Government of Saskatchewan
Ministry of Agriculture

ADF Project Final Report

1. **Project title, ADF file number and reporting period.**

   Enhancing the nutritional value of by-products through steam explosion – Proj #: 20160208.

2. **Name of the Principal Investigator and contact information.**

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4. **Abstract (Not more than 250 words).**

The objective of this project was to improve the digestibility of high fibre oil seed products, canola, camelina and Flax using steam explosion or similar hydrothermal treatments. The initial experiments focused on treating canola meal, a range of pressure and moisture combinations were tested but the water absorption capacity of the meal was too high and prevented steam explosion. Therefore the project shifted focus to treating hulls or whole seed. A method to dehull canola and camelina were successfully developed. Dehulling of flax was not effective. Removing the hulls significantly improved the nutritional content and digestibility of the meals. Steam explosion with and without pre-treatment with either water or NaOH solution significantly reduced fibre content of both canola and camelina. However, steam explosion of canola hulls decreased diet digestibility. Steam explosion of camelina hulls reduced intestinal viscosity and increased digestibility, likely due the degradation of mucilage to organic acids. Whole canola and flax seeds were exposed to a range of steam explosion treatments. Flax seed was significantly improved but canola was not. It was concluded that dehulling canola and camelina improves nutritional value. Canola hulls are to highly lignified to be improved by steam explosion treatments. Nutritional value of Camelina and flax seed is improved by steam explosion, primarily due to the degradation of the mucilage thereby reducing the negative effects of this highly viscous, indigestible compound.

5. **Introduction:**

   Steam treatment is used to degrade lignin and disrupt fibre in a number of industries. The process was originally developed to increase the fibre digestibility in ruminants but was adopted by the

cellulosic ethanol industry to pre-treat very low quality, highly lignified materials rendering them fermentable. In addition, steam explosion is utilized as a method to modify fibre for the production of fibre boards. The combination of high temperature and pressure, melt the lignin and change its physical relationship within the materials. In addition, a significant portion of the hemicellulose is degraded to organic acids and the structural fiber is physically disrupted increasing surface area and exposing encapsulated products to digestive enzymes. To achieve complete modification of cellulosic materials for ethanol production they are often treated at approximately 290 psi (200°C) for a short duration combined followed by a rapid decompression phase. Figure 1, shows the steam explosion system used in this research. Oilseeds such as canola, flax and camelina contain significant quantities of fibre and much of it is highly lignified. In addition, this fibre appears to encapsulate nutrients impairing their digestion by animals, especially monogastric species such as chickens. Steam explosion may be able to render these nutrients more available for digestion and absorption as well as increase the digestibility of the fibre fractions themselves by conversion to organic acids which may also have antimicrobial properties. High temperature treatments are energy intensive and can damage protein, so it may not be practical to treat at the temperatures used for cellulosic ethanol production. It may be possible, however, to use lower temperatures to minimize protein damage and costs but still achieve significant delignification of materials. The steam explosion process can be made more effective and therefore reduce the necessary processing temperatures through pre-treatments. One such pre-treatment is simply presoaking the product prior to steam explosion, this allows for increased water absorption into the fibrous matrix with increases the efficiency of steam expansion within the fibre during the decompression phase. The soaking can also serve to "soften" the fibre making it more susceptible to steam explosion. The other approach is to soak the product in a base solution which serves to dissolve a portion of the lignin which would also increase the effectiveness of the process at reduced temperatures. The objective of this research is to determine if steam explosion technology combined with or without pre-treatments can be used to improve the nutritional value of Canola, flax and camelina.

6. **Objectives and the *progress towards meeting each objective***

Objectives (*Please list the original objectives and/or revised objectives if Ministry-approved*	**Progress (e.g. completed/in progress)**

revisions have been made to original objective. A justification is needed for any deviation from original objectives)	
a) Determine the optimal conditions for Steam treatment, to minimize fibre content of canola, camelina and flaxseed	**Completed**
b) Determine the AMEn and Amino acid digestibility from these ingredients after the treatment	**Completed**
c) Economic analysis of the steam treatment	**Completed**
d) Communication of opportunity to industry	**Completed**

Please add additional lines as required.

