ± 2.92 kg) were used in this study. Four pigs per pen were assigned to 1 of 10 pens per treatment for a total of 70 single sex pens. Pens were equally divided into two blocks based on farrowing dates. Pigs were housed in a mechanically ventilated building with part-solid, part-slotted concrete floors throughout the study period. Pen divisions and gates consisted of vertical steel rods, and pen dimensions were 2.59 m x 1.83 m, which provided a floor space of 1.18 m^2/pig. Each pen had a single-space dry

box feeder mounted on the front gate and a nipple-type water drinker. The thermostat was set at 18.5˚C throughout the study period and ambient temperature was maintained using thermostatically controlled heaters and fan ventilation. Pigs (approximately 10 wk of age) were weighed at the beginning (d 0) of the experiment and again at the end of each of the 3 phases (d 35, d 63, and d 91). Daily feed allotments were recorded, and data were summarized to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio (G:F) for each pen, and measurements for pens were averaged and reported for each treatment group in all 3 phases. One pig from each pen was randomly selected for a meat quality evaluation at the end of the feeding period.

2.3.2 Slaughter Procedures and Evisceration

Selected pigs (35 per block) were transported to the University of Illinois Meat Science Laboratory and held overnight in lairage. Pigs were provided ad libitum access to water during this time, but had no access to feed. Pigs were weighed immediately prior to slaughter to determine ending live weight. Pigs were slaughtered under the supervision of the Food Safety and Inspection Service branch of the United States Department of Agriculture using head-to-heart electrical immobilization and exsanguination. Heart, liver, kidney, and thyroid gland weights were weighed immediately after evisceration. Intestinal weights were collected as described by Boler et al. (2014). Initially, the full intact intestinal tract was weighed. The large intestine was separated from the small intestine at the ileocecal junction. The small intestine was separated from the stomach between the pylorus of the stomach and the duodenum of the small intestine. The stomach was removed from the esophagus where the esophagus empties into the cardia of the stomach. Each section of the intestinal tract was rinsed with water to remove all digestive and fecal material. Mesenteric tissue that surrounds the intestinal tract was removed

and weighed separately. Gut fill was calculated as the difference in the weight of the full intestinal tract and the sum of the empty sections. Each section of the intestinal tract was expressed as the absolute weight of the organ and as a percentage of ending live weight.

2.3.3 Carcass characteristics and fresh meat quality

Carcasses were weighed approximately 45 min postmortem to determine HCW. Dressing percentage (carcass yield) was calculated by diving HCW by ending live weight. Carcasses were then allowed to chill at 4℃ for approximately 24 h. Fresh meat quality was determined on the left side of the carcass at approximately 24 h postmortem. The left side of each chilled carcass was cut between the 10^{th} and 11^{th} rib interface to expose the LM. Loins were allowed to bloom for approximately 20 min, and ultimate pH was determined using a MPI hand-held pH meter (MPI pH-Meter, Topeka, KS; 2 point calibration: pH 4 and 7). Subjective color and marbling scores (NPPC, 1999) and firmness scores (NPPC, 1991) were conducted by a single individual according to standards established by the National Pork Producers Council. Objective L*, a*, and b* values were collected with a Minolta CR-400 utilizing a D65 light source, a 0˚observer and an aperture size of 8 mm. Backfat was measured at ¾ the distance of the loin muscle from the dorsal process of the vertebral column. Loin eye area (LEA) was measured by tracing the face of the longissimus muscle on double matted acetate paper. Loin tracings were measured in duplicate using a digitizer tablet (Wacom, Vancouver, WA) and Adobe Photoshop CS6 and the average of the two measurements was reported. A section of the loin, posterior to the 10^{th} rib, was excised and cut into one 1.25 cm chop and three 2.54 cm thick

chops to determine water holding capacity, proximate composition, and Warner-Bratzler shear force. One 2.54 cm chop was retained as a replacement sample.

2.3.4 Water Holding Capacity

Water holding capacity was estimated using the drip-loss method as described by Leick et al. (2010). Briefly, a 1.25 cm chop was suspended from a fish hook in a Whirl-pak (Nasco, Fort Atkinson, WI) bag for approximately 24 h at 4˚C. Chops were weighed prior to and immediately after suspension. Results were reported as weight loss as a percentage of initial weight.

2.3.5 Loin Proximate Composition

Prior to analysis, chops for proximate composition were individually packaged in Whirl-pak (Nasco, Fort Atkinson, WI) bags and stored at -2˚C. Chops were trimmed of all subcutaneous fat and homogenized using a Cuisinart Food Processor (Model DLC 5-TX, Cuisinart, Stamford, CT). Duplicate 10 g samples of each homogenized chop were weighed, placed in aluminum pans, and covered with Whatman #1 filter paper. Each sample was oven dried at 110˚C for approximately 24 h to determine percent moisture. The dried sample was washed multiple time in an azeotropic mixture of warm chloroform:methanol as described by Novakofski et al. (1989) and weighed to determine extractable lipid content.

2.3.6 Warner Bratzler Shear Force

Chops were vacuum packaged and stored at 4˚C until d 7 post mortem. Chops were frozen at the end of the aging period and held until analysis. Twenty-four h prior to analysis, chops were removed from the freezer and thawed in a 4˚C cooler. Chops were trimmed of

subcutaneous fat and cooked on a Farberware Open Hearth grill (Model 455N, Walter Kidde, Bronx, NY). Chops were cooked on one side to an internal temperature of 35˚C, flipped, and cooked to a final internal temperature of 70˚C. Internal temperature was monitored using copper-constantan thermocouples (Type T, Omega Engineering, Stanford, CT) connected to a digital scanning thermometer. Next, chops were allowed to cool to 25˚C and four 1.25 cm diameter cores were removed parallel to the orientation of the muscle fibers. Cores were sheared using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) with a blade speed of 3.3 mm/sec and a load capacity of 100 kg. Shear force was determined on each core, and the average of 4 cores was reported. Cook loss was determined by weighing chops used for shear force immediately before and after cooking. Values were reported as moisture lost during cooking as a percentage of raw weight.

2.3.7 Carcass Fabrication

Chilled right sides were weighed and initially fabricated into ham, loin, belly (spareribs left on) and whole shoulder (jowl and neck bones left on). Each primal piece was weighed prior to skinning, trimming, and further fabrication.

Hams were fabricated as described by Boler et al. (2010). Hams were initially cut to meet the specifications of NAMP (North American Meat Association) #401 and were designated as a whole ham. Hams were then skinned and trimmed of excess fat to meet the specification of NAMP #402. Hams were weighed again for a trimmed ham weight. After trimming, hams were fabricated into 5 separate pieces: inside ham (NAMP #402F), outside ham (NAMP #402E), knuckle (NAMP (#402H) quadriceps with the tensor fasciae latae removed), inner shank portion (gastrocnemius), and light butt (gluteus medius). All 5 pieces were individually weighed and

identified. Identification of the inside, outside, and knuckle were retained to collect ultimate pH and objective L*, a*, and b* color measurements at approximately 48 h postmortem. Ultimate pH was measured on the semimembranosus (blonde spot, medial side), adductor (proximal face), semitendinosus (medial edge of the distal end), biceps femoris (medial side), rectus femoris (proximal face), and vastus lateralis (proximal edge) using a MPI hand-held pH meter (MPI pH-Meter, Topeka, KS; 2 point calibration: pH 4 and 7). Color measurements were evaluated on the same muscles using a Minolta CR-400 utilizing a D65 light source, a 0˚observer and an aperture size of 8 mm.

Skin-on bone-in loins were skinned to meet the specifications of a NAMP #410 loin. Trimmed loins were weighed and then fabricated into a NAMP #414 Canadian back, NAMP #415A tenderloin (side muscle off), and the sirloin end. The whole sparerib-in belly had the spareribs and teat line removed, and flank end squared to meet the specifications of a NAMP #408 belly. The bellies were retained to make bacon at a later time. The whole shoulder was fabricated into a NAMP #406 bone-in Boston butt and a NAMP #405 bone-in picnic shoulder. Each piece was then boned out to meet specifications of a NAMP #406A boneless Boston butt and a NAMP #405A boneless picnic shoulder.

Weights were collected on all subprimal pieces following fabrication. Carcass cutout data were expressed as absolute values and as a percentage of the chilled right side weight (CSW) by dividing the weight of the piece by the CSW and multiplying by 100. Estimated carcass lean was calculated using the following equation: 8.588 + (0.465 x HCW, lb.) – (21.896 x 10^{th} rib fat depth, in.) + (3.005 x 10^{th} rib loin muscle area, in^2) and then converted to kilograms (Burson, 2001).

2.3.8 Statistical Analysis

Data were analyzed with the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) in a randomized complete block design with the pen as the experimental unit. Block was defined as slaughter date. The statistical model included the fixed effects of dietary treatment and sex and a random effect of block. There were few treatment by sex interactions, thus only effects of dietary treatments were analyzed. Least square means were separated with the PDIFF option. Orthogonal polynomial contrast statements were used to test linear and quadratic effects of increasing proportions of CM-HP or CM-CV to the diets. Normality of data was confirmed and outliers were tested using the UNIVARIATE procedure of SAS. Statistical significance and tendencies were accepted at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

2.4 RESULTS AND DISCUSSION

2.4.1 Growth Performance

During phase 1 (d0 to d35), there were no linear or quadratic effects ($P \geq 0.15$) of increasing inclusion rate of CM-HP or CM-CV for ADG, ADFI, G:F, or d 35 BW in phase 1 (Table 2.4). However, pigs fed CM-CV had 3% greater ($P = 0.03$) ADG and 4% greater ($P = 0.03$) ADFI compared with pigs fed CM-HP.

During phase 2 (d35-d63), ADG was increased (P = 0.04) by 0.04 kg in pigs fed CM-CV (1.03) compared with pigs fed CM-HP (0.99) (Table 2.4). Pigs fed 66% CM-CV (2.93) and 100% CM-CV (2.87) had 6% greater ($P < 0.01$) ADFI compared with the control diet (2.68) and pigs fed 66% CM-HP (2.63) in phase 2. Furthermore, there was a linear increase ($P = 0.02$) in ADFI in pigs fed CM-CV. There were no linear or quadratic differences ($P \geq 0.09$) among pigs fed any level of CM-HP and CM-CV for G:F or d 63 BW.

During phase 3 (d63-d91), there was a quadratic effect ($P = 0.05$) in ADG in pigs fed CM-HP. There were no linear or quadratic effects ($P \geq 0.06$) in ADFI, G:F, or d 91 BW fed any level of CM-HP or CM-CV (Table 2.4). However, pigs fed CM-CV had about 3.5% greater ($P = 0.02$) ADFI and about 3% greater d91 BW compared with pigs fed CM-HP.

Entire feeding period Overall, ADG was increased ($P = 0.01$) by 3% in pigs fed CM-CV (0.94) compared with pigs fed CM-HP (0.91; Table 2.4). ADFI was increased ($P \leq 0.05$) by about 6% for pigs fed 66% CM-CV (2.67) when compared with pigs fed all levels of CM-HP and pigs fed the control diet. Furthermore, there was a linear increase ($P = 0.03$) in ADFI as CM-CV inclusion level increased. There were no overall linear or quadratic effects ($P \geq 0.15$) in pigs fed CM-HP for ADG, ADFI, and G:F (Table 2.4). There, was a linear decrease ($P = 0.02$) in G:F as CM-CV inclusion level increased, which was a result of increased ADFI. Diets in this study were not isocaloric, resulting in pigs fed CM-CV having increased feed intake and weight gain compared with pigs fed CM-HP and the control diet.

