EVALUATION OF HEMPSEED MEAL AS A PROTEIN SOURCE IN SWINE FINISHING RATIONS

A Dissertation

by

REBECCA KIRKPATRICK KEMP

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Chair of Committee,	Kerri B. Gehring
Committee Members,	H. Russell Cross
	David P. Anderson
	Joe L. Outlaw
Interim Head of Department,	Andy Herring

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ABSTRACT

Hempseed meal (HSM) was studied as an alternative protein source for grow-finish swine diets. This study utilized 44 barrows randomly assigned to a treatment diet containing HSM or control diet containing soybean meal (SBM) as the primary protein source. Diets did not affect ($P > 0.05$) feed intake, feed conversion, or average daily gain. Barrows were harvested over 5 days. No differences ($P > 0.05$) were found between diets for hot carcass weight, liver and lung scores, carcass pH, dressing percentage, or quality and yield grades. Carcasses were fabricated and additional quality attributes investigated via shelf-life, Warner Bratzler Shear (WBS) force, and proximate analysis. SBM chops had less ($P = 0.0438$) drip loss than HSM. Interaction between diet and chop type was significant ($P < 0.05$) for days 2, 6, and 7, and days 0, 4, 6, and 7 for lightest and darkest color, respectively. HSM chop discoloration was darker ($P < 0.0001$) and had higher ($P < 0.05$) percent discoloration than SBM chops for days 6 and 7. No differences ($P > 0.05$) were found for L*, a*, and b* values. Aerobic plate counts were higher ($P < 0.05$) for HSM chops on days 4 and 6. HSM chops had higher ($P < 0.05$) TBARS values on days 2, 4, 6, and 7. SBM chops were more ($P = 0.0145$) tender than treatment chops for WBS force values. SBM rib chops had higher ($P < 0.05$) protein, fat, and moisture contents. SBM bellies were firmer ($P = 0.0022$) than HSM bellies. Muscle tissue, liver, urine, and plasma were collected on the harvest floor for all HSM carcasses and subjected to biochemical analysis to detect delta 9-tetrahydrocannabinol (THC) and cannabinol (CBD) residue. CBD and 7-carboxy-CBD were detected at low levels in both urine and plasma. THC was not detected in any samples. Economic differences in feed

costs by ingredient, total feed costs, and price to producer at harvest were assessed. No differences ($P > 0.05$) were seen for estimated prices to producers for carcasses, major and minor cuts, or slaughter costs when premiums/discounts were applied based on 10th rib backfat.

DEDICATION

This dissertation is dedicated to my husband, Jon, and my family. Jon, thank you for always supporting me, listening to me, and reminding me when to take a break. To my family, thank you for encouraging me in all my educational endeavors over the past decade. My success is truly rooted in each one of you. I would not be who I am today without your love, support, and guidance. Thank you.

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NOMENCLATURE

THC	delta-9 tetrahydro cannabidiol
CBD	Cannabidiol
HSM	Hempseed meal
SBM	Soybean meal

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CHAPTER I

INTRODUCTION

Congress included *Cannabis sativa* L., also known as "hemp," as a production crop in the Agriculture Improvement Act of 2018, commonly known as the 2018 Farm Bill (H.R. 2 - 115th Congress (2017-2018), 2018). It is important to note that though hemp and marijuana are from the same species, *Cannabis sativa*, they are not considered the same plant (Johnson, 2019). Hemp is differentiated from marijuana due to different uses and cultivation practices, chemical makeup, and regulatory oversight (Johnson, 2019). For example, hemp has been removed from the Controlled Substances Act (CSA) due to its agricultural purpose. However, there are still restrictions surrounding growing, harvesting, and selling hemp and hemp products. For instance, hemp must not have more than 0.3 percent of delta 9-tetrahydrocannabinol (THC) concentration on a dry weight basis (National Conference of State Legislatures, 2020).

States and Indian tribes were given the authority for regulation of hemp production within their territory, and the U.S. Department of Agriculture (USDA) was tasked with establishing the U.S. Domestic Hemp Production Program and approving state and tribal hemp production plans (H.R. 2 - 115th Congress (2017-2018), 2018). Additionally, the Food and Drug Administration (FDA) maintains authority over hemp products from a food, dietary, human, and veterinary drugs, and cosmetics standpoint (Abernethy, 2019; H.R. 2 - 115th Congress (2017-2018), 2018). While the 2018 Farm Bill granted U.S. farmers the right to grow hemp as a cash crop, it did not approve hemp or hemp products for use in food for humans or animals (Association of American Feed

Control Officials, 2019). Thus, there is a gap in research on the use of hemp products as a feedstuff for livestock destined for human consumption.

The primary objective of this study is to evaluate the use of hempseed meal as a protein source in finisher swine diets destined for human consumption. This study will assess growth rates and meat quality of swine fed hempseed meal. Additionally, the safety of feeding hempseed meal will be evaluated through testing for THC and cannabidiol (CBD) in various tissues and blood of the animals. Lastly, this study will gauge the economic impact of FDA approval of hempseed meal as a feedstuff for swine.

CHAPTER II

LITERATURE REVIEW

Hemp Production

Hemp is primarily grown to produce cannabidiol (CBD) oil from the leaves and branch tips. Fiber from the stalks, or grain from the seed and has very low concentrations of delta 9-tetrahydrocannabinol (THC) (Johnson, 2018). Hemp is a dual-purpose crop. For example, producers can harvest the leaves and branches to produce CBD oil and harvest the seeds to produce hempseed oil. Figure 1 demonstrates the variety of products that can be produced by modern industrial hemp.

Hemp-based products are estimated to exceed 2.5 billion USD by 2022, an increase of roughly 15% since 2018 (Conway, 2019). The largest portion of this increase is driven by hemp derived CBD products and industrial applications (Conway, 2019). The increase in production of hemp-based products was originally due to what is being called the “green rush” that happened after USDA included hemp in the 2018 Farm Bill. Producers saw hemp as a fast-growing industry even with the high costs, market uncertainty, and regulatory confusion. Yet, within just a few years, producers are already adjusting their expectations to an emerging market that is still struggling to develop complete national data, has unpredictable prices, and restrictive regulations (Quinton, 2021).

In January of 2021, USDA's Agricultural Marketing Service published the final rule for establishing a domestic hemp production program (Agricultural Marketing Service, 2021a). Currently, 48 states across the U.S. have proposed or approved

legislation that established hemp production programs or allows for research focused on hemp cultivation (National Conference of State Legislatures, 2020). In 2018, 90,000 acres of industrial hemp were planted across 22 states with 3,852 approved hemp licenses (Olson, Thornsbury, & Scott, 2020). These planted acres included greenhouse spaces and field acreage, with an average of about 20 acres per planting area (Olson et al., 2020). According to Hemp Benchmarks (2021), as of October 2021, planted hemp was reported at just over 40,000 acres, down over 100,000 acres compared to the estimated planted acres in 2020 suggesting that the "green rush" is over. Multiple factors that have played into producers' decisions on planting hemp in 2021. However, the two main factors seem to be drought and lack of infrastructure. Drought conditions affected Colorado, Oregon, and California three of the leading hemp producers in the United States (Hemp Benchmark, 2021). Additionally. Quinton (2021) reported that many producers still have previous years' hemp bagged in storage facilities hoping to sell once the market stabilizes, thus making them less likely to plant hemp at the same rate in 2021 as they did from 2018 through 2020.

For the purpose of this research, the following hemp information will focus on hempseeds and their by-products. Whole, full oil hempseeds can contain 25 to 34% protein, approximately 30% carbohydrate, between 30 to 35% oil containing over 80% of the polyunsaturated fatty acids, and is rich in vitamins (Kolodziejczyk, Ozimek, & Kozlowska, 2012; Russo & Reggiani, 2015). There are two main proteins in hempseeds, albumin and edestin, which are rich in essential amino acids (Callaway, 2004). Callaway (2004) also reported that hempseed is comparable to high-quality proteins, such as egg

whites and soybeans, when comparing protein amino acid profiles. Moreover, hempseeds contain only trace amounts of CBD and THC which is most likely due to cross contamination from other parts of the plant during harvesting and processing (Food and Drug Administration, 2018).

Hempseed oil can be removed from hempseeds under extraction conditions based on specific temperature, pressure, and time parameters (Aladić, Jarni, Barbir, Vidović, Milić, & Jokić, 2015). Hempseed meal (HSM) is a by-product produced from oil extraction. Data provided by Hemp Feed Coalition (2020) found that HSM contains approximately 33% crude protein, 33% crude fiber, and 9.8% crude fat on average. For context, soybean and sunflower meals average 44% protein, 7% fiber, and .5% fat and 32% protein, 21% fiber, and 1% fat, respectively (National Sunflower Association, n.d.; Soybean Meal Info Center, 2022).