7. Methodology:

Summary of experimental design and overall experimental approach

A series of experiments were conducted to study the potential to improve the digestibility of high fibre oilseed products including Canola, Camelina and Flax. A range of pre-treatments, ranges in pressure and durations were tested and are described in detail in the following sections. Products tested were seed, meal and hulls. In the case of flax, the whole seed was tested as we were not able to successfully dehull the seed and the majority of the product on the market is seed. In addition, working with canola meal, we found that steam explosion of extracted meal was not effective due to excessive water absorption so the decision was made to focus on the hulls and seed. The final experiments were digestibility studies in broiler chickens and laying hens to test the effect of selected steam explosion treatments of canola and flax seed on nutrient utilization and growth performance. The appropriate controls were also tested in the digestibility studies. This includes water treatment and drying without steam explosion to ensure the addition of water and subsequent drying does not account for the differences observed rather than steam explosion. Table 1 summarizes the experiments conducted during this project.

Table 1. Summary of processing treatments tested by seed and product type

Seed Type	Product	Analysis	Pre-treatment	Pressure (PSI)	Time (min)
Canola	Meal	Composition	30% H_2O	100-300 (increments of 20)	5
	Meal	Composition	20% H_2O	200-300 (increments of 20)	5
	Meal	Composition	1.5, 2 & 2.5 X water	50, 100, 150	4
	Seed	Composition	20% H_20	200 – 300 (increments of 20)	5
	Seed	Composition	none	100 &160	2 & 5
	Seed	Digestibility Broilers	Expelled Meal		
	Seed	Digestibility Broilers	De-hulling, expelling		
	Seed	Digestibility Broilers	Untreated		
	Seed	Digestibility Broilers	Water Treated		
	Seed	Digestibility Broilers	Exploded	180	5
	Seed	Digestibility Layers	Untreated		
	Seed	Digestibility Layers	Water Treated		
	Seed	Digestibility Layers	Exploded	180	5
	Hulls	Composition	none	160, 180, 200	2, 5 & 10
	Hulls	Digestibility Broilers	Dehulling		
	Hulls	Digestibility Broilers	Exploded	250	5
	Hulls	Digestibility Broilers	Just Water	250	5

	Hulls	Digestibility Broilers	Water & 3.5% NaOH	250	5
Camelina	Seed	Digestibility	De-hulling, expelling		
	Hulls	Composition	none	160, 180, 200	2, 5 & 10
	Hulls	Digestibility Broilers	Water & 3.5% NaOH	250	5
Flax	Seed	Composition	30% water	100, 200 & 300	5
	Seed	Digestibility Broilers	Untreated		
	Seed	Digestibility Broilers	Water Treated		
	Seed	Digestibility Broilers	Exploded	180	5
	Seed	Digestibility Layers	Untreated		
	Seed	Digestibility Layers	Water Treated		
	Seed	Digestibility Layers	Exploded	180	5

Canola meal

The initial focus was on improving solvent extracted meals so a wide range of treatment were attempted using canola meal as the initial starting point. The concept was to approximate steam explosion of meal directly from the desolventizer/toaster but with some added moisture to enhance the steam explosion process. However, the consistency of the product did not flow well through the steam explosion system and the product plugged the exit pipe on route to the cyclone. Therefore, a series of experiments were conducted at a reduced moisture content, mimicking the approximate moisture content of canola meal upon desolventization toasting prior to drying/cooling. However, even at this low moisture content the system tended to plug and the changes in nutritional composition (reduced protein quality) were not favorable. The third study focused on using excess water as a means to facilitate flow through the system as well as potentially enhance effects of steam explosion, unfortunately this resulted in excess drying and was deemed economically infeasible.

Canola seed treatment

Canola seed was treated using a range of processing conditions during steam explosion. The concept was the majority of the fibre in which we were attempting to disrupt is located in the hull of the seed and therefore whole seed treatment would concentrate the effects of this treatment on the fibre. In addition, we believed that the hull surrounding the seed would protect the protein and soluble components from the steam explosion process thereby eliminating the negative effects on protein and the issues with water absorption causing plugging. Whole canola seed was exposed to steam explosion ranging from 200 to 300 PSI with 20% added water and the changes to nutritional composition measured. An additional experiment was conducted without added water as it appeared the added water was not a benefit and added additional drying costs to the system. Canola seed was the treated at 180 PSI for 5 minutes and examined in digestibility studies in Broiler chickens and laying hens to determine if protein or energy utilization was improved.