2.4.2 Carcass Characteristics

There was a linear decrease ($P = 0.04$) in final farm weight in pigs fed CM-HP (Table 2.5). There was also a 2 kg increase in weight from final farm weight to ending live weight in pigs fed 66% CM-HP. This is unusual since pigs were not provided access to feed while in lairage, but is most likely the result of increased water intake prior to slaughter. There was a trending ($P = 0.07$) quadratic effect for carcass yield in pigs fed CM-CV. There were no differences ($P \geq 0.11$) among treatments for ending live weight, HCW, LEA, backfat thickness, and estimated carcass lean. On the contrary, Shelton et al. (2001) reported pigs fed diets with canola meal as the sole source of supplemental intact protein had increased ($P < 0.05$) average

backfat thickness compared with pigs fed SBM. However, Castell and Falk (1980) reported no differences in backfat thickness and other carcass characteristics in pigs fed 15% canola seeds relative to those fed SBM. Similarly, Busboom et al. (1991) fed pigs diets containing SBM, 20% intact canola, or 20% ground canola and reported no differences in carcass measurements. These conflicting results could be explained by differing inclusion levels, different types of CM, different canola seed processing techniques, or AA supplementation.

2.4.3 Viscera

There were no differences ($P \geq 0.12$) in heart, kidney, liver, thyroid gland, full GI tract, esophagus, or gut fill weights among all treatment (Table. 2.6). The presence of glucosinolates in canola meal has caused hypothyroidism and an increase in thyroid size, which can lead to decrease in ADG and muscle protein accretion (Spencer, 1985; Canola Council of Canada, 2009). However, the variety of canola meal used in this study was estimated to contain < 30 µmol/g glucosinolates; which is the amount generally accepted as low enough to minimize potential effects on the thyroid gland, based on the reported thyroid gland weights and previous research (Bell, 1993; Gonzalez-Vega and Stein, 2012). Stomach weights were greater ($P \leq 0.05$) in pigs fed control (0.63 kg) compared with pigs fed 33% CM-HP (0.55 kg) and 100% CM-HP (0.57 kg) and 66% CM-CV (0.57 kg) and 100% CM-CV (0.58 kg). Furthermore, there were linear ($P \leq 0.05$) effects of stomach weight in pigs fed both types of CM. There was also a linear decrease ($P = 0.05$) in small intestine weights for pigs fed CM-HP. There was a linear decrease ($P = 0.04$) in large intestine weights in pigs fed CM-CV. There were also linear tendencies in empty GI tract weights in pigs fed both types of CM. There were no differences in heart, thryoif gland, full GI tract, esophagus, small intestine, large intestine, empty GI tract, and gut fill weights as a percentage of live weight among all treatments (Table 2.6). There was a linear

increase ($P \leq 0.05$) in kidney weights as a percentage of live weight in pigs fed both types of CM. Liver weights as a percentage of live weight were greater ($P \leq 0.05$) in pigs fed 100% CM-CV (1.70%) compared with pigs fed control (1.55%), pigs fed 33% CM-HP (1.54%) and 100% CM-HP (1.59%), and 33% CM-CV (1.53%) and 66% CM-CV (1.58%). There was a linear increase ($P < 0.01$) in liver percentage as CM-CV inclusion increased. On the contrary, Busato et al. (1991) reported liver enlargement in pigs fed 5 and 10% of high glucosinolate meal (86.5 mmol/kg) , but reported no liver enlargement in pigs fed 10% of low glucosinolate meal (1.9 mmol/kg). Busato et al. (1991) reported the cause of liver enlargement to be a result of cell hypertrophy rather than hyperplasia, with the cytoplasmic fraction being particularly increased. That study concluded there were no differences in proximate composition of the liver, although there was a greater percentage of water in thyroid glands with canola meal inclusion. Furthermore, Busato et al. (1990) reported ensiling canola meal led to decreased liver weights and increased thyroid gland weights, suggesting different substances in canola meal were responsible for either thyroid inhibiting or hepatotoxic effects. Thiocyanates, for example, are a product of glucosinolate breakdown and have negative effects on the liver (Bones and Rossiter, 1996). Results from the current study would suggest the presence of glucosinolates can affect the thyroid gland and the liver differently. There were also trending quadratic effects in stomach weights as a percentage of live weight.

2.4.4 Meat Quality

There were no differences ($P \geq 0.19$) in shear force, cook loss, all subjective evaluations (color, marbling, firmness), loin composition (moisture and fat), and drip loss among all treatments (Table 2.7). However, there was a linear decrease ($P = 0.01$) in ultimate pH in loins from pigs fed CM-HP. There was also a linear decrease ($P < 0.01$) in L* values as inclusion of

CM-HP increased. The decreased L* value indicates a darker color, and agrees with results from Dransfield et al. (1985), who reported that loins from pigs fed canola meal were darker than loins from pigs fed soybean meal. However, they were unable to offer an explanation. There was a trending quadratic effect for b* values in loins from pigs fed CM-HP. Objective a* values were not different ($P = 0.38$) among any treatments. Overall, inclusion of canola meal in diets had no detrimental effects on loin quality. There were no differences ($P \geq 0.11$) among any treatment groups for pH and all objective color scores for the semimembranosus, adductor, semitendinosus, biceps femoris, and rectus femoris (Table 2.8). Ultimate pH for the vastus lateralis was increased by about 4% ($P \leq 0.02$) in pigs fed 33% CM-CV (6.12) compared with pigs fed 66% CM-HP (5.79) and 66% CM-CV (5.91). Objective b* values were increased by about 30% ($P \leq 0.04$) in pigs fed 66% CM-HP (7.10) compared with pigs fed control (5.30) and 33% CM-CV (4.8). There were no differences ($P \geq 0.38$) among treatments for L* and a* for the vastus lateralis. Overall, canola meal had no detrimental effects on ham quality. Loin quality is often regarded as a meat quality measurement for the whole carcass, and loin and ham quality are rarely evaluated in combination. One of the goals of this study was to evaluate how canola meal affected meat quality, thus both loin and ham quality measurements were recorded to get a better evaluation of meat quality of the entire carcass.

2.4.5 Carcass Cutability

There were very few differences in carcass cutout weights (Table 2.9). However, there were linear decreases ($P \leq 0.04$) in weights of bone-in picnic and boneless picnic in pigs fed CM-HP. There were also linear decreases in sirloin and knuckle weights in pigs fed CM-CV. Furthermore, pigs fed 100% CM-CV (1.21) had decreased ($P \leq 0.05$) knuckle weights compared with pigs fed 33% CM-HP (1.36 kg) and 100% CM-HP (1.31 kg), 33% CM-CV (1.34 kg), and

control (1.37 kg). However, there were no differences ($P = 0.25$) in knuckle weights as a percentage of chilled side weight among all dietary treatments (Table 2.10). Pigs fed CM-HP had increased ($P \leq 0.04$) whole shoulder, Canadian back, and light butt weights as a percentage of chilled side weight compared with pigs CM-CV. However, pigs fed CM-HP had decreased ($P = 0.03$) whole belly weight as a percentage of chilled side weight compared with pigs fed CM-CV. Overall, canola meal had no detrimental effects on carcass cutability.

2.5 CONCLUSION

The objective of this study was to determine the acceptable inclusion levels of CM-HP and CM-CV in replacement of SBM in growing and finishing swine diets. Therefore, growth performance, carcass characteristics and cutability, and loin quality were determined for pigs fed 33-100% CM-HP and CM-CV in replacement of SBM. Though feed intake was marginally increased in pigs fed 66% and 100% CM-CV compared with SBM fed pigs, ADG and G:F were unaffected by CM inclusion. Growth performance was similar between CM-HP and CM-CV fed pigs. Furthermore, carcass characteristics and cutting yields were not affected by CM inclusion. Similarly, CM inclusion was not detrimental to loin quality. Therefore, these data suggest that SBM can be completely replaced by CM-HP and CM-CV without harming growth performance, meat yield, and loin quality.

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2.7. TABLES

Table 2.1. Ingredient composition of experimental diets, phase 1

	Diet						
	Control[1]	CM-HP[1]			CM-CV[1]		
	0%	33%	66%	100%	33%	66%	100%
Corn	68.33	67.93	67.48	66.96	66.08	63.72	61.33
Canola meal, high protein	0.00	9.57	19.15	28.72	0.00	0.00	0.00
Canola meal, conventional	0.00	0.00	0.00	0.00	11.68	23.35	35.00
Soybean meal, 48%	27.00	18.00	9.00	0.00	18.00	9.00	0.00
Phytase	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.21	1.30	1.38	1.30	1.13	0.92	0.60
Dicalcium phosphate	0.52	0.25	0.00	0.00	0.15	0.00	0.00
L-Lysine HCL	0.18	0.21	0.25	0.28	0.23	0.28	0.34
DL-Met	0.02	0.00	0.00	0.00	0.00	0.00	0.00
L-Threonine	0.02	0.02	0.02	0.02	0.01	0.01	0.01
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vit-mineral[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed nutrient composition							
DM, %	88.98	88.78	89.33	88.52	87.66	89.64	89.34
CP, %	19.10	20.57	18.59	18.68	19.74	20.16	19.75
ADF, %	4.44	4.70	6.38	7.24	5.25	7.01	8.27
NDF, %	8.72	9.14	10.50	12.53	10.45	12.27	13.12
Ca, %	0.76	0.70	0.74	0.95	0.60	0.40	0.68
P, %	0.43	0.44	0.44	0.45	0.41	0.43	0.52
Indispensable AA, %							
Arg	1.17	1.13	1.00	0.95	1.15	1.12	1.03
His	0.49	0.49	0.45	0.45	0.49	0.51	0.49
Ile	0.80	0.77	0.70	0.66	0.78	0.78	0.71
Leu	1.74	1.64	1.53	1.50	1.63	1.67	1.55
Lys	1.06	1.08	0.95	0.98	1.12	1.05	1.08
Met	0.30	0.32	0.31	0.33	0.32	0.33	0.35
Phe	0.93	0.87	0.77	0.73	0.87	0.86	0.76
Thr	0.72	0.73	0.67	0.68	0.71	0.75	0.73
Trp	0.22	0.23	0.22	0.21	0.21	0.23	0.23
Val	0.89	0.90	0.85	0.86	0.91	0.95	0.92
Total	8.32	8.16	7.45	7.35	8.19	8.25	7.85
Dispensable AA,%							
Ala	1.00	0.96	0.91	0.91	0.96	1.00	0.95
Asp	1.81	1.63	1.34	1.15	1.64	1.49	1.24
Cys	0.29	0.33	0.36	0.39	0.32	0.38	0.43
Glu	3.42	3.38	3.08	3.05	3.33	3.41	3.26
Gly	0.77	0.80	0.76	0.79	0.80	0.86	0.86
Pro	1.16	1.18	1.15	1.22	1.15	1.25	1.27
Ser	0.83	0.78	0.70	0.66	0.78	0.77	0.71
Tyr	0.59	0.53	0.49	0.47	0.57	0.53	0.50
Total	9.87	9.59	8.79	8.64	9.55	9.69	9.22
All AA	18.19	17.75	16.24	15.99	17.74	17.94	17.07