The nutritional content of HSM has the potential to create additional market opportunities for industrial hemp producers as animal feed. Unfortunately, the FDA does not allow hemp or hemp by-products to be used in food animal feeds due to the lack of scientific research proving the safety of hemp as an animal food ingredient (Association of American Feed Control Officials, 2019). For this reason, research dedicated to feeding hemp by-products is imperative to the industrial hemp industry.

Swine Production in the United States

According to United States Department of Agriculture (2019), the U.S. is the third-largest producer and consumer of pork globally, with the majority of the pork production occurring in the Midwest and eastern North Carolina. Like any commodity,

keeping costs low and efficiencies high are vital to being competitive. For pork producers, approximately 75% of production costs are from feed, facility, and labor (Bang, 2020). Unfortunately, feed costs tend to be extremely volatile throughout a given year due to weather conditions, seasonality, and supply and demand (Langemeier, 2020). Moreover, the goal of a ration fed to swine at any production stage is to increase feed efficiency, especially from the wean to finish.

Soybean meal (SBM) is the primary protein source used in swine diets due to being high in limiting amino acids - lysine, threonine, and tryptophan (Stein, Roth, Sotak, & Rojas, 2013). SBM is also easily digestible for monogastric livestock species, such as pigs, and has comparable digestible and metabolizable energy to corn (Stein et al., 2013). However, researchers have been looking for decades to identify alternative protein sources that would decrease production costs while maintaining feed efficiency. For example, Richard C. Wahlstrom (1977) found that replacing approximately 60% of the SBM in grow-finish swine diets with rotary steam-dried blood meal did not negatively affect performance of the pigs. Dried distiller grains (DDGS), a by-product of ethanol production, have also been shown to be a good source of energy and phosphorous in swine diets at any phase (Stein & Shurson, 2009). However, the inclusion of DDGS in grow-finish diets can negatively affect iodine values, which correlates to softer, less desirable fat (Cromwell et al., 2011).

Pork Quality

Improving the quality of meat, from any species, is an important aspect of

meat science research. This starts with understanding consumer perceptions of pork products, learning what consumers want from their pork, and determining how producers can exceed their expectations. Grunert, Larsen, Madsen, and Baadsgaard (1996) developed the Total Food Quality Model (TFQM) to analyze consumer perception of food and how it relates to purchasing decisions and production of food products. TFQM allows for both pre- and post-purchase assessments to be evaluated when determining the quality of a product. Consumer assessments prior to purchase include the expected quality of the product and are based on appearance, cost, marketing strategies, and healthiness of the product. Taste, tenderness, and length of preparation are experiential quality aspects of the product and occur after the purchase has already been made (Grunert, Bredahl, & Brunsø, 2004).

Production strategies, such as breed type, feeding programs, handling at slaughter, and chilling methods, all affect the quality of fresh pork (Rosenvold & Andersen, 2003). During the late 1900s, the focus on healthy eating pushed the pork industry to focus on genetic selection for lean, heavily muscled carcasses which resulted in reduced eating quality (Ellis, McKeith, & Miller, 1999; Martinez & Zering, 2004). Kauffman, Cassens, Scherer, and Meeker (1993) believed that consumer dissatisfaction with pork stemmed from a variation in quality, likely due to the lack of quality assessment and consumer acceptability of fresh pork. This conclusion led to the examination of fresh pork across the United States to define ‘ideal’ quality of fresh pork.

The ‘ideal’ fresh pork cut was defined as having a normal bright uniform color, reddish-pink, being firm and free of surface exudation, and containing slight amounts of

marbling (Kauffman et al., 1993). While these three criteria are still used to determine fresh pork quality (Nold, 2006), many researchers have looked into what causes changes in color, firmness or wetness, marbling and their importance in consumer acceptance. Bray (1966) concluded that marbling is highly correlated with juiciness and affects fresh pork and pork chop palatability greater than cured pork and pork roasts, respectively. Muscle pH is also a crucial factor of fresh pork quality. As muscle pH rises and falls outside of the isoelectric point for pork (5.1 pH), water-holding capacity and color are impacted, which can affect tenderness and juiciness (Boler et al., 2008; Lonergan, 2012).

Low muscle pH (< 5.1 pH) will cause a higher cooking loss in fresh pork due to its increase in drip loss and decrease in water holding capacity. Additionally, lower muscle pH can result in lighter colored and softer textured fresh pork (Huff-Lonergan, Baas, Malek, Dekkers, Prusa, & Rothschild, 2002). Rapid drop of muscle pH after slaughter while the carcass temperature is still high can lead to fresh pork being classified as pale, soft, and exudative (PSE) (Buege, 2006). PSE pork is considered low quality and undesirable to consumers (Marriott & Schilling, 2006). Utilization of PSE pork is minimal at best. PSE pork can only be incorporated into processed products and fresh restructure products up to 25% of the formulation with the use of marinades and injected adjuncts, like tripolyphosphate and salt (Marriott & Schilling, 2006). Muscle pH that rises higher than the isoelectric point, typically rising about 6.0 pH, can cause dark, firm, and dry (DFD) pork. However, Huff-Lonergan et al. (2002) reported that darker fresh pork tended to be firmer, have a higher water-holding capacity, and be more tender. PSE and DFD are caused before, during and after harvest due to chemical and

physical changes in the muscle (Buege, 2006). Typically, genetics and stress from animal handling are the culprit for causing PSE and DFD. Yet, it is important to understand how incorporating a new protein source, such as HSM, into a swine diet may affect the quality of the meat.

CHAPTER III

EVALUATING THE EFFECT OF HEMPSEED MEAL IN SWINE FINISHING RATIONS ON PIG PERFORMANCE AND MEAT QUALITY

Materials and Methods

Feeding Study

Barrows (n = 44 total) were raised at the Texas A&M Swine Center (College Station, TX) and distributed across four treatment pens. It is important to note, that due to illnesses three barrows (SBM = 1 and HSM = 2) were removed from the study, therefore n = 41 barrows completed the study. The control group (n = 11 per pen, n = 22 total) was fed a SBM-based diet, and the treatment group (n = 10 and 11 per pen, n = 21 total) was fed a HSM-based diet. All barrows used in this study were born within a two-week window and from the same commercial genetics (Yorkshire × Landrace sows artificially inseminated using pooled semen from five purebred Duroc sires).

Barrows were housed in an open-air barn with partially slatted concrete floors. Pens had a single-sided, four-hole, 215.4 kg (475 lb) capacity dry-box feeder (Hog Slat Wean to Finish Platinum Series 300, Newton Grove, NC) attached to the side and a two-nipple waterer. A three-phase, 94-day feeding program was utilized for each diet type. Pigs were fed a grower diet from days 0 to 29, early finisher diet from days 30 to 59, and a late finisher diet from 60 to 94 days. All diets were formulated to be isocaloric. Samples of each ration (n = 6; one per ration per phase) were collected and sent to Rock River labs (Watertown, WI) to quantify: dry matter, moisture, crude protein, acid detergent fiber, neutral detergent fiber, calcium, phosphorus, magnesium, potassium,

sulfur, ash, lignin, starch, and TDN, and NEm, NEg, NEl. A certificate of analysis for THC (d9-THC, d9-THCA, d8-THC, and THCV) and eight commonly found CBDs (CBC, CBD, CBG, CBN, CBDA, CBGA, CBDV, and CBDVA) and amino acid content were also obtained for the HSM rations.

Feed intake per pen was recorded daily. Barrows were individually weighed on days 0, 30, 59, and 91. Feed conversion and average daily gain were calculated using recorded feed intake, feed removed at end of phase, and weights for each phase.

1. $Average\ daily\ gain = \frac{(Weight\ at\ end\ of\ phase - Weight\ at\ end\ of\ previous\ phase)}{Number\ of\ days\ within\ phase}$
2. $Feed\ intake\ per\ pen\ per\ day = \frac{\left[\frac{(sum\ of\ feed\ intake - amount\ of\ feed\ removed)}{number\ of\ barrows\ in\ pen}\right]}{number\ of\ days\ within\ phase}$
3. $Feed\ conversion = \frac{feed\ intake\ per\ pen\ per\ day\ for\ phase}{average\ daily\ gain\ for\ phase}$

Harvest, Carcass Fabrication, and Carcass Characteristics

Barrows (*n* = 20 HSM barrows; *n* = 21 SBM barrows) were transported over a five-day period to Rosenthal Meat Science and Technology Center (RMSTC; College Station, Texas) for harvest. Barrows were harvested in accordance with Institutional Animal Care and Use Committee (IACUC) at Texas A&M University (AUP #2021-0005). Treatment barrows were rendered inedible per the Food and Drug Administration guidelines. Therefore, any product procured from treatment barrows that was not used for analysis in this study were rendered inedible and did not enter commerce.