Canola Hull Treatment

The primary objective of the project was to improve nutritional value of oilseeds by modifying fibre using steam explosion. Therefore it was decided to conduct steam explosion treatments on canola hulls. A process to dehull canola seed was developed and consisted of drying the seed, cracking using a roller mill equipped with smooth rolls (reduction or flaking rolls), separating the hulls from the embryo using air fractionation and further purification of the hulls using sieving. The seed which was not dehulled in the first pass were cracked again by further closing the roll gap and running the process as described above. The impact of dehulling on nutritional value of the meal was examined in a broiler digestibility study after expelling the oil. The hulls were subjected to a range of steam explosion treatments in order to attempt to improve nutritional composition. Hulls were treated between 160 to 200 psi for 2, 5 and 10 minutes. The hulls proved to be resistant to steam explosion so a more extreme set of treatments were applied to create products which were evaluated in a broiler digestibility study where the products were inluded at 6 and 12% of the diet. The hulls were treated at 250 psi for 5 minutes. An additional treatment which included pre-treatment with 3.5% NaOH solution prior to steam explosion also at 250 psi for 5 minutes. Alkaline treatment has been used previously to treat highly lignified materials prior to steam explosion so it was tested in this experiment as well. In addition to measuring changes in chemical composition and digestibility, Scanning Electron Microscopic analysis was conducted to examine the physical effects of the treatments on the hulls.

Camelina Hulls

Based on the issues we had treating canola meal, specifically the plugging of the steam explosion unit, it was decided not to treat camelina meal but to focus our efforts on the treatment of the hulls. Camelina hulls were dehulled in the same manner as canola described above except the seed did not require drying prior to cracking and the gap in the flaker roller had to be much smaller to fracture the hull prior to air classification and sifting. The hulls were treated at 160, 180 and 200 psi for 2, 5 and 10 minutes prior to drying and analyzing for chemical composition. The treatments were significantly more effective in altering camelina hulls than canola, however, when we conducted the digestibility study it was decided to use the more extreme conditions developed for canola to determine if the process could be even more effective under more extreme conditions. Hulls were treated with either water or 3.5% NaOH, 250 psi for 5 minutes before drying. The ingredient was fed to broilers at 6 and 12% inclusion in a digestibility study designed to determine the effects of steam explosion on energy and protein utilization. The maximum inclusion of 12% was chosen as CFIA limits the inclusion of camelina in broiler diets to this level.

Dehulled canola and camelina meal

The effects of dehulling of canola and camelina on nutrient utilization of the meal was determined by conducting a digestibility study in broiler chickens where we compared camelina expeller meal and dehulled expeller meals in terms of energy and protein utilization. The meals were included in the diets at 6 and 12% inclusion as CFIA limits the meal in broiler diets to 12%.

Flax Seed

The majority of flax used in poultry diets is either as ground whole seed or an expelled combination product such as that sold by O&T. Flax meal is available in North Dakota and Europe but given the issues we encountered treating canola meal, specifically plugging of the steam explosion system and damage to protein quality, we chose to focus on treating whole seed. The expeller meal could have been studied but it has already undergone extensive hydrothermal treatment and additional treatment would likely have been less effective. We considered dehulling the seed and applying the treatments to the hulls, however, given the flat elongated shape of the seed, we were not able to effectively dehull the material so studies focused on the seed. The primary target of the process is

degradation of mucilage so based the results from the camelina trials, which effectively degraded mucilage the information was used to design the flax trials. Flax seed was treated at 100, 200 and 300 psi for 5 minutes with 30 % added water. Due to the affinity for the seed for this water and issues with handling and drying, the remaining research was conducted by treating dry seed in the steam explosion unit. Flax seed was treated at 180 PSI for 5 minutes prior to drying, grinding and incorporating in diets for digestibility studies in broilers and laying hens.

Detailed Materials and Methods

Steam Explosion Pilot System

The steam explosion system (Figures 1&2) is composed of a steam generator: HSI – High Steam Industries, with the capacity to produce steam up to 500 PSI. Custom made by HIS Hydro Steam Industries, 551 South County Line Road, Franklin Park, Illinois 60131-1013, Model # STH-1640-30-4E. 30 KW. It also comprises of a 20.3cm diameter pressure vessel with a volume and pressure capacity of 40L and up to 482 PSI, respectively. Custom made by JNE Welding Ltd. (3915 Thatcher Ave, Saskatoon, SK) and inspected by Pressure Vessel Engineering (120 Randal Drive, Suite 8, Waterloo, On). The gauges are all in PSI so pressures in this report will be in that unit of measure rather than Bar or Kilopascals. Pressure is controlled through the manual opening, and closing of the main steams feeding valve to the vessel and the time is controlled using a timer. Pressure was monitored using a manual pressure gauge located at on the side of the unit. Pressure was regulated by opening and closing of the steam inlet valve using an electric/pneumatic valve.