[1]Percentage of canola meal as a replacement for soybean meal

[2] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate

Table 2.2. Ingredient composition of experimental diets, phase 2

	Diet						
	Control[1]	CM-HP[1]			CM-CV[1]		
	0%	33%	66%	100%	33%	66%	100%
Corn	74.50	74.16	73.83	73.43	72.73	70.91	69.05
Canola meal, high protein	0.00	7.45	14.89	22.34	0.00	0.00	0.00
Canola meal, conventional	0.00	0.00	0.00	0.00	9.08	18.16	27.24
Soybean meal, 48%	21.00	14.00	7.00	0.00	14.00	7.00	0.00
Phytase	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.15	1.23	1.28	1.20	1.10	0.90	0.65
Dicalcium phosphate	0.40	0.18	0.00	0.00	0.10	0.00	0.00
L-Lysine HCL	0.20	0.23	0.25	0.28	0.24	0.28	0.32
L-Threonine	0.03	0.03	0.03	0.03	0.03	0.03	0.02
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vit-mineral[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed nutrient composition							
DM, %	88.16	88.42	88.61	88.36	88.65	88.52	88.29
CP, %	15.55	15.78	15.26	17.36	16.57	16.80	15.98
ADF, %	3.59	4.38	4.69	5.41	5.06	6.17	7.28
NDF, %	9.03	10.21	9.84	10.47	11.23	12.23	12.60
Ca, %	0.62	0.76	0.70	0.86	0.70	0.55	0.39
P, %	0.39	0.43	0.42	0.43	0.38	0.39	0.42
Indispensable AA, %							
Arg	0.93	0.93	0.89	0.88	0.90	0.88	0.88
His	0.39	0.41	0.41	0.42	0.39	0.40	0.41
Ile	0.63	0.65	0.62	0.59	0.57	0.62	0.61
Leu	1.40	1.49	1.42	1.40	1.30	1.40	1.37
Lys	0.83	0.97	0.92	0.88	0.96	0.89	0.97
Met	0.25	0.26	0.30	0.31	0.25	0.31	0.32
Phe	0.73	0.74	0.70	0.66	0.66	0.69	0.66
Thr	0.57	0.62	0.60	0.63	0.58	0.61	0.64
Trp	0.20	0.18	0.20	0.19	0.18	0.19	0.19
Val	0.72	0.76	0.76	0.77	0.70	0.76	0.78
Total	6.65	7.01	6.82	6.73	6.49	6.75	6.83
Dispensable AA,%							
Ala	0.83	0.88	0.84	0.86	0.81	0.84	0.85
Asp	1.42	1.32	1.18	1.04	1.20	1.16	1.06
Cys	0.24	0.28	0.34	0.38	0.26	0.34	0.36
Glu	2.70	2.91	2.85	2.88	2.54	2.73	2.80
Gly	0.63	0.68	0.68	0.71	0.65	0.68	0.73
Pro	0.97	1.07	1.09	1.13	0.97	1.05	1.10
Ser	0.67	0.68	0.63	0.62	0.63	0.62	0.62
Tyr	0.50	0.49	0.46	0.44	0.44	0.46	0.44
Total	7.96	8.31	8.07	8.06	7.50	7.88	7.96
All AA	14.61	15.32	14.89	14.79	13.99	14.63	14.79

[1]Percentage of canola meal as a replacement for soybean meal

[2] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxir hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 2.3. Ingredient composition of experimental diets, phase 3

	Diet						
	Control[1]	CM-HP[1]			CM-CV[1]		
	0%	33%	66%	100%	33%	66%	100%
Corn	77.82	77.51	77.19	76.84	76.27	74.67	73.07
Canola meal, high protein	0.00	6.38	12.77	19.15	0.00	0.00	0.00
Canola meal, conventional	0.00	0.00	0.00	0.00	7.78	15.57	23.35
Soybean meal, 48%	18.00	12.00	6.00	0.00	12.00	6.00	0.00
Phytase	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.07	1.15	1.12	1.07	1.04	0.82	0.60
Dicalcium phosphate	0.24	0.06	0.00	0.00	0.00	0.00	0.00
L-Lysine HCL	0.14	0.17	0.19	0.21	0.18	0.21	0.25
L-Threonine	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vit-mineral[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed nutrient composition							
DM, %	90.25	90.11	90.35	90.12	90.07	90.09	90.07
CP, %	17.11	15.15	15.72	16.13	15.74	15.65	15.74
ADF, %	3.47	3.94	4.82	5.13	5.03	5.59	6.47
NDF, %	9.09	9.25	9.33	10.91	10.33	11.22	12.82
Ca, %	0.53	0.55	0.57	0.68	0.45	0.44	0.42
P, %	0.35	0.35	0.37	0.40	0.33	0.35	0.41
Indispensable AA, %							
Arg	0.89	0.86	0.92	0.78	0.96	0.82	0.87
His	0.39	0.39	0.43	0.38	0.42	0.39	0.42
Ile	0.63	0.59	0.63	0.54	0.67	0.58	0.60
Leu	1.47	1.38	1.46	1.34	1.52	1.38	1.41
Lys	0.83	0.82	0.92	0.74	0.87	0.77	0.97
Met	0.26	0.24	0.28	0.27	0.29	0.29	0.30
Phe	0.74	0.69	0.72	0.62	0.77	0.66	0.67
Thr	0.55	0.55	0.61	0.54	0.62	0.56	0.64
Trp	0.17	0.19	0.20	0.18	0.19	0.19	0.19
Val	0.71	0.71	0.78	0.70	0.78	0.71	0.78
Total	6.64	6.42	6.95	6.09	7.09	6.35	6.85
Dispensable AA,%							
Ala	0.83	0.82	0.88	0.80	0.89	0.82	0.87
Asp	1.35	1.21	1.23	0.93	1.39	1.09	1.05
Cys	0.26	0.26	0.33	0.33	0.30	0.33	0.36
Glu	2.72	2.65	2.92	2.56	2.91	2.62	2.79
Gly	0.58	0.62	0.70	0.61	0.68	0.63	0.72
Pro	1.00	1.01	1.12	1.06	1.08	1.05	1.14
Ser	0.65	0.63	0.67	0.56	0.70	0.61	0.63
Tyr	0.50	0.46	0.46	0.42	0.51	0.44	0.45
Total	7.89	7.66	8.31	7.27	8.46	7.59	8.01
All AA	14.53	14.08	15.26	13.36	15.55	13.94	14.86

[1]Percentage of canola meal as a replacement for soybean meal

[2] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl aceta 11,136 IU; vitamin D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadior dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyrido hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 2.4. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on growth performance of finishing pigs

	Diet								P-values					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Pens, n	10	10	10	10	10	10	10							
d 0 to 35														
ADG, kg/d	0.84	0.84	0.82	0.82	0.84	0.87	0.86	0.02	0.29	0.23	0.94	0.25	0.84	0.03
ADFI, kg/d	1.95	1.95	1.91	1.93	2.00	2.07	1.97	0.05	0.30	0.57	0.81	0.55	0.15	0.03
G:F	0.432	0.431	0.431	0.424	0.423	0.425	0.440	0.01	0.89	0.59	0.76	0.55	0.21	0.97
d 35 BW, kg	57.12	57.02	56.27	55.89	57.55	58.01	57.77	1.68	0.90	0.45	0.91	0.68	0.80	0.20
d 35 to 63														
ADG, kg/d	1.00	1.00	0.97	1.00	1.04	1.01	1.03	0.02	0.37	0.51	0.54	0.67	0.66	0.04
ADFI, kg/d	2.68^{c}	2.69^{bc}	2.63^{c}	2.72^{bc}	2.78^{abc}	2.93^{a}	2.87^{ab}	0.11	0.02	0.77	0.54	0.02	0.21	<0.01
G:F	0.376	0.374	0.368	0.366	0.373	0.361	0.362	0.01	0.59	0.22	0.93	0.09	0.76	0.46
d 63 BW, kg	86.73	85.13	83.33	93.74	86.58	86.31	85.82	1.72	0.59	0.13	0.52	0.67	0.91	0.09
d 63 to 91														
ADG, kg/d	0.98	0.93	0.91	0.95	0.96	0.93	0.98	0.02	0.24	0.21	0.05	0.61	0.18	0.12
ADFI, kg/d	3.07	3.07	3.00	3.07	3.12	3.14	3.23	0.11	0.20	0.76	0.57	0.07	0.78	0.02
G:F	0.319	0.304	0.305	0.309	0.309	0.298	0.303	0.01	0.59	0.40	0.18	0.08	0.33	0.69
d 91 BW, kg	114.16	111.14	108.77	110.19	113.85	112.70	113.12	1.68	0.22	0.06	0.19	0.57	0.83	0.03
d 0 to 91														
ADG, kg/d	0.93	0.92	0.89	0.91	0.94	0.94	0.94	0.01	0.22	0.20	0.29	0.70	0.88	0.01
ADFI, kg/d	2.49^{bc}	2.52^{bc}	2.46^{c}	2.52^{bc}	2.59^{abc}	2.67^{a}	2.63^{ab}	0.07	0.04	0.89	0.70	0.03	0.19	<0.01
G:F	0.373	0.365	0.364	0.362	0.363	0.352	0.358	0.01	0.24	0.15	0.57	0.02	0.17	0.20

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

Each least square mean represents 10 pens of 4 pigs per pen

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

Table 2.5. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on carcass characteristics of finishing pigs

	Diet								P-values					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Final farm wt, kg	119.40	115.18	113.60	112.85	117.70	116.40	114.15	2.31	0.41	0.04	0.46	0.10	0.91	0.25
Ending live wt, kg	116.68	114.25	115.60	111.67	117.79	115.63	112.81	2.60	0.57	0.21	0.76	0.20	0.42	0.43
HCW, kg	90.99	89.60	89.81	87.32	92.56	90.48	87.83	1.97	0.49	0.21	0.77	0.18	0.27	0.38
Carcass yield, %	78.01	78.41	77.68	78.22	78.58	78.27	77.84	0.28	0.25	0.94	0.80	0.51	0.07	0.57
Loin eye area, cm^2	50.81	51.62	51.22	52.22	50.03	49.52	49.49	1.58	0.84	0.59	0.95	0.53	0.81	0.12
Backfat, cm	2.03	1.77	1.69	1.78	1.89	1.78	1.88	0.15	0.47	0.11	0.13	0.27	0.31	0.27
Estimated carcass lean[4], %	53.89	53.82	53.95	52.87	54.67	53.77	52.37	0.98	0.72	0.51	0.61	0.22	0.27	0.95

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

[4]Estimate carcass lean = 8.588 + (0.465 x hot carcass wt., lb) - (21.896 x 10th rib fat depth, in.) + (3.005 x 10th rib loin muscle area, sq. in.)

Table 2.6. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on viscera weights of finishing pigs

	Diet								P-value					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Heart, kg	0.37	0.38	0.36	0.36	0.37	0.36	0.35	0.02	0.80	0.54	0.53	0.38	0.63	0.43
Kidney, kg	0.42	0.42	0.45	0.43	0.42	0.44	0.43	0.02	0.61	0.31	0.40	0.42	0.50	0.93
Liver, kg	1.80	1.76	1.89	1.78	1.80	1.83	1.91	0.06	0.39	0.82	0.56	0.17	0.45	0.40
Thyroid Gland, g	11.89	11.30	13.15	11.80	12.78	12.81	11.36	0.75	0.43	0.64	0.61	0.64	0.12	0.70
Full GI tract, kg	7.84	7.46	8.00	7.47	7.68	7.62	7.67	0.36	0.86	0.67	0.80	0.68	0.72	0.94
Esophagus, g	70.63	57.63	71.14	65.01	67.02	66.65	65.88	3.96	0.23	0.84	0.37	0.38	0.71	0.53
Stomach, kg	0.63^{a}	0.55^{c}	0.60^{abc}	0.57^{bc}	0.60^{ab}	0.57^{bc}	0.58^{bc}	0.02	0.03	0.05	0.18	0.01	0.26	0.52
Small Intestine, kg	1.57	1.46	1.47	1.37	1.54	1.46	1.55	0.10	0.37	0.05	0.88	0.63	0.37	0.12
Large Intestine, kg	1.58	1.41	1.48	1.47	1.58	1.55	1.41	0.12	0.17	0.38	0.18	0.04	0.23	0.24
Empty GI tract, kg	3.84	3.47	3.63	3.48	3.79	3.64	3.59	0.21	0.16	0.06	0.30	0.08	0.96	0.10
Gut Fill, kg	4.00	3.98	4.29	3.99	3.89	3.98	4.08	0.23	0.94	0.79	0.54	0.75	0.66	0.59
Heart, % Live wt	0.31	0.33	0.31	0.32	0.31	0.31	0.31	0.01	0.54	0.86	0.60	0.85	0.97	0.11
Kidney, % Live wt	0.36	0.36	0.39	0.38	0.36	0.38	0.38	0.01	0.15	0.03	0.41	0.05	0.76	0.50
Liver, % Live wt	1.55^{bc}	1.54^{bc}	1.63^{ab}	1.59^{bc}	1.53^{c}	1.58^{bc}	1.70^{a}	0.03	0.01	0.14	0.67	<0.01	0.07	0.57
Thyroid Gland, % Live wt	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.80	0.77	0.47	0.59	0.13	0.82
Full GI tract, % Live wt	6.71	6.53	6.93	6.67	6.51	6.59	6.80	0.22	0.74	0.74	0.85	0.68	0.30	0.65
Esophagus, % Live wt	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.003	0.350	0.61	0.20	0.95	0.32	0.73
Stomach, % Live wt	0.54	0.49	0.52	0.51	0.51	0.49	0.51	0.01	0.10	0.25	0.09	0.07	0.06	0.99
Small Intestine, % Live wt	1.33	1.27	1.27	1.23	1.30	1.26	1.38	0.07	0.37	0.15	0.78	0.70	0.12	0.15
Large Intestine, % Live wt	1.35	1.23	1.29	1.32	1.35	1.34	1.25	0.09	0.55	0.87	0.15	0.18	0.44	0.49
Empty GI tract, % Live wt	3.29	3.04	3.15	3.12	3.21	3.15	3.19	0.15	0.54	0.30	0.19	0.37	0.48	0.23
Gut Fill[4], % Live wt	3.42	3.49	3.72	3.55	3.29	3.43	3.61	0.17	0.72	0.43	0.51	0.37	0.39	0.33