Live weight was collected prior to stunning. On the harvest floor, liver scores, lung scores, and muscle pH using a digital pH meter (model IQ 150; Spectrum

Technologies, Aurora, IL) and a round-tipped probe (PH57-SS) of hot carcasses were recorded for each barrow. Liver scoring included liver abscesses (0 = none, 1 = abscess <0.77 in and/or up to 4 abscesses <1.57 in diameter, 2 = abscess >1.57 in or >5 small abscesses) and milk spots (0 = absence, 1 = presence) (E. J. McCoy, 2017). The five point lung scoring system (0 = no lesions, 1 = <25% of the lobe surface, 2 = 25 - 49% of lobe surface across both lobes, 3 = 50-74% of lobe surface across both lobes, 4 = ≥75% of both lobe surfaces) followed Fraile, Alegre, López-Jiménez, Nofrarías, and Segalés (2010) use of both the Slaughterhouse Pleurisy Evaluation System (SPES) and enzootic pneumonia-like lesion scoring system. Carcasses were weighed and chilled at 0 °C for approximately 24 h. Dressing percentage [(live weight/carcass weight) × 100] was calculated using live and carcass weights recorded at harvest.

Surface and internal temperatures were collected from each carcass approximately 24 h post-harvest. The left side of each chilled carcass (n = 41) was fabricated to produce the following cuts according to Institutional Meat Purchase Specifications (IMPS) pork loin, bone-in (IMPS #410), picnic shoulder (IMPS #405), boston butt (IMPS #406), spareribs (IMPS #416), bone-in ham (IMPS #401A), and pork belly (IMPS #408) (North American Meat Institute, 2015). Weights for each cut were recorded and used to calculate the percent of the four lean cuts [((loin + boston butt + picnic shoulder + ham)/total side weight) × 100]. Loss was determined by weighing lean trimmings, fat, and waste. Carcass grade data were collected from the right side of each carcass (n = 41) 48 h post-chill. Right sides were ribbed between the 10th and 11th rib and loin eye area, last rib fat thickness, 10th rib fat depth, and muscle scores were

collected. USDA grade for each carcass was calculated [(4 * last rib backfat) – (1 * muscle score)].

A 2.54-cm thick sample (approximately 100 g) was procured from the 10th rib of each fabricated loin (*n* = 41) for drip loss. pH measures were obtained at three separate locations on the cut lean surface and exterior fat surface upon sample excision. Evaluation of drip loss followed methods described by Honikel (1998). Samples were placed in a net, suspended in a plastic container, and held at 0 °C for 24 h. Initial and post 24 h weights were recorded for each sample.

The remaining portions of each loin were sliced into 2.54-cm thick, ribeye chops, boneless (*n* = 5 per loin or *n* = 205 total, IMPS #1413-2), and New York chops, boneless (*n* = 5 per loin or *n* = 205 total, IMPS #1413-3) (American Meat Science Association, 2015). Each chop was randomly assigned to either shelf life (*n* = 4 chops per loin or *n* = 156 chops), Warner Bratzler Shear force (WBS) (*n* = 2 chop per loin or *n* = 78 chops), or proximate analyses (*n* = 2 chops per loin or *n* = 78 chops), vacuum-packaged, and stored frozen (-40 °C) until subsequent analysis.

Loin Characteristics

Retail shelf-life was assessed using *n* = 20 of each chop type per treatment group (*n* = 80 total chops or *n* = 40 ribeye chops, boneless and *n* = 40 New York chops, boneless). Chops were thawed at approximately 4 °C for 48 h. Once thawed, chops were removed from vacuum packaging, placed on a foam tray with an absorbent pad, overwrapped in oxygen-permeable polyvinylchloride film, and placed in a retail display case (4 °C, 16w LED bright white lighting, 1650 – 2200 lux). Subjective color,

instrumental color, and pH was measured on 8 chops per treatment group on days 0, 2, 4, 6, and 7 (n = 16 chops per day). Instrumental color (L^*, a^*, b^*) was measured in triplicate using a Hunter MiniScan EZ (HunterLab) colorimeter (31.8 mm port, 25 mm viewed area, 45° illumination). Subjective color was measured by an 8-person trained panel using a 6-point scale (1 = pale pinkish-gray to white; 6 = dark purplish-red). Once color and pH were recorded, two chops per type per treatment (n = 8 chops per day) were randomly selected for lipid oxidation analysis. Chops selected for lipid oxidation analysis were homogenized in a model 7011HS Waring Commercial blender (Waring Commercial, Stamford, CT) for approximately 3 min. Powdered samples were stored at -80 °C until further analysis.

Microbiological analysis was conducted on each assessment day (days 0, 2, 4, 6, and 7) from an additional eight chops per treatment group (n = 16 chops per day, n = 80 total chops). Each chop surface was swabbed ten times within a 5 x 5 cm section with a sterile hydrated sponge (3M™, St. Paul, MN, USA). Sponges will be placed in a sterile sample bag with 25 ml of Butterfield's buffer (3M™, St. Paul, MN, USA), hand massaged for 60 sec, and transported to Texas A&M Food Microbiology Laboratory (College Station, Texas) for microbiological analysis. Enumeration was performed by decimal dilutions in 0.1% peptone diluent and plating on 3M™ Petrifilm™ Aerobic Count Plates (St. Paul, MN, USA). Films were incubated at 35 ±1 °C for 48 ± 3 hours before counting.

Chops (n = 82 total chops or 41 ribeye chops, boneless and 41 New York chops, boneless) destined for WBS were thawed at approximately 4 °C for 48 h before cooking.

Chops were cooked on grated electric char-broilers (Star-Max® Radiant Electric Charbroiler, Smithville, TN). Grills were preheated to 177 °C, chops were turned upon reaching an internal temperature of 35 °C and removed at a final internal temperature of 70 °C. Raw weight, cooked weight, and cook times were recorded. Chops then were placed on trays without any overlap, covered with plastic wrap, and placed in a cooler for approximately 12 to 18 h at 4 °C. After chilling, chops were allowed to equilibrate to room temperature. At least three 1.3-cm cores were removed from each muscle, parallel to the muscle fibers, and sheared once, perpendicular to the muscle fibers. The peak force (N) was recorded, and a mean for each chop calculated and used for statistical analysis.

Chops assigned to proximate analyses were thawed in a single layer under refrigerated conditions (approximately 4 °C) for 48 h before homogenization in a model 7011HS Waring Commercial blender. After homogenization, (approximately 50 g) were sent to NP Analytical Laboratories (St. Louis, MO) for protein, moisture, and ash analysis. The remaining powdered sample was stored at -20 °C until total fat analysis. Samples were analyzed in triplicate for total fat content analysis following methods developed by Folch, Lees, and Stanely (1956). Powdered samples were weighed out (0.5 g), approximately 15 mL of Chloroform:Methanol (2:1) (Ch. Meth.) was added and shaken for 10 min. Homogenate was filtered through a glass filter funnel into a clean tube. Both the tube and filter were rinsed with 20 to 30 mL of Ch. Meth. then 8 mL of 0.74% KCl was added. Tubes were capped and vortexed for 30 sec. Homogenate was transferred to a 50 mL graduated cylinder. Tube was rinsed with additional Ch. Meth,

cylinder was sealed with parafilm, and left to sit for at least 12 h. After samples had sat for 12 h, the KCl was suctioned off the top of the homogenate and 10 mL of the homogenate was transferred into cool, dry scintillation vials with an additional 5 mL of Ch. Meth. Scintillation vials were placed in an N-Evap to evaporate the sample using nitrogen. Once the entire sample had evaporated, the scintillation vials were placed in an oven at 100 °C for 10 min. Data recorded includes: sample weight, cool, dry scintillation vial weight, total volume of Ch. Meth. in graduate cylinder post-12 h rest, and final scintillation vial with lipid weight. Actual lipid weight (g) was calculated by subtracting the vial weight from the vial plus lipid weight. Percent lipid was calculated with the equation below.

$$Percent\ Lipid = \frac{(Total\ volume\ of\ Ch.Meth\ (mL) \div 10) \times (Lipid\ (g))}{Sample\ Weight\ (g)}$$

Pork chops assigned to lipid oxidation, previously homogenized post-shelf life analyses, were analyzed in duplicate following the Oxidative Rancidity Rapid, Wet Method protocol (American Meat Science Association, 2012). Samples were weighed out (0.5 g) then 2.5 ml of TBA stock solution (0.375% thiobarbituric acid, 15% trichloroacetic acid, and 0.25 N HCL) was added to each sample and mixed well. Samples were heated in boiling water for 10 min then cooled in tap water for 5 min. Cooled samples were then centrifuged at 5000 × g for 10 min at 4 °C. Lastly, the supernatant was pipetted into a 96-well plate (VWR, Radnot, PA). An Epoch monochromator (Biotek Instruments Inc., Winooski, VT) and Gen5 Microplate Data Collection and Analysis software (Biotek Instruments Inc., Winooski, VT) was used to measure the absorbance at 532 nm. A blank, consisting of all the reagents except the

sample, was used to verify the samples. Mean TBARS value (nm) were converted to ppm by multiplying the absorbance value at 532 nm by 2.77.