Figures 1& 2 Custom steam explosion system installed at the Canadian Feed Research Centre in North Battleford, SK

Improvement of Canola Meal through Steam Explosion

Steam explosion has primarily been used to improve the fermentability of highly lignified, high fibre crop residues such as straw. No information is available on the processing of high fibre oilseed residues such as canola, flax or camelina meal or the seeds of these crops. The first set of testing was to determine the form of oilseed meal and the moisture content required to achieve steam explosion. The first experiments attempted to use dry, pelleted canola meal and rely on condensed steam as the source of moisture for the fiber explosion. The objective was to find the lowest cost process that provides maximum nutrient availability and therefore it is necessary to use the lowest pressure time combination possible.

The initial experiment consisted of adding 20 kg of pelleted canola meal to the system which almost fully filled the vessel then pressurizing it to 100 psi for 5 minutes before rapid decompression was initiated. Unfortunately, the moisture pressure combination was too low and the dry meal plugged the vessel at its base where the diameter is reduced significantly. The system was disassembled, cleaned and made ready for the next test. Since the meal was so dry it appeared there was not enough condensation during the heating/pressurization of the system to act as a lubricant and therefore the next experiments examined the impact of increasing levels of water mixed into the meal prior to processing.

A series of experiments were conducted, primarily focused on canola meal for the initial range of conditions. In experiment 1, it was determined that the pellets might be interfering with the steam explosion process and therefore all meal treatments were conducted on ground meal. To do this 3 tonnes of canola meal pellets were ground in a hammer mill through a 9/64" screen and this same batch of canola was used for all experiments.

An opportunity arose to conduct a digestibility study in weaned pigs as part of the Canola Council's Science Cluster research being conducted at the University of Alberta. To conduct this study they required, 600 kg each of three treatments consisting of 1) unprocessed meal, 2) Low intensity steam exploded canola meal and 3) High intensity processed canola meal. The product for this trial was produced in Experiment 3 as shown below. Due to issues of occasional plugging at the outlet of the

system associated with the location of the lower steam inlet which is about 30 cm above the bottom of the vessel, it was decided to add 2 kg of canola meal @ 50% water to prevent dry product from plugging the bottom of the vessel. This appeared to work but it was difficult to separate this plug of high moisture product from the treated meal. The product was dried using the fluidized bed drier on the extrusion line at the CFRC and shipped to the University of Alberta in the beginning of Nov 2018 and digestibility studies completed. Based on these challenges, a modification was designed and eventually made to the system, where the bottom steam inlet was extended within the vessel and pointed down towards the outlet valve. When steam is introduced into the product, it blows the product from below the entrance upward and appears to prevent plugging of the unit.

Once the product for the Piglet study was completed several experiments were conducted examining combinations of moisture, pressure, canola meal, flax seed and flax meal were tested to determine effects on fibre structure and predictors of nutrient availability. The treatments are listed below. Due to the large number of potential combinations a decision was made to use a statistical model design feature in SAS JMP program to design treatments using central composite design and analyzed using surface plot methodology to attempt to find the optimal conditions while keeping the process conditions down to a manageable number of treatments.

Experiment 1 - The Effect of Pressure During Steam Explosion Treatment on the Nutritional Value of Camelina Hulls

The experiment was conducted at the Canadian Feed Research Center (CFRC), located in North Battleford, SK. The camelina (variety Midas) used for this trial was a commercial seed obtained from Landis producer Co-op Ltd, located in Landis, SK. It was passed through a reduction roller mill (capacity of 100kg/hr, roll diameter of 10”, roll length of 6”, roll differential speed ratio 2:1, roll weight 50kg) (figure 3.1) with a 0.015mm gap as determined using a feeler gauge. The product was processed at these conditions twice to enhance the separation between hull and cotyledon. Following rolling, the product was separated using an ISM 10 Fractionating Aspirator (rented from Flaman’s Agriculture Saskatoon, SK) and was equipped with a cyclone sedentary chamber (figure 3.2), which accumulated the lightest portion (mostly hulls) whereas the heaviest portion (cotyledon) fed into the side bins #1-7. The fractionating aspirator was set at 6% airspeed and the material in last bin before the cyclone was put

through the fraction aspirator twice. After the separation of seed components, the hull fraction was further purified using a custom 870 mm by 220 mm sieve box (hole size of 4/64" and hole separation of 4 mm) (figure 3.3), which removed most of the remaining cotyledon from the hull fraction. The hulls that were generated (figure 3.4) were used in the steam explosion.