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

[4]Gut fill = fill GI tract - empty GI tract

Table 2.7. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on loin quality of finishing pigs

	Diet								P-value					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Shear force, kg	3.34	3.31	3.68	3.44	3.80	3.68	3.57	0.23	0.67	0.52	0.64	0.57	0.22	0.27
Cook Loss, %	22.28	22.12	24.20	22.71	24.89	21.80	22.99	1.61	0.66	0.61	0.64	0.88	0.61	0.82
pH	5.48	5.47	5.51	5.53	5.51	5.51	5.52	0.03	0.12	0.01	0.38	0.10	0.34	0.35
Objective Color														
L*	49.30^{ab}	51.35^{a}	47.72^{bc}	46.69^{c}	49.52^{ab}	47.73^{bc}	47.81^{bc}	0.85	0.01	<0.01	0.07	0.10	0.93	0.74
a*	7.81	8.57	8.23	8.48	8.49	7.68	8.96	0.45	0.38	0.39	0.56	0.18	0.49	0.90
b*	2.93	3.96	2.91	2.45	3.17	2.42	3.54	0.40	0.08	0.17	0.07	0.55	0.27	0.84
Subjective evaluations														
Color	3.0	3.0	2.9	3.1	3.0	3.0	3.2	0.09	0.40	0.63	0.25	0.15	0.28	0.38
Marbling	1.3	1.3	1.2	1.4	1.3	1.3	1.6	0.19	0.70	0.78	0.53	0.21	0.35	0.45
Firmness	2.8	2.4	2.9	2.7	2.7	2.8	2.9	0.19	0.70	0.78	0.53	0.21	0.35	0.45
Loin Composition														
Moisture, %	74.23	74.05	74.65	74.38	74.27	74.47	74.2	0.22	0.59	0.29	0.84	0.91	0.50	0.78
Fat, %	2.37	2.53	1.99	2.04	2.58	2.19	2.55	0.26	0.48	0.19	0.84	0.89	0.78	0.23
Drip Loss, %	4.38	5.21	3.73	4.01	4.51	4.40	4.73	0.56	0.63	0.31	0.63	0.71	0.86	0.62

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

Table 2.8. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on fresh ham quality of finishing pigs

	Diet								P-value					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Semimembranosus														
L*	44.79	45.22	44.93	44.25	44.33	43.01	44.48	1.26	0.88	0.71	0.63	0.66	0.40	0.36
a*	14.55	15.38	14.80	15.03	14.58	17.18	15.84	1.01	0.54	0.85	0.77	0.16	0.50	0.34
b*	3.99	4.36	4.44	4.39	2.96	4.37	3.23	0.65	0.50	0.66	0.75	0.76	0.93	0.10
pH	5.71	5.64	5.63	5.76	5.76	5.67	5.74	0.05	0.23	0.51	0.04	0.99	0.83	0.23
Adductor														
L*	39.93	42.48	41.58	41.52	40.98	41.55	42.14	1.01	0.41	0.29	0.11	0.05	0.78	0.65
a*	13.22	13.12	13.25	12.5	11.33	14.07	11.78	0.91	0.29	0.60	0.70	0.68	0.81	0.42
b*	4.05	4.5	4.25	4.35	2.59	5.06	4.28	0.79	0.17	0.81	0.78	0.25	0.58	0.43
pH	5.73	5.66	5.65	5.68	5.8	5.71	5.68	0.05	0.30	0.46	0.32	0.28	0.31	0.08
Semitendinosus														
L*	45.96	48.91	46.3	50.28	49.26	49.43	49.13	2.89	0.29	0.12	0.73	0.15	0.23	0.52
a*	12.25	11.47	13.53	11.71	10.77	11.72	11.95	1.78	0.36	0.90	0.52	0.99	0.29	0.25
b*	1.72	2.78	3.84	4.25	3.30	3.47	3.99	1.06	0.68	0.07	0.76	0.15	0.62	0.97
pH	5.86	5.80	5.70	5.76	5.90	5.79	5.90	0.06	0.17	0.14	0.30	0.99	0.60	0.03
Biceps Femoris														
L*	43.98	43.71	43.83	44.49	44.08	44.10	46.15	1.31	0.63	0.71	0.64	0.14	0.32	0.34
a*	16.46	17.40	17.78	16.94	18.21	17.19	17.41	0.72	0.69	0.56	0.21	0.56	0.28	0.69
b*	6.09	6.64	6.23	6.44	6.93	6.70	7.23	0.66	0.90	0.82	0.80	0.28	0.81	0.34
pH	5.9	5.84	5.68	5.75	5.89	5.71	5.78	0.08	0.25	0.08	0.35	0.10	0.64	0.53
Rectus Femoris														
L*	45.21	47.68	47.34	47.78	47.56	46.59	48.30	1.40	0.64	0.18	0.40	0.13	0.79	0.90
a*	11.10	9.70	10.60	9.79	9.51	11.22	9.99	0.73	0.50	0.36	0.69	0.62	0.81	0.73
b*	3.78	3.19	4.28	4.57	2.39	4.26	4.11	0.97	0.30	0.27	0.52	0.36	0.37	0.45
pH	5.96	5.82	5.74	5.89	6.03	5.84	5.93	0.07	0.11	0.36	0.05	0.40	0.86	0.05
Vastus Lateralis														
L*	42.91	41.77	43.33	41.85	40.41	42.21	41.79	0.90	0.38	0.69	0.85	0.70	0.25	0.26
a*	18.01	19.47	19.46	18.31	19.05	19.07	19.76	0.65	0.45	0.77	0.05	0.08	0.79	0.69
b*	5.30	6.34	7.10	5.51	4.80	5.77	6.92	0.59	0.07	0.60	0.03	0.03	0.17	0.32
pH	5.99^{ab}	6.05^{ab}	5.79^{c}	5.96^{abc}	6.12^{a}	5.91^{bc}	6.03^{ab}	0.06	0.01	0.22	0.41	0.74	0.90	0.09

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

Table 2.9. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on carcass cutout weights of finishing pigs

	Diet								P-value					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Whole shoulder, kg	11.34	11.45	11.21	11.08	11.36	11.07	10.75	0.29	0.65	0.42	0.67	0.11	0.55	0.43
Bone-in Boston, kg	3.39	3.58	3.54	3.41	3.48	3.41	3.28	0.12	0.61	0.97	0.17	0.44	0.34	0.22
Boneless Boston, kg	3.11	3.29	3.22	3.08	3.23	3.13	2.99	0.12	0.55	0.76	0.16	0.36	0.25	0.38
Bone-in Picnic, kg	4.27	4.28	3.94	3.94	4.13	4.00	3.98	0.14	0.35	0.04	0.95	0.11	0.68	0.87
Boneless Picnic, kg	3.43	3.44	3.11	3.14	3.29	3.20	3.15	0.12	0.29	0.03	0.90	0.09	0.69	0.86
Whole loin, kg	11.43	10.96	11.41	11.08	11.64	11.46	10.90	0.29	0.45	0.65	0.81	0.18	0.19	0.44
Trimmed loin, kg	9.28	9.02	9.31	8.85	9.29	9.19	8.85	0.26	0.61	0.35	0.67	0.19	0.45	0.79
Canadian back, kg	3.38	3.55	3.51	3.36	3.35	3.35	3.32	0.11	0.65	0.84	0.14	0.69	1.00	0.13
Tenderloin, kg	0.39	0.38	0.41	0.39	0.39	0.39	0.37	0.02	0.75	0.70	0.97	0.31	0.70	0.36
Sirloin, kg	0.79	0.69	0.76	0.69	0.76	0.69	0.71	0.04	0.16	0.13	0.54	0.04	0.41	0.75
Whole ham, kg	10.88	10.89	10.68	10.39	10.88	10.65	10.29	0.26	0.40	0.12	0.54	0.07	0.45	0.82
Trimmed ham, kg	9.09	9.12	8.88	8.64	8.94	8.79	8.53	0.29	0.40	0.10	0.54	0.06	0.80	0.48
Inside, kg	1.68	1.73	1.70	1.57	1.66	1.60	1.58	0.06	0.31	0.15	0.11	0.18	0.99	0.27
Outside, kg	2.36	2.36	2.31	2.19	2.33	2.29	2.21	0.08	0.37	0.06	0.35	0.10	0.76	0.79
Knuckle, kg	1.37[a]	1.36[a]	1.28[ab]	1.31[a]	1.34[a]	1.28[ab]	1.21[b]	0.03	0.04	0.13	0.59	<0.01	0.57	0.15
Light butt, kg	0.30	0.35	0.32	0.32	0.30	0.32	0.27	0.05	0.33	0.79	0.29	0.57	0.36	0.07
Shank meat, kg	0.68	0.71	0.65	0.66	0.67	0.65	0.63	0.02	0.20	0.26	0.83	0.07	0.66	0.24
Whole belly, kg	8.59	8.31	8.27	8.17	8.84	8.76	8.13	0.47	0.28	0.26	0.73	0.21	0.09	0.12
Belly, kg	5.40	5.30	5.32	5.18	5.57	5.62	5.21	0.19	0.51	0.42	0.92	0.51	0.11	0.18
Spareribs, kg	1.63	1.58	1.55	1.50	1.65	1.65	1.50	0.07	0.16	0.06	0.99	0.10	0.13	0.20

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

Table 2.10. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on carcass cutout percentages of finishing pigs