Belly Characteristics

Bellies were skinned, and green weight, length, and width recorded. A standard bar test was utilized to determine belly firmness (Larsen, Wiegand, Parrish, Swan, & Sparks, 2009; Thiel-Cooper, Parrish, Sparks, Wiegand, & Ewan, 2001) by suspending the mid-point of each belly across a stainless-steel rod longitudinally. The distances between each end of the belly were recorded, lean side up and lean side down. Belly thickness was measured at eight locations and averaged. The first four measurements taken along the dorsal edge, and the last four along the ventral edge, both starting at the anterior end. Bellies were labeled, vacuum-packaged and stored frozen (-40 °C) until subsequent analysis.

Bellies were thawed at approximately 4 °C for 96 h. Each belly was injected with a 12% brine, smoked, and thermally processed to an internal temperature of 55 °C. After thermal processing, bacon slabs were chilled for 24 h at 4 °C and weighed again for a chilled final weight. Slabs were sliced anterior to posterior at 2.54-mm thick and laid out in a single layer in the order they were sliced. Slices were graded according to Person et al. (2005). Grade 1 slices must be at least 1.9-cm wide, and the *M. cutaneous trunci* must be greater than 50% of the length of the slice. Slices that did not meet both requirements for grade 1 were graded as a 2. Ends and pieces are considered grade 3. Each grade of slices per slab of bacon were weighed separately and recorded to calculate percent of grade 1, 2, and 3 slices from each belly. After grading, six slices, two from each end and

two from the middle were selected from each slab (n = 6 slices per slab of bacon). Each set of six slices (n = 41 sets of six slices of bacon) were assigned to either lipid oxidation (n = 20) or color and cook yields (n = 21). Once assigned to an assay, each set of bacon was individually identified, vacuum-packaged, and stored fresh at approximately 2 °C.

Bacon sets (n = 10 treatment, n = 11 control, n = 21 total) were utilized to measure color and cook yields. CIE color space values (L^*, a^*, and b^*) color was measured at 3 locations on every slice using a Hunter MiniScan EZ (Model 4500; HunterLab, Reston, VA) colorimeter (12.5 mm port, 25 mm viewed area, 45° illumination). Color space values were averaged across each set to provide an average L^*, a^*, and b^* value for each set of 6 bacon slices. Slices were weighed before cooking.

The frying method described by Larsen et al. (2009) and Olson et al. (1985) was followed by cooking slices beyond the "limp" stage on an pre-heated electric skillet (Hamilton Beach™, Southern Pines, NC) set to 176 °C. Slices were cooked for 2 min and 30 s, turned, cooked for an additional 1 min and 30 s, turned a second time and cooked for a final 30 s. Slices were removed from the pan, blotted dry with a paper towel, and weighed. Cook yield was calculated as an average of the six slices in each set.

Bacon assigned to lipid oxidation was held without exposure to light at approximately 2 °C for 0, 30, 60, 90, or 120 days. Two bacon sets per treatment group (n = 4 sets of bacon per day) were analyzed on days 0, 30, 60, 90, and 120 following methods published by Zipser and Watts (1962). Each analysis day, bacon was removed from refrigerated conditions, chopped, and stored at -80 °C. Once all bacon had been chopped and frozen, each set was homogenized in a model 7011HS Waring Commercial

blender (Stamford, CT) for approximately 3 min. Powdered samples were weighed (30 g) in duplicate and mixed with 43.5 ml of distilled water, 15 ml of a 0.5% PG+EDTA solution, and sulfanilamide reagent which differed in amount based on residual nitrite levels (ppm) listed in Table 1 until a slurry formed. The slurry (30 g) was transferred into a Kjeldahl flask and 2 ml of an HCL solution (1:2) was added. The Kjeldahl flask was heated, and 50 ml of the distillate was collected. In a screw cap test tube, 5 ml of the distillate and 5 ml of TBA reagent were mixed. The test tube was placed in a boiling water bath for 35 min then cooled in tap water for 10 min. Cooled samples were pipetted into a 96-well plate and read at 530 nm absorbance level using an Epoch monochromator (Winooski, VT) and Gen5 Microplate Data Collection and Analysis software (Winooski, VT). A blank, containing 5 ml of distilled water and 5 ml of TBA reagent was utilized. Mean values (nm) were converted to mg malonaldehyde/kg by multiplying the absorbance value by 7.8.

Statistical Analysis

Data were analyzed using JMP Software (JMP®, Version 15. SAS Institute Inc., Cary, NC, 1989-2007.) and Microsoft Excel. As appropriate, analysis of variance was conducted using the Fit Y by X function, and Student's t-test used to conduct least squares means comparisons with an α less than 0.05. The distribution function was used to determine frequency distributions, means, standard deviations, and minimum and maximum values.

Results and Discussion

Feeding Study

Table 2 shows the nutritional differences between each diet within the three phases the feeding program. These phases are grower (approx. 16 weeks of age), early finisher (approx. 20 weeks of age), and finisher (approx. 26 weeks of age) until market ready at roughly 6 months old and 280 pounds. Nutritional requirements for swine diets are determined based on the physiological state, performance potential, and environmental conditions. Protein is a key component in swine diets. Swine breakdown protein into amino acids through digestion, absorption, and postabsorptive metabolism to build muscle (National Research Council, 2012). Cereal grains, such as corn, typically provide 30-60% of the essential amino acids required in swine diets while the remaining essential amino acids are provided by other protein sources like soybean meal (National Research Council, 2012). This is important to understand for this study due the substitution of hempseed meal for soybean meal in these diets. Higher crude protein, total digestible nutrients (TDN), and lower fat content can be seen for the SBM diets in phases 1 and 2 compared to HSM diets. In contrast, Hessle, Eriksson, Nadeau, Turner, and Johansson (2008) reported protein feed consisting of 50% soybean meal and 50% rolled barley had less dry matter and crude protein than 100% cold-pressed hempseed cake. Presto, Lyberg, and Lindberg (2011) found that HSM did not affect CP digestibility for growing pigs. However, acid-detergent fiber (ADF) is 3-4% higher in the HSM rations which was a concern when developing the rations due to ADF being harder to digest for monogastric species like swine. Likewise, Kass, Van Soest, Pond,

Lewis, and McDowell (1980) found that swine slaughtered at 89 kg had a higher rate of passage of digesta resulting in lower digestibility of fiber.

No differences ($p > 0.05$) were found between diets across any of the three feeding phases for feed intake, feed conversion, or live weights (Tables 3, 4, and 5). Barrows fed the control diet had significantly higher ($P = 0.0426$) average daily gain (ADG) than hemp-fed barrows during the grower phase (d 0 – 30). However, no differences ($p > 0.05$) were seen for ADG between diets during early finisher and finisher diets (Table 6). This is similar to findings by Gibb, Shah, Mir, and McAllister (2005) who reported that adding full-fat hempseeds to steer diets did not affect dry matter intake, ADG or overall gain. Live weight gain and feed efficiency were also not affected when steers were fed cold-pressed hempseed cake (Hessle et al., 2008).

Harvest, Carcass Fabrication, and Carcass Characteristics

No differences ($p > 0.05$) were found for HCW between HSM and SBM barrows (Table 7). Similarly, Larsen et al. (2009) found no difference between HCW in swine when crude fat varied between 4.24 and 7.10 percent of the total diet fed. HCWs for both HSM and SBM-fed barrows in this study averaged 87.26 and 92.25 kg, respectively, which is lower than commercial raised barrows and gilts (96.61 kg) (United States Department of Agriculture, n.d.). This difference is likely due to environmental conditions between this study and commercially raised barrows. Additionally, while not statistically different ($p > 0.05$), three SBM and two HSM livers did have milk spots and one HSM liver had an abscess. No differences ($p > 0.05$) were found in lung scores between SBM and HSM.

Muscle pH affects pork quality in a variety of ways. Lower pH causes a denaturation of the myoglobin the muscle which leads to a lighter color, myosin denaturation causing the muscle to be soft, and a decrease in water holding capacity due to no net charge at pH 5.1 (Lonergan, 2012). Water holding capacity is an important factor in pork quality because it is directly correlated to cooking loss (Warner, 2017). As water holding capacity decreases, pork quality also decreases.