Pressure was controlled through the manual opening, and closing of the main steams feeding valve to the vessel and the time was controlled using a timer set at five minutes for all three pressure treatments (160, 180, 200 PSI). The product after steam explosion was collected and placed in tin foil trays and dried in a forced air oven at 55^0C for 48-72 hours.

Experimental Design

Three different steam explosion pressures (160,180,200 PSI) and five minutes processing were ran in triplicate.

Sampling and Analysis

The material collected from the cyclone after steam explosion was immediately analyzed for pH (Beckman pH Meter Model: PHI 34 Serial # 247116). After drying the material was ground (1 mm screen) using a centrifugal mill (Retzsch ZM 100, Retsch GmbH, Haan Germany) then analyzed for NDF (Neutral Detergent Fiber Method (A2000)), ADF (Acid Detergent Fibre Method (A2000)), and NDIN (neutral detergent insoluble nitrogen) (AOAC method 984.13).

Figure 3.1 Custom reduction roller mill (left) used to dehull camelina located at the Canadian feed research Centre in North Battleford, SK.

Figure 3.2 ISM 10 Fractionating aspirator used to separate the camelina hull from the cotyledon.

Figure 3.3 Custom sieve box used to purify the camelina hulls from cotyledons following air fractionation

Figure 3.4 Separated camelina hulls (top) and cotyledon (bottom)

Figure 3.5 Custom steam explosion system installed at the Canadian Feed Research Centre in North Battleford, SK and used to treat camelina hulls

Experiment Two: The Effect of Steam Explosion on The Nutrient Utilization of Camelina Meal and Steam Exploded Hulls in Boiler Chickens

Ingredient Processing

There were two types of ingredients in this experiment which included expeller meal ingredients and steam exploded hulls ingredients. Each ingredient was processed then ground in a lab scale hammer mill (hammer mill- Colorado milling equipment HMS. 20X) and added to the diet at 12% inclusion level.

Expeller meal ingredients

The oil was extracted using a KOMET CA-85 oil expeller press set at speed 3.5, with the external heating element on the and barrel turned on to maximize the oil extraction rate (figure 3). Camelina seed and the dehulled camelina (without hulls) generated from experiment one was expelled under those conditions, and the resulting meals were used in the experimental diets. The expelled camelina seed and dehulled seed were given the descriptors CMEX and CMDEX respectively. It is important to note that the dehulled camelina product generated in experiment one was only partially dehulled since some hulls did remain in the final product.

Figure 3 Expelling of dehulled camelina using a lab scale Komet oil expeller press

Steam explosion hulls ingredients

There was three steam exploded camelina hull ingredients in total and of the three, two of them were pretreated by being soaked in water or 3% sodium hydroxide (NaOH) before being steam exploded at 250 PSI for five minutes. The first pretreated ingredient which was given the descriptor CMHSOWEX was created by soaking hulls in water at a 2.5:1 ratio by weight (solution: product) for 24 hours then steam exploded. The second pretreated ingredient which was given the descriptor CMHSOBEX was made by soaking hulls in NaOH at a 2.5:1 ratio by weight (solution: product) for 24 hours then steam exploded. The third ingredient which was given the descriptor CMHEX was produced by steam exploding hulls. The steam explosion system used in experiment one was also used in this experiment (refer to section 3.1 for steam explosion specifications). The resulting material after steam explosion was very wet and viscous, and attempts were made to collect as much solid and liquid as possible. The wet

material was spread out on tarps on the floor and exposed to blowing fans, as well as a warm room (room was located next to the feed mill boiler room) until it was partially dried (72 hours). The partially dried product was then put in tin foil trays and placed in a forced air oven at 55^0C for 4-6 hours until the product was dry.