	Diet								P-value					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Whole Shoulder, % chilled side wt	25.50	26.24	25.56	25.87	25.13	25.03	25.44	0.34	0.21	0.79	0.53	0.85	0.26	0.02
Bone-in Boston, % chilled side wt	7.62	8.18	8.08	7.93	7.72	7.74	7.75	0.21	0.44	0.39	0.09	0.67	0.82	0.06
Boneless Boston, % chilled side wt	6.99	7.52	7.35	7.18	7.15	7.12	7.07	0.20	0.56	0.67	0.08	0.83	0.61	0.15
Bone-in Picnic, % chilled side wt	9.59	9.81	8.99	9.23	9.11	9.03	9.42	0.24	0.14	0.08	0.95	0.56	0.07	0.42
Boneless Picnic, % chilled side wt	7.71	7.87	7.09	7.37	7.25	7.21	7.46	0.21	0.12	0.06	0.78	0.40	0.10	0.43
Whole loin,% chilled side wt	25.73	25.11	26.01	25.83	25.80	25.92	25.82	0.59	0.69	0.47	0.55	0.81	0.81	0.51
Trimmed loin, % chilled side wt	20.91	20.67	21.20	20.80	20.58	20.80	20.96	0.63	0.93	0.90	0.82	0.82	0.51	0.71
Canadian back, % chilled side wt	7.63	8.12	8.01	7.84	7.43	7.57	7.87	0.28	0.16	0.56	0.10	0.33	0.21	0.03
Tenderloin, % chilled side wt	0.89	0.87	0.93	0.92	0.86	0.89	0.88	0.06	0.79	0.33	0.82	0.99	0.70	0.26
Sirloin, % chilled side wt	1.78	1.57	1.73	1.62	1.69	1.55	1.69	0.08	0.20	0.29	0.46	0.20	0.10	0.90
Whole ham, % chilled side wt	24.52	24.96	24.34	24.28	24.11	24.11	24.36	0.66	0.60	0.38	0.46	0.76	0.33	0.22
Trimmed ham, % chilled side wt	20.51	20.90	20.24	20.22	19.81	19.97	20.20	0.78	0.44	0.36	0.58	0.61	0.18	0.11
Inside, % chilled side wt	3.79	3.97	3.87	3.67	3.67	3.63	3.75	0.14	0.34	0.38	0.11	0.75	0.28	0.10
Outside, % chilled side wt	5.34	5.42	5.27	5.11	5.16	5.18	5.23	0.22	0.72	0.17	0.40	0.61	0.40	0.50
Knuckle, % chilled side wt	3.08	3.12	2.93	3.08	2.96	2.91	2.88	0.08	0.25	0.60	0.51	0.07	0.63	0.07
Light butt, % chilled side wt	0.68	0.81	0.73	0.75	0.65	0.73	0.64	0.12	0.26	0.57	0.32	0.86	0.58	0.04
Shank meat, % chilled side wt	1.53	1.62	1.47	1.55	1.50	1.47	1.49	0.06	0.12	0.62	0.96	0.42	0.52	0.07
Whole belly, % chilled side wt	19.28	19.03	18.84	19.01	19.57	19.76	19.27	0.77	0.39	0.48	0.51	0.91	0.22	0.03
Belly, % chilled side wt	12.13	12.16	12.12	12.04	12.33	12.68	12.34	0.27	0.69	0.81	0.85	0.42	0.32	0.12
Spareribs, % chilled side wt	3.67	3.62	3.52	3.50	3.64	3.72	3.55	0.10	0.38	0.09	0.80	0.42	0.39	0.17

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

Chapter 3:

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

3.1 ABSTRACT

The objective was to compare processing and sensory attributes of dry or conventionally cured bacon from barrows and gilts fed canola meal from high protein (CM-HP) or conventional varieties (CM-CV) of canola seeds in a 3-phase feeding system. Seven diets were fed to test the effects of increasing inclusion rates of CM-HP and CM-CV compared with no canola meal (control). Inclusion rates were 33, 66, or 100% replacement of soybean meal with canola meal for both CM-HP and CM-CV. One hundred forty bellies (2 bellies each from 70 pigs) were used. Left and right side bellies were evaluated for bilateral symmetry of dimensional characteristics and fatty acid profile. Belly fat firmness was evaluated using a Check Line durometer. Bellies from the left side of each carcass were randomly assigned to the dry cured or conventionally (wet) cured treatment, and the matching right sides were assigned to the opposite treatment. Conventionally cured bellies were injected with a cure solution to a target of 110% of original weight. Dry cured bellies were cured for approximately 2 weeks for a target of 2.54 cm of sodium migration per week. Right side bellies had greater ($P \leq 0.05$) width, flop distance, thickness, belly weight, and fat firmness when compared with left sides. There were no differences ($P \geq 0.12$) in essential fatty acid concentrations (C18:3n-3, C20:5n-3, C22:5n-3, and C22:6n-3) between left and right bellies. There were no differences ($P \geq 0.07$) in belly weight, length, width, flop distance, and fat firmness among treatments. There was a quadratic effect ($P = 0.03$) on average thickness for pigs fed CM-CV. There were few differences in fatty acid profile of bellies. However, there was a linear decrease ($P = 0.02$) in total PUFA as CM-HP inclusion increased, and a linear decrease ($P < 0.01$) in ω6:ω3 ratio as CM-CV inclusion

increased. Processing characteristics, bacon slice characteristics, and proximate composition were unaffected by dietary treatments for both conventionally cured and dry cured bellies. Furthermore, sensory panel evaluations of saltiness, flavor intensity, off flavor, and off odor were also similar among dietary treatments in both types of bacon. Overall, high protein and conventional canola can replace soybean meal in growing-finishing pig diets without any detrimental effects on processing characteristics and sensory attributes of dry cured and conventionally cured bacon.

3.2 INTRODUCTION

Canola meal (CM) can be an alternative to soybean meal (SBM) as a protein supplement for pigs (Bell, 1975; McKinnon and Bowland, 1977; Baidoo et al., 1987). However, conventional CM has less crude protein (35-40%) than SBM (48.5) and about 3 times as much fiber, limiting the availability of essential amino acids and lowering the digestible energy (DE) in pig diets (Thacker and Kirkwood, 1990). A new hybridized variety of high protein CM contains less fiber and is thought to have a greater DE than conventional CM. Canola meal contains some anti-nutritional factors such as glucosinolates and sinapine. Glucosinolates can cause liver hemorrhage and inhibit thyroid production, thus inhibiting animal growth (Busato et al., 1991). However, previous research reported new varieties of CM containing less than 30 μmol/g of glucosinolates did not have negative effects on animal growth, liver size, or thyroid hormone production (Busato et al., 1991; Bell, 1993). Sinapine can cause a "fishy" smell in the eggs of layer hens (Pearson et al., 1980). Previous research reported no effects on sensory characteristics on loins from pigs fed CM (Dransfield et al., 1985). However, no research has been conducted to evaluate sensory effects on bacon from pigs fed CM. Canola meal is also generally high in PUFA; a characteristic resulting in thin and soft pork bellies that are challenging to process into

bacon (Person et al., 2005; Leick et al., 2010). Therefore, the objective of this study was to determine processing and sensory attributes of dry or conventionally cured bacon from barrows and gilts fed CM from high protein or conventional varieties of canola seeds. Furthermore, left and right side bellies were analyzed for fresh belly characteristics to determine differences based on carcass side (bilateral symmetry).

3.3 MATERIALS AND METHODS

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

3.3.1 Experimental Design

One hundred forty bellies from 70 pigs were obtained from the University of Illinois Meat Science Laboratory, sourced from a previous experiment (Chapter 2). A complete description of slaughter and fabrication procedures was described in Chapter 2. Briefly, a 3-phase feeding program was used with grower diets fed from d 0 to d 35, finisher-1 diets from d 36 to d 63, and finisher-2 diets from d 64 to d 91. Therefore, a total of 21 diets were formulated with 7 diets in each phase. The 7 treatments within each phase consisted of a corn-soybean meal diet with no canola meal (control), 3 diets containing different levels of high protein canola meal (CM-HP; *Brassica napus* containing 45% CP), and 3 diets containing different levels of conventional canola meal (CM-CV; 40% CP). Canola meal replaced 33, 66, or 100% of SBM with both sources of CM. All diets were formulated to meet current estimates for nutrient requirements for growing and finishing pigs (NRC, 2012). Soybean meal was sourced from the University of Illinois feed mill, and CM-HP and CM-CV were provided by Dow AgroSciences LLC, Indianapolis, IN. Each dietary treatment was replicated 10 times (10 single sex pens per

treatment) for a total of 70 pens with 4 pigs per pen. At the conclusion of the feeding portion of the experiment, 1 pig per pen was randomly selected for an in depth meat and fat quality evaluation. Pigs were divided into 2 equal blocks (35 pigs per group) and transported to the University of Illinois Meat Science Laboratory and humanely slaughtered (under the supervision of the United States Department of Agriculture) over a 2 week time period.

3.3.2 Fresh Belly Characteristics

Left and right sides of each carcass were fabricated to comply with Institutional Meat Purchase Specifications (IMPS) as described by the North American Meat Processors Association (2010). Whole bellies had the spareribs removed, teat line trimmed, and flank end squared to meet the specifications of an IMPS #408 belly. Fresh skin-on bellies were allowed to equilibrate to approximately 2˚C for at least 24 h after fabrication. Bellies were laid flat and covered to minimize evaporative loss during equilibration. Bellies were evaluated for length, width, and flop distance using a ruler. Belly flop distances were collected by draping a belly vertically, skin side down, over a stationary bar and measuring the distance between the two skin edges. A wider flop distance was indicative of a more firm belly, and a narrower flop distance was indicative of a less firm belly. Belly thickness was measured at 8 different locations by pushing a sharpened ruler through a belly laid skin-side down. Measurements 1 through 4 were collected along the dorsal edge of the belly starting at the anterior end and working towards the posterior end. Measurements 5 through 8 were collected along the ventral edge of the belly starting at the anterior end and working towards the posterior end. Average belly thickness was calculated from the mean of the eight measurements. Belly fat firmness was evaluated on the dorsal edge of the anterior end of each belly using a Check Line durometer (Electromatic Equipment Co., Inc. Cedarhurts, NY) where a greater number is indicative of firmer fat. A fat

tissue sample containing all three fat layers was collected from the dorsal edge of the anterior end of each belly and used to determine fatty acid profiles. Dimensional measurements were collected on both bellies from each pig independently to evaluate bilateral symmetry between bellies and then averaged together to determine dietary effects.

3.3.3 Fatty Acid Profile Determination

Fat samples were prepared using the Folch method (AOAC, 1984). Fatty acid profiles were determined using a gas chromatograph equipped with a flame ionization detector. Total saturated fatty acids (SFA) were calculated using fatty acid profile data with the following equation: SFA = (C14:0) + (C15:0) + (C16:0) + (C17:0) + (C18:0) + (C20:0) + (C22:0) + (C23:0) + (C24:0). Total monounsaturated fatty acids (MUFA) were calculated using fatty acid profile data with the following equation: MUFA = (C14:1) + (C16:1) + (C17:1) + (C18:1n-9) + (C20:1n-9) + (C22:1n-9). Total polyunsaturated fatty acids (PUFA) were calculated using fatty acid profile data with the following equation: PUFA = (C18:2n-6) + (C18:3n-6) + (C18:3n-3) + (C20:2n-6) + (C20:3n-6) + (C20:4n-6) + (C20:3n-3) + (C20:5n-3) + (C22:2n-6) + (C22:4n-6) + (C22:5n-3) + (C22:6n-3). The ratio of unsaturated fatty acids to saturated fatty acids (UFA:SFA) was calculated using fatty acid profile data with the following equation: UFA:SFA = (total MUFA + total PUFA) / total SFA. The ratio of ω6 fatty acids to ω3 fatty acids was calculated using fatty acid profile data with the following equation: ω6:ω3 = [(C18:2n-6) + (C18:3n-6) + (C20:2n-6) + (C20:3n-6) + (C20:4n-6) + (C22:2n-6) + (C22:4n-6)] / [(C18:3n-3) + (C20:3n-3) + (C20:5n-3) + (C22:5n-3) + (C22:6n-3)]. Iodine values (IV) were calculated using two different equations. The first equation was: IV = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723; AOCS, 1998). The second equation was: IV = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.795) + C20:2 (1.57) + C20:3

(2.38) + C20:4 (3.19) + C20:5 (4.01) + C22:4 (2.93) + C22:6 (4.64) (Meadus et al., 2010). The second equation was used to account for the large relative proportion of UFA found in samples from pigs fed CM diets. Samples from the left and right sides were evaluated independently to evaluate bilateral symmetry between bellies and then averaged together to determine dietary effects.

3.3.4 Cured Belly Manufacturing

Bellies from the left side of the carcasses were randomly assigned to a dry cure or conventionally (wet) cure manufacturing process, and the matching right side was allotted to the opposite treatment. Fresh bellies were skinned and weighed to determine green weight.

Conventionally cured bellies were injected with a multi-needle injector using a Schroder Injector/Marinator, Model N50 (Wolf-Tec, Inc, Kingston, NY) with a cure solution to a target of 110% of original green weight, and were immediately weighed again to determine pump uptake. Cure solution was formulated to include 1.5% salt, 0.34% phosphate, 0.05% sodium erythorbate, 0.11% sugar, and 0.014% sodium nitrate in the finished product. Pump uptake was calculated using the following equation: $\frac{Pumped\ weight - Green\ weight}{Green\ Weight} * 100$. Bellies were allowed to equilibrate for 24 h after injection to allow for complete distribution of the cure solution. Bellies were then weighed again to determine equilibrium belly weight, combed from the flank end, and cooked in an Alkar smokehouse (Lodi, WI) to an ending internal temperature of 52.2˚C. Cured bellies were then placed in a cooler for 24 h and allowed to cool to 2˚C (Leick et al., 2010).