The pork industry has created three classifications for fresh pork based on pH including pale, soft, and exudative (PSE), red, firm, and dry (RFD), and dark, firm, and dry (DFD). Initial pH, collected within an hour of harvest, that is below 5.8 categorizes the carcass as PSE (Towers, 2016). So, while there were no differences (P = 0.3332) found between SBM and HSM carcass pH, it is important to note that 3 of the 20 HSM carcasses and 7 of the 21 SBM carcasses were categorized as PSE due to their initial pH levels (data not reported). Additionally, SBM carcasses had less (P = 0.0438) drip loss than HSM carcasses at the 24 h mark.

Grade data is reported in Table 8. Like the previous data, no differences (P> 0.05) were found between SBM and HSM dressing percentages or USDA grades. This is in line with multiple studies that fed varying amounts of dried distillers grain with solubles (DDGS) and found no differences in dressing percent (Wang, Wang, Shi, & Shan, 2012; Whitney, Shurson, Johnston, Wulf, & Shanks, 2006; Widmer, McGinnis, Wulf, & Stein, 2008). Gibb et al. (2005) and Hessle et al. (2008) also reported that feeding full-fat hempseeds or cold pressed hempseed cake, respectively, to steers had no effect on carcass traits. However, SBM carcasses reported higher (P = 0.0094 and P =

0.0055) grades for loin eye color and marbling than HSM carcasses, respectively (Table 8). SBM carcasses also had higher ($P = 0.0367$) percent four lean cut yields than HSM carcasses (Table 9).

Loin Characteristics

Shelf life

Primary differences between HSM and SBM fresh pork can be found in the shelf life portion of this study. Interaction between ration and chop was significant ($P < 0.05$) for days 2, 6, and 7 for both lightest and darkest lean color (Table 10). Huff-Lonergan et al. (2002) found that darker lean was highly correlated with firmer, less drip loss, and more tender fresh pork. However, as previously reported SBM chops had less drip loss whereas SBM rib chops were only darker ($P < 0.05$) on day 0 than HSM rib and New York chop and SBM New York chops were not darker ($P > 0.05$) than either of the HSM chops. Furthermore, darker ($P < 0.0001$) discoloration and higher ($P = 0.0008$ and $P < 0.0001$) percent discoloration for HSM were also seen on days 6 and 7, respectively (Table 11). Pasquali et al. (2020) treated minced beef with 50 mL of CBD extract and stored the meat at 4 °C for 8 days. Consequently, after 8 days the CBD-treated beef appeared lighter in color compared to the control beef (Pasquali et al., 2020). However, no differences ($P > 0.05$) were seen between rations within days 0, 2, 4, 6, or 7 for L*, a*, b* values or pH of lean and fat in this study. Similarly, Wang et al. (2012) found that dietary DDGS levels did not affect objective meat color values or muscle pH over time. Sheard, Enser, Wood, Nute, Gill, and Richardson (2000) reported that a diet rich in

polyunsaturated fatty acids did not impact color stability under simulated retail display conditions. The addition of oxidized corn oil into grower diets also had no effect on instrument color values (Monahan, Asghar, Gray, Buckley, & Morrissey, 1994).

APC enumeration was higher ($P < 0.05$) on HSM chop swabs on days 4 and 6 (Table 12). By day 7, APC enumeration on SBM chop swabs had the largest increase (approximately 1.4 log CFU/mL) so that no difference ($P = 0.5040$) was seen between diets. In contrast, Pasquali et al. (2020) reported that aerobic colony counts were lower for beef treated with CBD extract on day 4 when compared to non-treated beef. However, no differences were seen in aerobic counts by day 7 either (Pasquali et al., 2020).

TBARS data for fresh pork are reported in Table 13. HSM chops, regardless of chop type, reported higher ($P < 0.05$) on days 2, 4, 6 and 7 than SBM chops. In contrast, previous studies found that finisher swine diets containing higher amounts of unsaturated fatty acids did not affect lipid oxidation for fresh pork from day 0 to 7 (Leick et al., 2010; Rhee, Ziprin, Ordonez, & Bohac, 1988; Sheard et al., 2000; Wang et al., 2012). Similarly, Monahan et al. (1994) reported that feeding fresh or oxidized corn oil did not influence lipid oxidation in fresh pork. Additionally, TBARS values have been proven to be highly correlated with rancidity during sensory evaluation (Greene & Cumuze, 1981; Tarladgis, Watts, & Younathan, 1960; Turner, Paynter, Montie, Bessert, Struck, & Olson, 1953). Turner et al. (1953) reported that the threshold for rancidity in fresh pork was between TBARS value of 0.5 and 1.2. All chops in this study had a TBARS value of less than 1.2 (Table 14). Yet, no HSM chop had a TBARS value of less than 0.5.

Warner Bratzler Shear

No differences ($P > 0.05$) were seen between diets for cook time or cook loss. However, SBM carcasses were more tender ($P = 0.0145$) than HSM carcasses (Table 15). This contrasts with Wang et al. (2012) who reported no differences in shear force regardless of unsaturated fatty acid content provided by the addition of DDGS in finisher swine diets. Huff-Lonergan et al. (2002) observed that shear force and drip loss are highly correlated. This study also found this to be true as SBM carcasses had lower drip loss and lower shear force measurements when compared to HSM.

Proximate Analysis

Proximate analysis data are reported in Table 16. No differences ($P > 0.05$) were found between diets for percent ash, regardless of chop type. However, rib chops from SBM loins had higher ($P < 0.05$) percent protein, moisture, and lipid than HSM rib chops. SBM New York chops also had higher ($P = 0.0163$) percent moisture than HSM New York chops. Leick et al. (2010) stated that the addition of DDGS, which contain higher concentration of unsaturated fatty acids, in grow finish swine diets did not affect the percent moisture and lipid from chops. Similarly, Larsen et al. (2009) observed no differences for percent moisture, protein, or lipids in bacon when CLA was added to swine diets.

Belly Characteristics

Bellies can arguably be considered the most important cut for pork producers. Bacon is no longer considered just a breakfast item but has become a popular ingredient for many dishes that can be served throughout the day, making it one of the fastest-

growing food ingredients (Mandigo, 2002). Yet, bacon quality is still an issue that the pork industry struggles with today primarily due to lean, soft bellies.

Thick, firm bellies are more desirable due to their increased yields, increase slicing efficiency, and potential for longer shelf life (Correa, Gariépy, Marcoux, & Faucitano, 2008; Johnston & Li, 2011). SBM bellies were firmer ($P = 0.0022$) than HSM bellies (data not reported). It is important to note that four SBM bellies were not included in the firmness portion of this study due to data being collected improperly. Feed type has been seen as the primary cause for soft, oily pork for decades (Ellis, 1926). Ellis (1926) found that rations consisting solely of peanuts or soybeans produced undesirable carcasses due to the soft, oily fat. More recently, DDGS have been extensively researched and proven to decrease belly firmness (Johnston & Li, 2011; Whitney et al., 2006; Widmer et al., 2008). Both feed type and leanness causing soft, oily fat has been attributed to an increase in unsaturated fat content in the adipose tissue (Correa et al., 2008; Ellis, 1926; Whitney et al., 2006; Wood et al., 2004).

No differences ($P = 0.8540$) were found between SBM and HSM belly thickness. Table 17 shows the belly distribution across three thickness categories defined by Person et al. (2005). Person et al. (2005) found that thinner bellies had higher cooking shrink. However, no differences ($P > 0.05$) were observed between diets for green weight, cook loss, or total loss for bellies. Feeding various fat sources also had no effect on processing yields (green weight, pump weight, hot weight and chilled weight) (Larsen et al., 2009).

Additionally, no differences ($P > 0.05$) between diets were seen in bacon grades 1 and 2. However, more ($P < 0.0001$) HSM bacon slices were graded 3 than SBM bacon

slices (data not reported in table). This contrasts with Person et al. (2005) who reported thin bellies as having the highest percent of grade 2 and 3 slices. No differences ($p > 0.05$) were found in objective color scores (L*, a*, or b*) or bacon cook yields between rations. This is in line with Larsen et al. (2009) who also found no differences between cook yields from pigs fed various fat sources regardless of cooking method used.

Bacon assigned to lipid oxidation was analyzed at d 0, 30, 60, 90, and 120. No differences ($p > 0.05$) were seen between diets across days (Tables 18). Sheard et al. (2000) and Leick et al. (2010) also reported no differences in lipid oxidation regardless of unsaturated fat content in the diet. However, Larsen et al. (2009) observed that the addition of conjugated linoleic acid (CLA) in grow finish swine diets decreased bacon lipid oxidation at day 60, albeit the difference would most likely be too small for consumers to detect. As stated previously, Turner et al. (1953) reported that a TBARS value of approximately 0.5 – 1.2 is the threshold for consumers being able to detect off-flavors due to rancidity in both fresh and cured pork. TBARS values for bacon in this study ranged from 1.04 to 1.5 (data not reported). Moreover, 7 of the 10 HSM-bacon sets produced a TBARS value higher than 1.2.