Diet Formulation

The chicks consumed a corn-soybean starter diet (Table 2) in crumble form for the first 14 days. Day 14-21 they were fed a pelleted corn-soybean based diet with 12% inclusion of camelina from each of the experimental processes (Table 3), which include: expelled (CMEX), dehulled expelled (CMDEX), hulls (CMH), hulls steam exploded (CMHEX), hulls soaked in water and steam exploded (CMHSOWEX), and hulls soaked in NaOH and steam exploded (CMHSOBEX). The diets were isonitrogenous. The expeller ingredients and steam exploded hull ingredients were ground individually at the Canadian Feed Research Center in a lab scale hammer mill (hammer mill- Colorado milling equipment HMS. 20X), then mixed with the basal ingredients with the incorporation of titanium oxide (0.34% of the diet) as a digestibility marker. The diets were pelleted in a lab scale pellet mill (Colorado milling equipment ECO R30) with a die size of 3mm. The analyzed chemical composition of the six camelina ingredients (CMEX, CMDEH, CMH, CMHEX, CMHSOWEX, CMHSOBEX) are presented in the results section (table 4.2).

Table 2. Broiler starter diet day 0-14 (as fed)

Ingredients (%)	Diet
Corn grain ground	55.82
SBM-50% wo hull sol	37.68
Canola Oil	2.00
DiCalcium Phosphate	1.78
Calcium Carbonate	1.18
Poultry Vit/Min Pre-Mix[a]	0.50
dl-Methionine	0.34

Salt (Sodium Chloride)	0.34
Lysine HCl	0.24
L-Threonine	0.11
Calculated composition (%)	
Metabolic Energy (Kcal/kg)	3,000.00
Crude Protein	24.10
Ether Extract	4.36
Crude fibre	2.53
Calcium	0.96
Available Phosphorus	0.48
Methionine + Cystine	1.09

[a]Supplied per kilogram of feed: vitamin A, 2,200,000 IU; vitamin D, 440,000 IU; vitamin E, 6,000 IU; menadione, 400 mg; thiamine, 300 mg; riboflavin, 1,200 mg; pyridoxine, 800 mg; vitamin B12, 4 mg; niacin, 12,000 mg; pantothenic acid, 2,000 mg; folic acid, 120 mg; biotin, 30 mg, copper, 2,000 mg; iron, 16,000 mg;manganese, 16,000 mg; iodine, 160 mg; zinc, 16,000 mg; selenium, 60 mg; calcium carbonate, 100,000 mg; antioxidant, 125 mg; wheat midds, 754,546.

Table 3. Camelina experimental diets at 12% inclusion (as fed)

Ingredients (%)	Diet	
	Basal	12%
Corn grain ground	58.15	51.17
SBM-50% wo hull sol	33.93	29.86
DiCalcium Phosphate	1.90	1.67
Calcium Carbonate	1.59	1.40
Canola Oil	2.27	2.00
Poultry Vit/Min Pre- Mix[a]	0.57	0.50
Salt (Sodium Chloride)	0.50	0.44
Titanium oxide (TiO_2)	0.34	0.30
dl-Methionine	0.32	0.28
Lysine HCl	0.23	0.20
Choline Chloride	0.11	0.10
L- Threonine	0.09	0.08
Camelina test ingredient	0%	12%
Total	100%	100%
Calculated composition (%)		
Metabolic Energy (Kcal/kg)	3,011.46	2,795.78
Crude Protein	22.41	21.53
Ether Extract	4.66	6.51
Crude fiber	2.46	2.17
Calcium	1.14	1.00
Available Phosphorus	0.49	0.44
Methionine + Cystine	1.02	0.90

[a]Supplied per kilogram of feed: vitamin A, 2,200,000 IU; vitamin D, 440,000 IU; vitamin E, 6,000 IU; menadione, 400 mg; thiamine, 300 mg; riboflavin, 1,200 mg; pyridoxine, 800 mg;

vitamin B12, 4 mg; niacin, 12,000 mg; pantothenic acid, 2,000 mg; folic acid, 120 mg; biotin, 30 mg, copper, 2,000 mg; iron, 16,000 mg;manganese, 16,000 mg; iodine, 160 mg; zinc, 16,000 mg; selenium, 60 mg; calcium carbonate, 100,000 mg; antioxidant, 125 mg; wheat midds, 754,546.