Bellies assigned to the dry cured treatment were placed into coolers with either 4 or 5 bellies to a cooler, covered with ice packs, and transported to a USDA inspected bacon processing facility. Bellies were dry cured for approximately 2 weeks for a target of 2.54 cm of

sodium migration per week. Bellies were processed using proprietary techniques, packaged, and transported back to the University of Illinois Meat Science Laboratory to be sliced and further evaluated.

3.3.5 Bacon Slicing

All bellies were weighed just prior to slicing to determine cooked weight. Cooked yield was calculated from the following equation: $\frac{Cooked\ weight}{Green\ weight} * 100$. Bellies were sliced using a Treif PUMA slicer (TREIF USA Inc., Shelton, CT). Bellies were individually placed in the slicer and bacon was removed to maintain anatomical orientation. Ends and incomplete pieces were sorted out by a trained individual, and the sliced weight of each belly was recorded. Bellies were divided into 3 approximately equal zones. Zones were designated as blade end, middle, and flank end. Two slices were collected from the middle of each zone, packaged in a whirl-pac bag, and stored at -4˚C for later determination of proximate composition (moisture and lipid percentage). One complete slice was collected from the middle of each of the 3 zones for image analysis. Slices were laid flat on a 30.48 cm x 40.64 cm piece of white parchment paper with appropriate identification, cure treatment, and anatomical location of each slice (blade, middle, or flank). The three slices were vacuum packaged as a set, frozen, and stored for image analysis. Six slices were collected from the middle zone and used for sensory analysis.

3.3.6 Bacon Proximate Composition

Proximate composition was determined by homogenizing 2 slices from each of the 3 zones (blade, middle, flank) in a food processor (Cuisinart model CUI DFP-7BC, Cuisinart, East Windsor, NJ). A 5 gram sample of the homogenate was oven dried in duplicate at 110˚C for approximately 24 h to determine percent moisture. The dried sample was washed multiple time

in an azeotropic mixture of warm chloroform:methanol as described by Novakofski et al. (1989) and weighed to determine lipid content.

3.3.7 Bacon Slice Lean Image Analysis

Slices were identified based on anatomical location as blade end, middle, and flank end. Slices were photographed as a set using a Nikon D60 camera (Nikon Instruments Inc., Melville, NY) at a standardized distance from the samples. A ruler was included in each image to allow for the establishment of a known distance. Images were converted to a black and white TIFF file in Adobe Photoshop CS6. The individual slice outlines were selected using the magic wand tool, and image analysis was conducted using Image-J image processing and analysis software in Java. Threshold values were adjusted as needed within each image to account for variations in lean and fat color. Total slice length, width, and area were calculated using Adobe Photoshop CS6. Secondary lean area [cutaneous trunci (Person et al., 2005)] was calculated by pixel density in Image-J (Kyle et al., 2014). Lean to fat ratios were calculated using the following equation: Total lean area / (Total slice area – Total lean area). Percent lean area was calculated using the following equation: (Total lean area / Total slice area) * 100. Lean to fat ratios and percent lean area were calculated for the blade, middle, and flank slices. Averages of those measurements were used to calculate the reported lean:fat and percent lean area.

3.3.8 Sensory Evaluation

Bacon slices within each cure treatment were evaluated by 6 trained panelists. Bacon slices were placed on baking sheets and cooked at 177˚C for 10 min in a convection oven (Southbend Model V-15, Fuquay-varina, NC). Cooked slices were allowed to cool for approximately 5 min and then cut into 2.54 cm pieces. Each panelist received 4 pieces in a

plastic cup covered with a plastic lid. Panelists were separated in individual booths and provided apple juice and unsalted crackers to serve as a palate cleanser between each sample. Panelists evaluated each slice of bacon for saltines, flavor intensity, off-flavor, and off-aroma using a 15 cm unstructured line scale; where 0 represented the least intense for each parameter and 15 represented the most intense for each parameter.

3.3.9 Statistical Analyses

Bilateral symmetry data were compared using the paired option of the PROC T Test in SAS (SAS Inst. Inc., Cary, NC). Fresh belly and bacon data were analyzed with the MIXED procedure of SAS as a general linear mixed model. The fixed effects in the model were treatment (control, 33% CM-HP, 66% CM-HP, 100% CM-HP, 33% CM-CV, 66% CM-CV, and 100% CM-CV) and sex (barrow and gilt), and a random effect of block. Additionally, few interactions were detected between sexes so the effect of sex was pooled and the main effects of diet were analyzed. Least square means were separated with the PDIFF option and were calculated for each independent variable. Orthogonal polynomial contrasts statements were used to test linear and quadratic effects of increasing level of CM-HP and CM-CV on each dependent variable. Normality of diets was confirmed and outliers were tested using the UNIVARIATE procedure of SAS. Statistical significance and tendencies were accepted at $P \leq 0.05$ and $0.05 < P < 0.10$, respectively.

3.4 RESULTS AND DISCUSSION

3.4.1 Bilateral Symmetry

Fresh belly characteristics were evaluated to determine bilateral symmetry of left and right side bellies (Table 3.1). Right side bellies had greater ($P \leq 0.05$) width, flop distance, thickness, belly weight, and fat firmness when compared with left sides. Overall, right side

bellies were about 6.5% wider, 6% thicker, and about 7% heavier than left side bellies. This disagrees with Breidenstein et al. (1964) who reported no differences between the left and right sides of pork carcasses and less than a 2% difference in all whole muscle weights evaluated. Bellies were not weighed individually, so it is unclear if bellies in the study done by Breidenstein et al. (1964) were different. As pigs have gotten leaner in recent years, there may be more variation in high-fat subprimal pieces. The differences between left and right bellies may contribute, in part, to variation apparent in bacon processing.

There were no differences ($P \geq 0.17$) between left and right bellies for C14:1, C16:0, C17:1, C18:1n-9, C18:2n-6, C18:3n-6, C18:3n-3, C20:3n-6, C20:5n-3, C22:0, C22:1n-9, C22:2n-6, C23:0, C22:4n-6, C22:5n-3, C24:0, or C22:6n-3 (Table 3.2). The percentages of fatty acids C14:0, C16:1, and C20:4n-6 were increased ($P < 0.001$) in left sides compared with right sides. The percentages of C15:0, C18:0, C20:0, C20:n9, and C20:2n6 were increased ($P \leq 0.04$) in right side bellies compared with left sides. The percentages of C17:0 and C20:3n3 (ETE) tended ($0.05 < P < 0.10$) to be increased in right sides compared with left sides. However, all of these differences were less than half a percentage unit, thus, fatty acid differences between left and right side bellies would likely not have an effect on belly quality. There were also no differences in the ω6:ω3 ratio calculated iodine values.

3.4.2 Fresh Belly Characteristics

There were no differences ($P \geq 0.07$) for belly weight, length, and width among any dietary treatments (Table 3.3). Belly thickness at locations 2 and 5 were greater ($P \leq 0.02$) for pigs fed CM-CV compared with pigs fed CM-HP, and there were quadratic effects for pigs fed CM-CV at the same locations. Pigs fed CM-CV tended ($P = 0.07$) to have a greater average thickness compared with pigs fed CM-HP. There was a quadratic effect ($P = 0.03$) for average

thickness for pigs fed CM-CV. There were no differences ($P \geq 0.25$) among treatments for flop distance and durometer measurements.

3.4.3 Fatty Acid Profiles

There were no differences ($P \geq 0.19$) among any dietary treatment groups for C14:0, C14:1, C15:0, C16:0. C16:1, C18:0, C18:3n6, C20:0, C20:1n9, C20:3n6, C22:0, C22:1n9, C22:2n6, C24:0, or C22:6n3 (DHA) (Table 3.4). Pigs fed 100% CM-CV (1.31%) had a greater ($P \leq 0.05$) percentage of C18:3n3 (ALA) than pigs fed control (1.20%), pigs fed 33% CM-HP (1.21%), 66% CM-HP (1.18%), and 100% CM-HP (1.13%), and pigs fed 33% CM-CV (1.19%). Conventional CM has a high (32%) proportion of omega-3 unsaturated fatty acids, thus, increased levels of C18:3n3 were expected with increasing inclusion rates of CM-CV (CDC, 2012). On the other hand, the percentage of C18:3n3 tended to decline ($P = 0.06$) as inclusion level of CM-HP increased. Pigs fed control (0.79%) had a greater ($P \leq 0.05$) percentage of C20:2n6 than pigs fed 100% CM-HP (0.66%) and pigs fed 33% CM-CV (0.71%) and 100% CM-CV (0.71%). Pigs fed 100% CM-HP (0.14%) had a decreased ($P \leq 0.05$) percentage of C20:3n3 (ETE) compared with all other treatments. Also, pigs fed 100% CM-HP (0.0632%) had a decreased ($P \leq 0.05$) percentage of C22:5n3 (DPA) compared with pigs fed the control (0.0749%) and pigs fed 33% CM-CV (0.0711%), 66% CM-CV (0.0766%), and 100% CM_CV (0.0749%). There were no differences ($P \geq 0.10$) among treatments for total SFA, total MUFA, and UFA:SFA. However, there was a linear decrease ($P = 0.02$) in total PUFA as inclusion level of CM-HP increased. There were differences in ω6:ω3 with pigs fed the control (13.14) and pigs fed 66% CM-HP (13.16) and 100% CM- HP (13.18) having increased ($P \leq 0.05$) ratios. Furthermore, ω6:ω3 linearly decreased ($P < 0.0001$) with increasing inclusion level of CM-CV. Typically, Americans consume diets that contain ω6:ω3 of around 15:1 or 16:1 (Simopoulus,

2008). A ratio of 4:1 to 1:1 is advised for human diets, as consuming increased levels of ω6 PUFA can lead to many diseases, such as cardiovascular disease, cancer, and inflammatory diseases (Simopoulus, 2008; Stoll, 2001). Increasing levels of CM-CV can lower the ω6:ω3 of pork belly fat, but not to a degree that is necessary for improving human health. There were no differences ($P \geq 0.37$) among dietary treatments for either iodine value calculation. Although feeding increasing levels of CM-HP decreased total PUFA content, these differences were not at a great enough magnitude to affect calculated iodine value.

3.4.4 Processing Characteristics

There were no differences ($P \geq 0.09$) among any treatment groups for green weight, pumped weight, pump uptake, cooked weight, cooked yield, or sliced weight for conventionally cured bacon (Table 3.5). There were also no differences ($P \geq 0.09$) among any treatment groups for cooked yield or sliced weight for dry cured bacon (Table 3.5). However, there were quadratic effects ($P = 0.05$) on green weights and cooked weights of dry cured bacon from pigs fed CM-CV. Furthermore, green weights were greater ($P = 0.05$) in dry cured bacon from pigs fed CM-CV compared with bacon from pigs fed CM-HP. Conventionally cured bacon was not statistically compared with dry cured bacon; however, conventionally cured bacon had numerically greater cooked yields than dry cured bacon. Conventionally cured bacon was first pumped with a water and salt solution to a target of 110% of green weight, and then cooked back down to a target of 100% of green weight to meet the standards of identity for bacon (FSIS, 1995) thereby allowing for a cooked yield of close to 100%. Dry cured bacon was rubbed with a dry cure and then cooked. Dry cured bacon is expected to have a lesser cooked yield compared with conventionally cured bacon because excess water was not added to it prior to cooking.