CHAPTER IV

ASSESSMENT OF DELTA 9-TETRAHYDROCANNABINOL AND EIGHT COMMON CANNABINOIDS IN PORCINE TISSUE

Materials and Methods

At harvest, approximately 10 ml of blood was collected in duplicate from each barrow during exsanguination. Blood was collected in 10 ml BD Vacutainer® plastic EDTA vials (BD, Franklin Lakes, NJ). Vials were turned over three times, placed upright in a soft sided cooler with ice packs, and transported to Texas A&M Food Microbiology Laboratory (College Station, Texas). Within one hour of collection, blood was centrifuged (1400 ×g for 10 min at 4 °C) and plasma removed and pipetted into polypropylene tubes further analysis.

Urine was collected in duplicate on the harvest floor. Bladders were removed during bunging, punctured with a sterile knife, and urine was poured into plastic cups. Urine was then split evenly into two 10 ml centrifuge tubes (VWR International, LLC, Radnor, PA). Carcasses, kidneys, and livers were chilled (0 °C) for approximately 24 h before the start of sample collection. Samples (approximately 20 g) from chilled kidneys, livers, and jowls were collected for biochemical analysis. All samples were stored at -20 °C until being transported in chilled containers to Texas Veterinary Medical Diagnostic Laboratories (TVMDL) for biochemical analysis of THC and CBDs.

Results and Discussion

THC was not detected in any urine, plasma, or tissue samples analyzed. Cannabidiol (CBD) and 7-caboxy-CBD (7-COOH-CBD), a urinary metabolite of CBD,

were detected during the biochemical analysis of urine and plasma collected from the hemp-fed barrows at harvest (Table 19). A previous study by Pérez-Acevedo et al. (2020) found that 7-carboxy-CBD concentration is highest (118.03 ±64.94 ng/mL) in serum and the second most prevalent (65.9 ± 46.2 μg) in urine excretion after medical cannabis ingestion. Additionally, 7-carboxy-CBD was not fully eliminated from the serum during the 24 h collection period (Pérez-Acevedo et al., 2020). 7-carboxy-CBD is the most prominent metabolite found in plasma after administering a single dose of CBD (Taylor, Gidal, Graham, Tayo, & Morrison, 2018; Ujváry & Hanuš, 2016). Furthermore, it is important to note that Taylor et al. (2018) found no significant effect on maximum concentration of CBD or its metabolites in plasma when the test subjects fasted or where fed prior to dosage.

CHAPTER V

ECONOMIC IMPACT OF HEMPSEED MEAL AS A FEED COMPONENT

Materials and Methods

To understand the applicability of introducing HSM as an alternative feedstuff, creating a cost-benefit scenario was crucial. The cost of each treatment diet (control – SBM diet, treatment – HSM diet) was broken down by feedstuff. Pricing data for corn, soybean meal, and soybean oil was procured from Feed Grain Monthly Outlook Tables and Oil Crop Outlook Tables, respectively (Economic Research Service, 2022a, 2022b). Hempseed meal pricing was provided by a producer in North Dakota based on hempseed cake. The final ration ingredients, lysine, salt, limestone, monocalcium phosphate, amino acid balancer mix, and vitamin mix, costs were all based on the price charged when the rations were mixed. All prices were converted to dollars per lb. Total diet cost per ton, diet cost per pound, and total cost of feeding each diet for this study were calculated using the following equations.

1. $Diet\ cost\ per\ ton\ = cost\ of\ feedstuff\ per\ lb \times$
   $Amount\ of\ feedstuff\ per\ ton$
2. $Diet\ cost\ per\ lb = diet\ cost\ per\ ton\ \div 2000$
3. $Total\ cost\ of\ feeding\ each\ diet =$
   $total\ amount\ of\ feed\ consumed\ per\ diet\ \times cost\ of\ diet\ per\ lb$

Additionally, this study's data collected within performance, carcass composition, and meat quality was used to understand better the economic advantages of introducing

hempseed as a feedstuff in swine diets. Slaughter cost was determined using USDA AMS published slaughter data. Prices were assigned to carcasses based on 10^{th} rib back fat based on three categories defined in Table 22. Cost of slaughter was calculated by multiplying carcass weight by price assigned to carcass divided by 100. Primal cutout values over the 5-day slaughter period published by Agricultural Marketing Service (2021c) were utilized to determine value of carcass, loin, boston butt, picnic shoulder, spareribs, ham, and belly by multiplying cost/cwt (USD) by the weight (kg) for each cut divided by 100.

Statistical Analysis

Data in this section was analyzed using JMP Software (JMP®, Version 15. SAS Institute Inc., Cary, NC, 1989-2007.) and Microsoft Excel. Test utilized include Fit Y by X for analysis of variance and Student's t-test for least squares means comparisons with an α less than 0.05. The distribution function was used to determine frequency distributions, means, standard deviations, and minimum and maximum values.

Results and Discussion

Table 20 shows the cost of each diet by feedstuff, and Table 21 illustrates the total feed cost to producers for each diet based on consumption. Even though HSM diets were consistently more expensive per ton, less HSM was consumed during each phase of the trial leading to a lower total cost to feed HSM across all three phases. Atsbeha et al. (2020) reported that feeding rapeseed meal (RSM) was cheaper than feeding SBM to grow finish barrows. However, RSM negatively affected growth rates which led to lower profit efficiency (82.5%) for RSM compared to feeding SBM (85.3%) (Atsbeha et al.,

2020). In contrast, Karpiesiuk, Kozera, Bugnacka, Wozniakowska, and Jarocka (2018) that replacing 25% of the SBM with guar meal in finishing swine diets incurs the lowest feed cost per kg body weight. However, replacing 75% of the SBM meal with guar meal the most expensive per 1 kg of BW, even though it was the cheapest feed (Karpiesiuk et al., 2018).

Since the early 2000s, the majority of hogs raised for slaughter are done so on a contractual agreement (Plain & Grimes, 2019). Contractual agreement between producers and packer typically utilizes the base price publicly reported by USDA. Then packers can add carcass related premiums or discounts accordingly. Pork packers use marketing grids to value the carcass by adding premiums and discounts to the price of the carcass. These premiums and discounts typically place emphasis on HCW (Harris, Mellencamp, Johnston, Cox, & Shurson, 2017).

Packer premiums and discounts are proprietary; thus, this study did not have direct access to a marketing grid utilized in the commercial pork industry. Therefore, slaughter cost data published by Agricultural Marketing Service (2021b) was utilized to develop a premium and discount pricing system based on 10^{th} rib back fat. No difference ($p > 0.05$) between HSM and SBM carcasses for slaughter costs (data not reported) based on the pricing scheme developed for this study (Table 22). Distribution of carcasses across the pricing scheme are shown in Table 23. To further explore if profits may differ for producers than feed hempseed meal, cutout values were calculated using cutout prices published by Agricultural Marketing Service (2021c). No differences ($p > 0.05$) between SBM and HSM for cutout values (Table 24).

CHAPTER VI

CONCLUSIONS

Feed costs make up approximately 70% of total swine production costs. Decreasing producers' costs through substituting cheaper protein sources, like hempseed meal for soybean meal, has the potential to increase profits not only for swine producers but also hemp farmers. This study found that hempseed meal as the primary protein source does not significantly affect the live animal side of production. However, there were some differences in carcasses quality between the diets. Most significantly seen in the shelf life and tenderness portions of this study. Differences in bacon quality were also seen, primarily in bacon firmness. Additionally, HSM tended to negatively affect lipid oxidation in fresh pork earlier than SBM. Previous research has contributed softer pork to having higher unsaturated fat levels. Thus, it is likely that the unsaturated fatty acid profile in the fresh pork from HSM carcasses may have been an underlying factor in these differences. Unfortunately, this study did not investigate the fatty acid profile differences between the HSM and SBM carcasses.

HSM has the potential to be a viable protein source for swine in niche markets where HSM is readily available. However, additional research should be conducted focusing on varying levels of HSM in the diets, swine in other production stages, and the fatty acid profile of the fresh pork. Economic data should also be collected and analyzed in further studies to continue to better understand the effects HSM may have on profits to swine producers, hemp farmers, packers, and consumers.