Chick Management

A total of 170 male broilers (Ross 708) day old chicks were obtained from Sofina (commercial hatchery in Edmonton, AB), and randomly assigned to 45 cages of 50 x 50 cm floor space. The cages are located in Room 21 of the Poultry Research Centre, University of Saskatchewan. This room provides the birds with optimum temperatures, ventilation and lighting and is adjusted based on standard operating procedures with the bird's growth. The lighting scheme employed in the housing unit used 23 hours light to 1 hour dark from 0 – 7 d and 18 hours light to 6 hours dark from 7 – 21 d of age. The temperature of the broiler room is a standard curve, in which the temperature drops 0.43°C per 24 hours. It started at 34°C on day 0 and was reduced to 25°C by day 21. A front-mounted feed through 53.3 cm (21") length was used with a wire mesh restrictor placed inside the feed trough to minimize feed wastage after 5 days of age. The same wire mesh was placed in the front of the cage to prevent the chicks from escaping while they were small. Additionally, days 0-5 the chicks were given supplementary feeders and drinkers (ice trays).

On day 14, 170 male broilers were weighed and randomly allocated to 7 treatments. The birds were assigned to the treatments in a way that the average initial body weight was not significantly different across treatments. Birds were provided *ad libitum* access to water and feed for the full 21 days. On day 20 and 21 the birds were euthanized by a T61 intravenous injection.

Experimental Design

The experiment was a completely randomized block design involving 6 camelina products (Table 4) and a basal diet for a total of 7 dietary treatments. Each diet was replicated 5 times with 4 birds per replicate (cage), except for treatments CMH and CMHEX which only had 3 birds per replicate (cage) due to an insufficient amount of product. All the chicks were a fed starter diet in crumble form for the first 14 days, then fed the experimental diet for the remainder of the experiment period (day 14-21). Diets consisted of camelina meal types by 6 different processes: CMEX, CMDEX, CMH, CMHEX, CMHSOWEX,

CMHSOBEX each tested at 12% inclusion level. A corn-soybean meal basal diet was used to calculate energy and digestibility of the meal.

Table 4 Camelina experimental diets

Meal Type	Fraction	Product Name	Inclusion Level
Camelina	Expeller meal	CMEX	12
Camelina	Dehulled expeller meal	CMDEX	12
Camelina	Hulls	CMH	12
Camelina	Exploded hulls	CMHEX	12
Camelina	Hulls soaked in water exploded	CMHSOWEX	12
Camelina	Hulls soaked in NaOH exploded	CMHSOBEX	12
Basal	Basal	Basal	0

Sampling and Analysis

Feed intake (FI)

When the feed trial period began (day 14), the feed was weighed into trough feeders, and any additional feed was recorded. The feed was weighed at the end of the trial (day 20 and 21).

Body weight gain (BWG) day 14-21

Body weight was recorded on day 14 and then on day 20 and 21.

Mortality day 14-21

Dead birds were weighed, and the recorded weight was used to calculate the percent of mortality for the entire experimental period (day 14-21).

Feed efficiency

Feed intake was determined from day 14-21.

Excreta collection

Aluminium trays were placed under each cage on day 18. The excreta samples were cleaned from feed, and feather contaminants then an adequate representative amount was placed in a labelled 5lb poly bag and immediately frozen at -20°C. The excreta samples were collected every 12 hours during the last 3 days of the trial (D18 afternoon, D19 morning, D19 afternoon and D20 morning). The excreta samples from the four collects were pooled and then frozen for storage. Before analysis, the samples were dried in a forced air oven at 55 °C for 72-84 hours, followed by fine grinding (1 mm screen) using a centrifugal mill (Retzsch ZM 100, Retsch GmbH, Haan Germany).

Digesta collection and analysis

Content samples of anterior jejunum, posterior jejunum, anterior ileum, and posterior ileum was collected into a pre-weighed vial and stored immediately at -20 °C until chemical analysis. The empty weight of the proventriculus and gizzard were measured, and the pH (Beckman pH Meter Model: PHI 34 Serial # 247116) of the ceca and empty weight of the ceca was collected. Due to the time restraint of this study, the results pertaining to the intestinal contents were not obtained.

Chemical analysis of the diet and excreta for gross energy (Using an adiabatic oxygen bomb calorimeter), CP (AOAC method 990.03), DM (AOAC 930.15), NDF (Neutral Detergent Fiber Method (A2000)), ADF (Acid Detergent Fiber Method (A2000)), and titanium dioxide (method described by (Myers et al. 2004)) was completed. Fecal digestibility of CP, NDF, ADF and apparent metabolizable energy (AME) were calculated as follows using the equations described by Garcia et al. (2007).

a. Apparent (%) = {% nutrient in diet - [% nutrient in digesta x (% marker in dieta / % marker in digesta)]}/ % nutrient in diet
b. % of energy utilization = 100 x {1-[(marker in diet/marker in digesta) x (energy in excreta/energy in feed)]}
c. AME = (% of energy utilization/100) x diet energy

Statistical Analysis of Data

The experiment was a completely randomized block design. Analysis of variance (ANOVA) was conducted using JMP version 12 statistical software from SAS. Mean separation test was conducted

using Tukey HSD method and differences were considered to be significant when $p < 0.05$. *Pre-priori* contrast test was also performed.