3.4.5 Bacon Composition

There was a trending increase (P = 0.06) in percent moisture in conventionally cured bacon from pigs fed CM-HP compared with bacon from pigs fed CM-CV (Table 3.6). Additionally, percent fat was decreased (P = 0.04) by about 3 percentage units in conventionally cured bacon from pigs fed CM-HP compared with bacon from pigs fed CM-CV. This was unexpected as backfat and calculated percent lean were not different (P > 0.05) among all treatment groups. However, pigs fed CM-CV had greater ADFI than pigs fed CM-HP which may contribute to a higher fat percentage in the bacon (Chapter 2). There were no differences among any treatment groups for percent moisture ($P = 0.27$) or percent fat ($P = 0.23$) for dry cured bacon. Dry curing removes more moisture compared with conventional curing, and the magnitude of that moisture loss is enough to mask any potential differences caused by the dietary treatments.

3.4.6 Bacon Slice Lean:Fat Image Analysis

There were no differences ($P \geq 0.07$) among any treatments for average total slice area, secondary lean area, total lean area, lean:fat, slice length, and slice width for conventionally cured bacon (Table 3.6). Bacon slices from pigs fed CM-CV had 5% less ($P = 0.02$) percent lean area compared with slices from pigs fed CM-HP. This was expected as bacon from the pigs fed CM-CV also had increased ($P = 0.04$) lipid content compared with bacon from pigs fed CM-HP. There were no differences ($P \geq 0.06$) among any treatments for total slice area, total lean area, percent lean area, lean:fat, slice length, and slice width for dry cured bacon (Table 3.6).

3.4.7 Sensory Characteristics

There were no differences ($P \geq 0.26$) among treatments for saltiness, flavor intensity, and off odor for conventional bacon (Table 3.7). However, conventionally cured bacon from pigs

fed CM-CV had decreased ($P = 0.04$) off flavor scores compared with bacon from pigs fed CM-HP. However, the magnitude of difference was only 0.19 units on a 0-15 scale, a value that would likely not affect overall product acceptability. Bacon from pigs fed 100% CM-HP (0.31) had greater off flavor scores compared with bacon from pigs fed 33% CM-HP (0.19) and 66% CM-HP (0.18), which was most likely driving the average of CM-HP off flavor scores and causing the difference between CM-HP and CM-CV. There were no differences ($P \geq 0.47$) among treatments for saltiness, flavor intensity, off flavor, and off odor for dry cured bacon (Table 3.7). However, dry cured bacon from pigs fed CM-HP tended to be saltier ($P = 0.08$) than bacon from pigs fed CM-CV. There were no differences in any sensory parameter between bacon from pigs fed CM and bacon from pigs fed the control diet. It can, therefore, be assumed that neither glucosinolates nor sinapine were at a high enough level in the CM to affect bacon sensory attributes or that glucosinolates and sinapine do not affect bacon sensory attributes, regardless of inclusion level in CM.

3.5 CONCLUSION

The main objective of this study was to determine the effects of feeding CM-HP and CM-CV in replacement of SBM on bacon processing and sensory attributes using two different curing methods. Therefore, fatty acid profiles, fresh belly characteristics, and processing characteristics were determined on bellies from pigs fed 33-100% CM-HP and CM-CV in replacement of SBM. Overall, there were few differences among pigs fed SBM and differing levels of CM-HP and CM-CV. Pigs fed CM-CV had a lower ω6:ω3 ratio in belly fat compared with pigs fed the control diet, however, not at a low enough level to be considered a heart healthy alternative in human diets. There were very few differences among treatments for characteristics of belly processing, bacon slices, and sensory attributes. Therefore, these data suggest that SBM

can be completely replaced by CM-HP or CM-CV without any adverse effects on bacon processing attributes and sensory characteristics.

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3.7 TABLES

Table 3.1. Bilateral symmetry of left and right belly characteristics from pigs fed two varieties of canola meal

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

[1]Standard error of the difference of the mean

Table 3.2. Bilateral symmetry of left and right belly fatty acid profiles from pigs fed two varieties of canola meal

Item	Left	Right	Difference	SED[1]	P-value
Myristic (C14:0), %	1.228	1.212	0.016	0.004	<0.001
C14:1, %	0.020	0.021	-0.001	0.001	0.62
C15:0, %	0.054	0.057	-0.003	0.001	<0.01
Palmitic (C16:0), %	21.863	21.812	0.051	0.070	0.47
C16:1, %	2.425	2.355	0.069	0.017	<0.001
Margaric (C17:0), %	0.319	0.324	-0.005	0.003	0.07
C17:1, %	0.330	0.329	0.001	0.003	0.62
Stearic (C18:0), %	9.746	9.895	-0.148	0.071	0.04
C18:1n-9, %	42.252	42.111	0.141	0.103	0.17
Linoleic (C18:2n-6), %	17.893	17.980	-0.087	0.105	0.41
C18:3n-6, %	0.031	0.031	0.000	0.001	0.87
ALA (C18:3n-3), %	1.211	1.209	0.002	0.007	0.75
Arachidic (C20:0), %	0.197	0.203	-0.006	0.001	<0.0001
C20:1n-9, %	0.803	0.816	-0.014	0.004	<0.01
C20:2n-6, %	0.724	0.741	-0.017	0.006	0.01
C20:3n-6, %	0.096	0.096	0.000	0.001	0.58
C20:4n-6, %	0.272	0.264	0.008	0.001	<0.0001
ETE (C20:3n-3), %	0.157	0.159	-0.002	0.001	0.06
EPA (C20:5n-3), %	0.026	0.029	-0.003	0.002	0.12
Behenic (C22:0), %	0.027	0.025	0.002	0.003	0.57
C22:1n-9, %	0.026	0.028	-0.002	0.002	0.31
C22:2n-6, %	0.034	0.037	-0.003	0.005	0.62
C23:0, %	0.037	0.039	-0.002	0.003	0.35
C22:4n-6, %	0.093	0.093	0.000	0.001	1.00
DPA (C22:5n-3), %	0.072	0.071	0.001	0.001	0.19
Lignoceric (C24:0), %	0.027	0.027	0.000	0.002	0.89
DHA (C22:6n-3), %	0.037	0.036	0.001	0.003	0.84
Total SFA,[2] %	33.486	33.606	-0.120	0.13	0.36
Total MUFA,[3] %	45.863	45.651	0.213	0.12	0.08
Total PUFA,[4] %	20.649	20.742	-0.093	0.12	0.43
UFA:SFA ratio[5]	1.998	1.987	0.011	0.01	0.37
ω6:ω3[6]	12.750	12.810	-0.067	0.04	0.12
IV[7] (AOCS, 1998)	73.530	73.500	0.030	0.18	0.87
IV[8] (Meadus, 2010)	76.950	76.904	0.048	0.19	0.80

[1]standard error of the difference of the mean

[2]Total SFA = (C14:0) + (C15:0) + (C16:0) + (C17:0) + (C18:0) + (C20:0) + (C22:0) + (C23:0) + (C24:0)

[3]Total MUFA = (C14:1) + (C16:1) + (C17:1) + (C18:1n-9) + (C20:1n-9) + (C22:1n-9)

[4]Total PUFA = (C18:2n-6) + (C18:3n-6) + (C18:3n-3) + (C20:2n-6) + (C20:3n-6) + (C20:4n-6) + (C20:3n-3) + (C20:5n3) + (C22:2n-6) + (C22:4n-6) + (C22:5n-3) + (C22:6n-3)

[5]UFA:SFA = (total MFUA + total PUFA) / total SFA

[6]ω6:ω3= [(C18:2n-6) + (C18:3n-6) + (C20:2n-6) + (C20:3n-6) + (C20:4n-6) + (C22:2n-6) + (C22:4n-6)] / [(C18:3n-3) + (C20:3n-3) + (C20:5n-3) + (C22:5n-3) + (C22:6n-3)]

[7]Iodine value = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723)

[8]Iodine value = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.795) + C20:2 (1.57) + C20:3 (2.38) + C20:4 (3.19) + C20:5 (4.01) + C22:4 (2.93) + C22:6 (4.64)

Table 3.3. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on fresh belly characteristics of finishing pigs

	Diet								P-value					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Belly wt, kg	4.43	4.35	4.29	4.19	4.66	4.61	4.26	0.16	0.27	0.27	0.94	0.41	0.07	0.08
Length, cm	59.77	59.84	60.8	58.99	59.93	61.46	59.69	1.33	0.52	0.72	0.28	0.74	0.27	0.50
Width, cm	23.61	23.37	23.34	22.72	23.28	23.84	23.07	0.36	0.44	0.10	0.59	0.51	0.54	0.40
Thickness[4], cm														
Location 1	4.94	5.11	4.75	5.03	5.31	5.10	4.81	0.21	0.38	0.91	0.75	0.46	0.08	0.46
Location 2	4.08^{bc}	4.14^{bc}	3.74^{c}	4.10^{bc}	4.71^{a}	4.34^{ab}	4.08^{bc}	0.26	0.05	0.71	0.46	0.69	0.03	0.02
Location 3	3.35	3.32	3.1	3.42	3.57	3.57	3.28	0.21	0.38	0.97	0.27	0.76	0.12	0.14
Location 4	3.16^{b}	3.64^{a}	3.18^{b}	3.42^{ab}	3.63^{a}	3.47^{ab}	3.26^{ab}	0.36	0.05	0.62	0.39	0.82	0.01	0.67
Location 5	3.00^{c}	3.37^{ab}	3.18^{bc}	3.34^{ab}	3.58^{a}	3.42^{ab}	3.56^{a}	0.15	<0.01	0.08	0.33	<0.01	0.04	0.01
Location 6	3.23	3.30	3.16	3.18	3.42	3.41	3.24	0.11	0.49	0.54	0.77	0.97	0.11	0.12
Location 7	3.09	3.09	3.05	3.01	3.33	3.14	3.13	0.12	0.56	0.59	0.87	0.88	0.27	0.11
Location 8	3.52	3.34	3.7	3.61	3.76	3.48	3.52	0.25	0.30	0.28	0.73	0.63	0.43	0.70
Average thickness, cm	3.55	3.66	3.48	3.64	3.91	3.74	3.61	0.11	0.14	0.85	0.85	0.97	0.03	0.07
Flop distance, cm	15.16	13.91	13.13	15.42	17.01	15.38	13.13	3.90	0.69	1.00	0.32	0.33	0.25	0.48
Durometer	59.42	61.67	58.68	57.83	61.26	60.56	58.40	2.30	0.86	0.45	0.50	0.72	0.39	0.72

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

[4]Location 1 to 4 is from anterior to posterior position of dorsal edge of the belly; Location 5 to 8 is from anterior to posterior position of the ventral edge of the belly

Table 3.4. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on fatty acid profile of finishing pigs