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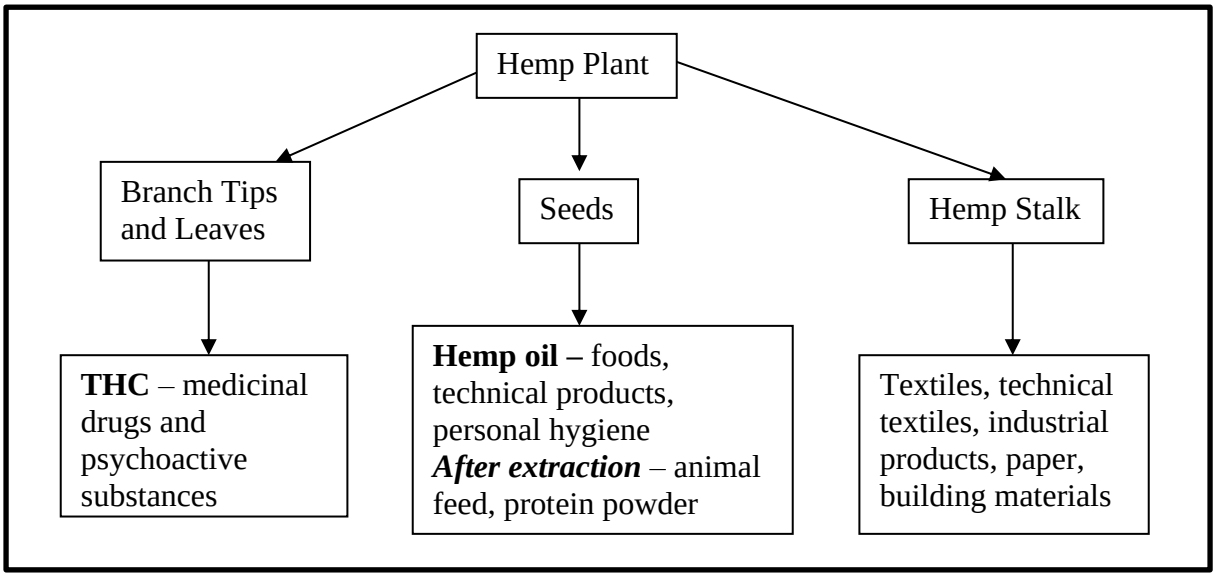
APPENDIX A

FIGURES

Figure 1 - Industrial Hemp Products



Source: Johnson (2018)

APPENDIX B

TABLES

Table 1. Sulfanilamide (ml) based on residual nitrite levels in bacon, ppm

	Day 0 100-150 ppm	Day 30 50-100 ppm	Day 60, 90, 120 0-50 ppm
Amount of Sulfanilamide (ml)	4.0	3	1.5

Table 2. Nutritional analysis of diets by phase, % dry matter

	Dry Matter	*Moisture*	*Crude Protein*	*ADF*	*aNDF*	*Fat*	*Ash*	*TDN*
Phase 1								
Soybean meal	90.4	9.6	20.4	3.4	8.0	4.4	6.3	86.0
Hempseed meal	88.5	11.4	18.7	16.0	19.9	9.7	6.5	82.9
Phase 2								
Soybean meal	90.8	9.1	16.9	2.5	8.3	3.3	4.9	85.9
Hempseed meal	89.1	10.8	16.6	11.8	20.1	9.2	5.8	84.7
Phase 3								
Soybean meal	90.3	9.6	15.0	2.6	12.4	2.1	3.9	85.0
Hempseed meal	88.7	11.2	15.1	9.4	16.4	7.6	4.7	85.9

Table 3. Feed intake[1] by treatment across diet phases, kg

Diet	n[2]	Grower	Early Finisher	Finisher
Hemp	2	1.5	2.2	3.3
Soybean	2	1.7	2.4	3.5
P-value		0.0568	0.1371	0.3251
SEM		0.01	0.07	0.09

[1]Feed intake = [((sum of feed intake – amount of feed removed)/number of barrow in pen)/number of days in phase]
[2]Number of pens within each phase

Table 4. Feed conversion[1] by treatment across diet phases

Diet	n[2]	Grower	Early Finisher	Finisher
Hemp	21	1.9	2.1	2.8
Soybean	22	1.8	2.5	2.8
P-value		0.2758	0.0755	0.7742
SEM		0.06	0.06	0.18

[1]Feed conversion = feed intake/average daily gain
[2]Number of barrows within each phase

Table 5. Live weights by treatment, kg

Diet	**n**[1]	**Day 0**	**n**[1]	**Day 30**	**n**[1]	**Day 59**	**n**[1]	**Day 91**
Hemp	22	20.1	21	44.7	21	74.4	20	112.0
Soybean	22	20.5	22	48.7	21	77.7	21	118.5
P-value		0.7939		0.2131		0.4876		0.2921
SEM		1.16		2.2		3.4		4.3

[1]Number of barrows within each phase

Table 6. Average daily gain by treatment across diet phases

Diet	**n**[1]	**Grower**	**n**[1]	**Early Finisher**	**n**[1]	**Finisher**
Hemp	21	0.8	21	1.0	20	1.1
Soybean	22	0.9	21	0.9	21	1,2
P-value		0.0426		0.7923		0.0630
SEM		0.04		0.06		0.05

[1]Number of barrows within each phase

Table 7. Hot carcass weight by diet, kg

Diet	**n**[1]	**Mean**
Hemp	20	87.2
Soybean	21	92.2
P-value		0.3231
SEM		3.5

[1]Number of carcasses per treatment

Table 8. Carcass grade data by diet

Diet	n[1]	Loineye area, cm[2]	Loineye color[2]	Last rib backfat, cm	Backfat thickness, cm	Marbling Score[3]	Muscle Score[4]	USDA Grade[5]
Hemp	20	44.8	2.2	6.1	5.1	1.1	2.6	1.3
Soybean	21	46.9	2.7	6.4	4.9	1.5	2.7	1.1
P-value		0.4047	0.0094	0.6046	0.7623	0.0055	0.2682	0.5212
SEM		1.76	0.11	0.46	0.35	0.01	0.08	0.12

[1]Number of carcasses graded
[2]Color score 6-point scale (1.0 = pale pinkish gray to white; 2.0 = grayish pink; 3.0 = reddish pink; 4.0 = dark reddish pink; 5.0 = purplish red; 6.0 = dark purplish red)
[3]Marbling score 10-point scale (1.0 = void of marbling; 10.0 = excessive marbling)
[4]Muscle score 3-point scale (1.0 = thin; 2.0 = average; 3.0 = thick)
[5]USDA grade = (4*last rib backfat) – (1*muscle score)

Table 9. Percent four lean cuts by diet

Diet	**n**[1]	**Mean**
Hemp	20	65.1
Soybean	21	66.2
P-value		0.0367
SEM		0.36

[1]Percent four lean cuts = ((loin + boston butt + picnic shoulder + ham)/total side weight) × 100
[2]Number of carcasses

Table 10. Subjective color[1] diet*chop type within day

	n[2]	Lightest	Darkest
Day 0			
HSM*Rib Chop	4	2.1	3.5[b]
HSM*NY Chop	4	2.7	3.0[c]
SBM*Rib Chop	4	3.1	3.9[a]
SBM*NY Chop	4	2.6	3.0[c]
P-value		0.1374	<0.0279
SEM		0.36	0.10
Day 2			
HSM*Rib Chop	4	2.1[c]	3.7
HSM*NY Chop	4	2.4[b]	2.8
SBM*Rib Chop	4	2.8[a]	4.0
SBM*NY Chop	4	2.7[ab]	2.8
P-value		0.0386	0.1831
SEM		0.10	0.11
Day 4			
HSM*Rib Chop	4	2.1	4.0[a]
HSM*NY Chop	4	2.1	2.7[c]
SBM*Rib Chop	4	2.6	3.8[a]
SBM*NY Chop	4	2.3	3.2[b]
P-value	n	0.3075	0.0047
SEM		0.09	0.10
Day 6			
HSM*Rib Chop	4	2.4[a]	4.3[a]
HSM*NY Chop	4	1.8[b]	2.5[d]
SBM*Rib Chop	4	2.5[a]	3.8[b]
SBM*NY Chop	4	2.6[a]	3.3[c]
P-value		0.0016	<0.0001
SEM		0.10	0.12
Day 7			
HSM*Rib Chop	4	2.2[b]	4.1[a]
HSM*NY Chop	4	1.8[c]	2.4[c]
SBM*Rib Chop	4	2.5[a]	4.1[a]
SBM*NY Chop	4	2.7[a]	3.2[b]
P-value		0.0011	0.0009
SEM		0.08	0.13

[1]Color score 6-point scale (1.0 = pale pinkish gray to white; 2.0 = grayish pink; 3.0 = reddish pink; 4.0 = dark reddish pink; 5.0 = purplish red; 6.0 = dark purplish red)
[2]Number of chops
[a-c]Least squares means in the same column and within the same day without common superscript letters differ ($P < 0.05$).

Table 11. Surface discoloration by diet within day

	n[1]	Color[2]	Percent[3]
Day 0			
HSM	8	0.2	0.2
SBM	8	0.3	0.1
P-value		0.5125	0.4818
SEM		0.08	0.04
Day 2			
HSM	8	0.1	0.1
SBM	8	0.0	0.0
P-value		0.2249	0.1907
SEM		0.04	0.04
Day 4			
HSM	8	0.4	0.3
SBM	8	0.5	0.4
P-value		0.3829	0.6002
SEM		0.10	0.08
Day 6			
HSM	8	1.5[a]	1.1[a]
SBM	8	0.7[b]	0.6[b]
P-value		<0.0001	0.0008
SEM		0.12	0.11
Day 7			
HSM	8	1.9[a]	1.4[a]
SBM	8	0.7[b]	0.5[b]
P-value		<0.0001	<0.0001
SEM		0.11	0.09

[1]Number of chops

[2]Surface discoloration 4-point color scale (0 = none; 1 = lightly tannish gray; 2 = moderately tannish gray; 4 = tan to brown)

[3]Percent surface discoloration 6-point scale [0 = none; 1 = slight discoloration (1-20%); 2 = small discoloration (21-40%); 3 = modest discoloration (41-60%); 4 = moderate discoloration (61-80%); 5 = extensive discoloration (81-100%)]

[a-b]Least squares means in the same column and within the same day without common superscript letters differ ($P < 0.05$).

Table 12. APC by diet across day, log CFU/mL

	n[1]	**APC**[2]
Day 0		
HSM	8	2.3
SBM	8	2.7
P-value		0.0645
SEM		0.14
Day 2		
HSM	8	2.3
SBM	8	2.2
P-value		0.6489
SEM		0.12
Day 4		
HSM	8	2.8[a]
SBM	8	2.4[b]
P-value		0.0160
SEM		0.10
Day 6		
HSM	8	3.3[a]
SBM	8	2.7[b]
P-value		0.0348
SEM		0.18
Day 7		
HSM	8	4.4
SBM	8	4.1
P-value		0.5040
SEM		0.30

[1]Number of chops
[2]APC = Aerobic Plate Counts
[a-b]Least squares means in the same column and within the same day without common

Table 13. TBARS value for chops by diet across day

		n[1]	TBARS value, ppm
Day 0			
	HSM	4	0.6
	SBM	4	0.5
	P-value		0.2728
	SEM		0.04
Day 2			
	HSM	4	0.7[a]
	SBM	4	0.4[b]
	P-value		0.0137
	SEM		0.04
Day 4			
	HSM	4	0.8[a]
	SBM	4	0.3[b]
	P-value		0.0486
	SEM		0.1
Day 6			
	HSM	4	0.8[a]
	SBM	4	0.5[b]
	P-value		0.0175
	SEM		0.06
Day 7			
	HSM	4	1.4[a]
	SBM	4	0.3[b]
	P-value		0.0059
	SEM		0.01

[1]Number of chops

[a-c]Least squares means in the same column and within the same day without common superscript letters differ ($P < 0.05$).

Table 14. Distribution of chop rancidity by diet across day based on Turner et al. (1953)

	n[1]	Not Rancid < 0.5 TBARS[2]	Borderline 0.5 – 1.2 TBARS[2]	Rancid > 1.2 TBARS[2]
Day 0				
HSM	4		4	
SBM	4	2	2	
Day 2				
HSM	4		4	
SBM	4	3	1	
Day 4				
HSM	4		4	
SBM	4	3	1	
Day 6				
HSM	4		4	
SBM	4	1	3	
Day 7				
HSM	4		4	
SBM	4	4		

[1]Number of chops
[2] TBARS value (ppm)

Table 15. Shear force by diet, N

Diet	n[1]	Force
HSM	20	23.4
SBM	21	21.4
P-value		0.0145
SEM		0.57

[1]Number of carcasses – two chops per carcass

Table 16. Protein, moisture, ash, and crude fat values by diet within chop type

Diet	n[1]	Protein, %	Moisture, %	Ash, %	Lipid, %
New York Chop					
SBM	21	20.8	66.4	0.9	14.1
HSM	20[2]	20.8	64.0	0.9	14.1
P-value		0.9760	0.0163	0.7329	0.9757
SEM		1.2	0.6	0.3	1.1
Rib Chop					
SBM	21	18.5	64.7	0.9	15.4
HSM	20	17.7	61.8	0.8	19.0
P–value		0.0288	0.0121	0.1398	0.0276
SEM		0.2	0.7	0.0	1.1

[1]Number of chops

[2]One chop was thrown out due result errors for protein analysis (n = 19).

Table 17. Belly distribution across three thickness categories[1] by diet based on Person et al. (2005)

Diet	n[2]	Thin ≥2.0 cm	Average 2.1 to 2.9 cm	Thick 3.0 cm≤
SBM	21	10	11	0
HSM	20	11	9	0

[1]Categories are based on Person et al. (2005) (category 1 = thin, belly thickness ≥2.0 cm; category 2 = average, belly thickness 2.1 to 2.9 cm; category 3 = thick, belly thickness 3.0 cm≤)
[2]Number of bellies

Table 18. TBARS value for bacon slices by diet across day

	n[1]	TBARS value, ppm
Day 0		
HSM	2	0.5
SBM	2	0.4
P-value		0.1010
SEM		0.02
Day 30		
HSM	2	0.4
SBM	2	0.3
P-value		0.1017
SEM		0.01
Day 60		
HSM	2	0.4
SBM	2	0.3
P-value		0.1270
SEM		0.01
Day 90		
HSM	2	0.4
SBM	2	0.3
P-value		0.1100
SEM		0.01
Day 120		
HSM	2	0.3
SBM	2	0.3
P-value		0.2062
SEM		0.00

[1]Number of bacon sets (6 slices per set)

[a-c]Least squares means in the same column and within the same day without common superscript letters differ ($P < 0.05$).

Table 19. Cannabinoids in urine and plasma, ng/ml

Level detected (ng/ml)	Cannabinoids (CBD)		7-Carboxy CBD	
	Urine	**Plasma**	**Urine**	**Plasma**
Average	0.0	0.7	93.9	46.2
Max	0.3	3.2	144.8	103.1
Min	<0.0	<0.0	35.9	9.7

Table 20. Feed costs broken down by ingredient based on one ton of feed, $/lb. in a ton

Diet by Phase	Soybean Meal	Hempseed Meal	Corn	Lysine	Vitamin Mix	Amino Acid Mix	Soybean Oil	Monocalcium phosphate (21%)	Limestone	Salt	Total diet cost per ton
SBM 1	121.8	0	127.7	0	15.9	8.5	8.9	17.5	2.9	0.9	$ 304.3
HSM 1	0	102.9	102.5	18.5	15.9	11.5	30.9	23.5	2.7	0.9	$ 309.5
SBM 2	82.7	0	148.0	1.1	11.3	12.8	5.1	15.2	2.8	0.9	$ 280.2
HSM 2	0	84.0	119.6	17.0	11.3	7.9	22.9	19.5	2.6	0.9	$ 286.0
SBM 3	55.6	0	161.7	0.5	11.3	14.9	5.4	12.8	2.6	0.9	$ 266.1
HSM 3	0	62.9	137.6	13.0	11.3	6.9	18.3	15.7	2.5	0.9	$ 269.5

Table 21. Total cost of feeding each diet

Diet by Phase	Total Amount of feed consumed, lb	Cost of feed, $/lb	Total cost of feeding the diet, $/lb
SBM 1	2474.1	$ 0.15	$ 376.4
HSM 1	2203.5	$ 0.15	$ 341.0
SBM 2	3340.7	$ 0.14	$ 468.0
HSM 2	3134.5	$ 0.14	$ 448.3
SBM 3	5291.6	$ 0.13	$ 704.2
HSM 3	4943.0	$ 0.13	$ 666.1

Table 22. Pricing scheme for slaughter costs, $/cwt

	10^{th} rib backfat, cm		
	2.54-2.77	**2.03-2.51**	**1.65-2.00**
Price	$91.00/cwt	$92.87/cwt	$94.67/cwt

Table 23. Distribution of slaughter cost using premium/discount prices from USDA based on 10th rib backfat

	n[1]	Discount $91.00	Base Price $92.87	Premium $94.67
Hemp	20	4	8	8
Soybean	21	1	11	9

[1]number of head

Table 24. Cutout values, USD

	n[1]	Value per CWT
Carcass		
HSM	20	25.36
SBM	21	24.71
P-value		0.7225
SEM		1.3
Ham		
HSM	20	16.5
SBM	21	17.0
P-value		0.5579
SEM		0.06
Loin		
HSM	20	25.8
SBM	21	26.2
P-value		0.8178
SEM		1.1
Picnic shoulder		
HSM	20	6.8
SBM	21	6.5
P-value		0.4444
SEM		0.23
Boston butt		
HSM	20	9.3
SBM	21	9.3
P-value		0.9668
SEM		0.38
Belly		
HSM	20	24.5
SBM	21	23.8
P-value		0.7225
SEM		1.23
Spareribs		
HSM	20	4.0
SBM	21	4.2
P-value		0.4603
SEM		0.17

[1]Number of cuts