	Diet								P-values					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Myristic (C14:0), %	1.22	1.23	1.22	1.26	1.23	1.19	1.19	0.05	0.83	0.59	0.66	0.35	0.91	0.25
C14:1, %	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.002	0.62	0.59	0.49	0.42	0.52	0.43
C15:0, %	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.003	0.93	0.46	0.81	0.93	0.77	0.26
Palmitic (C16:0), %	21.80	21.74	21.62	22.34	22.15	21.67	21.55	0.62	0.52	0.29	0.22	0.38	0.46	0.67
C16:1, %	2.42	2.39	2.39	2.43	2.35	2.36	2.39	0.09	1.00	0.96	0.72	0.86	0.58	0.64
Margaric (C17:0), %	0.35	0.32	0.30	0.29	0.34	0.34	0.31	0.02	0.23	0.04	0.53	0.17	0.46	0.08
C17:1, %	0.36	0.32	0.31	0.30	0.35	0.35	0.32	0.02	0.19	0.02	0.52	0.13	0.63	0.07
Stearic (C18:0), %	9.62	9.95	9.57	10.21	10.02	9.78	9.58	0.39	0.64	0.29	0.59	0.79	0.31	0.63
C18:1n-9, %	41.72	41.56	42.54	42.26	42.02	42.51	42.66	0.41	0.32	0.14	0.87	0.06	0.85	0.40
C18:2n-6, %	18.47	18.49	18.10	17.15	17.64	17.76	17.96	1.05	0.30	0.03	0.26	0.46	0.23	0.72
C18:3n-6, %	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.003	0.84	0.16	0.74	0.33	0.91	0.60
ALA (C18:3n-3), %	1.20^{bc}	1.21^{b}	1.18^{bc}	1.13^{c}	1.19^{bc}	1.25^{ab}	1.31^{a}	0.08	<0.01	0.06	0.23	<0.01	0.19	<0.01
Arachidic (C20:0), %	0.19	0.20	0.20	0.20	0.21	0.21	0.20	0.01	0.64	0.22	0.98	0.43	0.11	0.43
C20:1n-9, %	0.80	0.80	0.82	0.79	0.80	0.83	0.82	0.03	0.94	0.99	0.56	0.48	0.79	0.62
C20:2n-6, %	0.79^{a}	0.77^{ab}	0.75^{ab}	0.66^{c}	0.71^{bc}	0.73^{ab}	0.71^{bc}	0.04	<0.01	<.0001	0.11	0.02	0.22	0.61
C20:3n-6, %	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.01	0.55	0.26	0.69	0.38	0.29	0.47
C20:4n-6, %	0.29	0.27	0.27	0.25	0.27	0.27	0.25	0.02	0.52	0.06	0.96	0.06	0.87	1.00
ETE (C20:3n-3), %	0.16^{a}	0.16^{a}	0.16^{a}	0.14^{b}	0.15^{a}	0.16^{a}	0.16^{a}	0.01	0.01	<0.01	0.06	0.53	0.32	0.07
EPA (C20:5n-3), %	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.004	0.27	0.07	0.19	0.39	0.02	0.95
Behenic (C22:0), %	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.84	0.46	0.31	0.61	0.94	0.41
C22:1n-9, %	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.004	0.38	0.31	0.31	0.77	0.67	0.37
C22:2n-6, %	0.04	0.03	0.03	0.05	0.03	0.03	0.04	0.01	0.65	0.46	0.16	0.66	0.25	0.86
C23:0, %	0.04	0.04	0.03	0.04	0.03	0.04	0.04	0.004	0.36	0.54	0.49	0.85	0.79	0.67
C22:4n-6, %	0.10	0.09	0.09	0.08	0.10	0.09	0.09	0.005	0.05	<0.01	1.00	0.04	0.51	0.28
DPA (C22:5n-3), %	0.0749^{ab}	0.0700^{abc}	0.0695^{bc}	0.0632^{c}	0.0711^{ab}	0.0766^{a}	0.0749^{ab}	0.003	0.01	<0.01	0.78	0.62	0.68	<0.01
Lignoceric (C24:0), %	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.004	0.62	0.33	0.69	0.49	0.74	0.25
DHA (C22:6n-3), %	0.04	0.04	0.04	0.03	0.03	0.04	0.04	0.005	0.90	0.37	0.66	0.71	0.53	0.89

Table 3.4 (cont.)

Total SFA,[4] %	33.33	33.58	33.04	34.47	34.09	33.34	32.97	1.04	0.51	0.28	0.32	0.49	0.34	0.63
Total MUFA,[5] %	45.34	45.13	46.11	45.82	45.56	46.10	46.24	0.45	0.44	0.21	0.93	0.10	0.93	0.43
Total PUFA,[6] %	21.33	21.29	20.84	19.71	20.35	20.56	20.80	1.19	0.24	0.02	0.26	0.52	0.21	0.91
UFA:SFA ratio[7]	2.01	2.00	2.03	1.91	1.94	2.01	2.04	0.09	0.54	0.25	0.29	0.50	0.36	0.64
ω6:ω3[9]	13.14[a]	13.08[ab]	13.16[a]	13.18[a]	12.84[b]	12.22[c]	11.83[d]	0.10	<0.001	0.65	0.66	<0.0001	0.69	<0.0001
IV[10] (AOCS, 1998)	74.04	73.94	74.04	72.02	72.75	73.58	74.24	1.85	0.44	0.11	0.25	0.70	0.24	0.78
IV[11] (Meadus, 2010)	77.63	77.39	77.44	75.13	76.07	76.98	77.55	1.99	0.37	0.07	0.25	0.87	0.24	0.77

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

[4]Total SFA = (C14:0) + (C15:0) + (C16:0) + (C17:0) + (C18:0) + (C20:0) + (C22:0) + (C23:0) + (C24:0)

[5]Total MUFA = (C14:1) + (C16:1) + (C17:1) + (C18:1n-9) + (C20:1n-9) + (C22:1n-9)

[6]Total PUFA = (C18:2n-6) + (C18:3n-6) + (C18:3n-3) + (C20:2n-6) + (C20:3n-6) + (C20:4n-6) + (C20:3n-3) + (C20:5n3) + (C22:2n-6) + (C22:4n-6) + (C22:5n-3) + (C22:6n-3)

[7]UFA:SFA = (total MFUA + total PUFA) / total SFA

[9]ω6:ω3= [(C18:2n-6) + (C18:3n-6) + (C20:2n-6) + (C20:3n-6) + (C20:4n-6) + (C22:2n-6) + (C22:4n-6)] / [(C18:3n-3) + (C20:3n-3) + (C20:5n-3) + (C22:5n-3) + (C22:6n-3)]

[10]Iodine value = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723)

[11]Iodine value = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.795) + C20:2 (1.57) + C20:3 (2.38) + C20:4 (3.19) + C20:5 (4.01) + C22:4 (2.93) + C22:6 (4.64)

Table 3.5. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on bacon processing characteristics of finishing pigs

	Diet								P-values					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Conventional Cure														
Green wt, kg	4.41	4.45	4.24	4.20	4.59	4.62	4.28	0.18	0.55	0.31	0.82	0.66	0.16	0.19
Pump wt, kg	4.88	4.92	4.71	4.66	5.07	5.08	4.74	0.22	0.60	0.32	0.80	0.65	0.18	0.21
Pump uptake, %	10.67	10.42	11.13	10.80	10.37	10.10	10.83	1.49	0.58	0.53	0.91	0.90	0.19	0.28
Cooked wt, kg	4.30	4.39	4.14	4.11	4.54	4.55	4.21	0.21	0.52	0.36	0.76	0.76	0.13	0.17
Cooked yield, %	97.37	98.5	97.71	97.63	98.69	98.53	98.15	1.11	0.36	1.00	0.22	0.32	0.09	0.20
Sliced wt, kg	3.52	3.74	3.21	3.43	3.82	3.67	3.43	0.21	0.42	0.41	1.00	0.66	0.20	0.29
Dry Cure														
Green wt, kg	4.45	4.25	4.34	4.17	4.74	4.59	4.23	0.17	0.15	0.31	0.92	0.27	0.05	0.05
Cooked wt, kg	4.12	3.95	4.02	3.89	4.4	4.27	3.92	0.18	0.20	0.39	0.92	0.32	0.05	0.07
Cooked yield, %	92.26	92.95	92.60	93.04	92.81	92.84	92.59	0.83	0.86	0.28	0.75	0.57	0.33	0.73
Sliced wt, kg	3.64	3.41	3.48	3.44	3.82	3.84	3.41	0.17	0.33	0.51	0.59	0.40	0.09	0.09

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

Table 3.6. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on bacon slice characteristics of finishing pigs

	Diet								P-values					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Conventional Cure														
Average														
Total Slice Area, cm^2	74.02	73.01	67.32	69.67	75.44	74.94	69.48	3.97	0.51	0.22	0.62	0.35	0.31	0.23
Seconday Lean, cm^2	11.82	11.77	11.35	11.63	10.11	11.19	11.43	0.65	0.56	0.74	0.80	0.98	0.14	0.21
Total Lean Area, cm^2	40.99	42.56	37.52	40.04	38.28	37.97	37.75	2.03	0.50	0.39	0.81	0.27	0.54	0.22
Percent lean, %	54.76	58.34	55.63	58.00	51.70	51.04	54.58	3.22	0.25	0.52	0.80	0.91	0.18	0.02
Lean:Fat	1.39	1.53	1.35	1.84	1.20	1.11	1.27	0.28	0.48	0.30	0.49	0.70	0.49	0.07
Length, cm	22.82	22.30	22.04	21.80	23.14	23.08	21.98	1.07	0.56	0.23	0.82	0.35	0.25	0.17
Width, cm	2.95	2.91	2.78	2.85	2.86	2.86	2.86	0.13	0.97	0.39	0.62	0.59	0.69	0.88
Bacon composition														
Moisture, %	49.35	49.54	50.07	49.08	46.85	47.05	48.85	1.75	0.48	0.96	0.65	0.82	0.10	0.06
Fat, %	34.61	34.52	33.67	34.96	38.54	38.33	35.45	2.48	0.34	0.98	0.70	0.77	0.06	0.04
Dry Cure														
Average														
Total Slice Area, cm^2	73.49	70.31	68.7	69.81	79.19	72.94	70.05	5.03	0.18	0.33	0.46	0.20	0.14	0.06
Seconday Lean, cm^2	11.80	10.64	11.15	10.96	11.04	10.23	10.15	0.76	0.54	0.48	0.44	0.04	0.58	0.38
Total Lean Area, cm^2	39.79	37.57	36.49	37.11	38.86	36.05	37.66	1.77	0.77	0.25	0.43	0.25	0.48	0.75
Percent lean, %	55.10	53.48	52.96	53.77	49.85	50.10	54.25	4.15	0.75	0.71	0.66	0.85	0.09	0.37
Lean:Fat	1.42	1.29	1.18	1.57	1.10	1.10	1.30	0.31	0.82	0.77	0.30	0.73	0.30	0.37
Length, cm	23.05	22.50	23.58	22.97	23.76	23.32	23.05	0.69	0.51	0.67	0.94	0.83	0.27	0.33
Width, cm	2.63	2.76	2.57	2.73	2.82	2.88	2.59	0.12	0.51	0.85	0.89	0.92	0.06	0.44
Bacon composition														
Moisture, %	44.42	44.45	44.59	44.44	43.08	43.06	43.87	1.63	0.95	0.98	0.94	0.77	0.40	0.27
Fat, %	38.09	38.29	37.73	37.99	40.32	40.35	38.81	2.61	0.91	0.92	0.99	0.79	0.32	0.23

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

Table 3.7. Effects of high protein canola meal (CM-HP) and conventional canola meal (CM-CV) on bacon sensory characteristics of finishing pigs

	Diet								P-values					
	Control[1]	CM-HP[1]			CM-CV[1]					CM-HP		CM-CV		CM-HP vs
	0%	33%	66%	100%	33%	66%	100%	SEM	Diet	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Conventional Cure														
Saltiness	6.32	6.01	6.03	6.07	6.23	5.98	6.20	0.32	0.98	0.59	0.57	0.66	0.60	0.69
Flavor Intensity	6.46	6.49	6.51	6.92	6.69	6.31	6.60	0.35	0.93	0.37	0.59	0.98	0.94	0.71
Off Flavor	0.16	0.19	0.18	0.31	0.16	0.13	0.10	0.08	0.26	0.10	0.41	0.42	0.77	0.04
Off Odor	0.10	0.13	0.22	0.19	0.13	0.11	0.14	0.09	0.75	0.19	0.62	0.72	0.93	0.27
Dry Cure														
Saltiness	8.90	9.18	9.41	9.20	8.95	8.65	8.53	0.47	0.66	0.51	0.52	0.41	0.83	0.08
Flavor Intensity	9.17	9.10	9.43	9.06	8.88	8.92	8.67	0.36	0.74	1.00	0.64	0.30	0.95	0.15
Off Flavor	0.18	0.31	0.15	0.25	0.15	0.18	0.35	0.10	0.63	0.93	0.85	0.21	0.30	0.92
Off Odor	0.11	0.07	0.06	0.15	0.05	0.14	0.17	0.05	0.47	0.61	0.17	0.25	0.34	0.52

Means within a row for experimental treatments without a common superscript differ ($P \leq 0.05$)

[1]Percentage of canola meal as a replacement for soybean meal

[2]Quadratic effects of increasing canola meal

[3]Pooled effects of high protein canola meal versus pooled effects of conventional canola meal

Sensory characteristics were assessed on a 15 point scoring system, with 0 representing least intense and 15 representing most intense