The Effect of Steam Explosion on The Nutrient Utilization of Steam Exploded Hulls in Boiler Chickens

An experiment, identical to the experiment entitled "The Effect of Steam Explosion on The Nutrient Utilization of Camelina Meal and Steam Exploded Hulls in Boiler Chickens" above was conducted but examining canola hulls and meal. Please refer to that section for a description of the experimental design.

Steam Exploded Flax and Canola Seed Digestibility Study - Broilers

Experimental Diets

This experiment followed a Randomized Completely Block Design (RCBD) with a 2 x3 factorial arrangement representing two seed types, Canola Seed and Linseed. Canola seed was used as a comparison to linseed. The experimental diets included the following three different treatments for each seed type: Linseed steam-exploded (LSEXP), Linseed water treated (LSW) and Linseed untreated (LSUN), Canola seed Exploded (CSEXP), Canola seed treated with water (CSW) and Canola seed untreated (CSUN). Water treatment was included to control for the effects of steam and moisture during the steam -explosion process. Titanium Oxide was included in all diets as an indicator of digestibility. Steam-explosion treatment was performed for less than five minutes using a high pressure device under 180 PSI while steam heating the seeds at 180 to 240 C° under increasing pressure of 1000 to 3450 kPa, followed by sudden release of pressure to produce explosive decompression of the seed coat. Water-treatment was performed by mixing seeds with an equivalent amount of moisture added in the steam chamber using a cement mixer for under five minutes. Both water treated and steam-explosion treated seeds were dried on screens for two weeks before grinding.

The experimental variable (canola seed or linseed) was added to a corn and soybean mean starter/grower basal diet at a 20 percent inclusion rate (Table 5). Each experimental diet was fed to five cages each holding four birds for a total of five replication per experimental diet. Chicks were fed the starter/grower basal diet from days 0-7. Experimental diets were offered during days 8-22 of the trial.

Experimental Animals and Procedures

All experimental procedures were reviewed and approved by the University of Saskatchewan Animal Research and Ethics board (Protocol 19930072) prior to the initiation of the studies described below. One hundred and twenty day-old mixed-sex broiler chicks (Ross 107 308) were obtained Prairie Pride and hatched on September 10th (day 0). Chicks were weighed and housed in groups of four within 30 wire-bottom bio-assay cages measuring 0.51 x 0.51 x 109 0.46 meters. Cages were kept within an environmentally controlled room at the Poultry Research Centre, University of Saskatchewan. Temperature, ventilation, and lighting were monitored twice daily and adjusted for optimal bird welfare. The lighting program employed in the room used 23 hours light to 1 hour dark for the first week of life followed by 20 hours light to 6 hours dark from 7 to 21 days of age. Feed and water was checked twice daily and provided for ad libitum consumption. Water was offered by supplementary drinkers (ice trays) for the first week of life, then by drip waterers. Feed was provided by flip-top supplementary feeders for the first week of life, and by front-mounted feed troughs for the remainder of the trail. Wire mesh restrictors were used until chick 6 size prevented risk of escape. Feed for each cage of birds were stored in separate bags based on treatment type. Bird weight and feeder weight were recorded weekly as well as the weight of each bag of feed. Excreta was collected on a belt beneath the cages which moved excreta to a manure pit. Birds were checked twice daily for appropriate welfare and mortality.

Sample Collection and Analysis

On days 19, 20, and 21, aluminum trays were placed on the collection belt and replaced every 12 hours to obtain consistent excreta samples. Samples were cleaned from feed, feather and other contaminants before a handful of the sample was placed into bags and immediately frozen at -20 C°. Fresh excreta was collected on the morning of the last trial to analyze moisture content. On the last day of the trial (day 22), all birds were euthanized using lethal injection and dissected. The distal ileum was cut one inch above the ileo-cecal junction and emptied by finger pressure, collected and immediately frozen at -20 C°. Ileal contents and excreta were dried in a force-air draft oven at 55C for 72 hours then ground in centrifugal Retsch Mill (model ZM, 100) over a 1mm screen. Samples were chemically analyzed for gross energy, crude protein, dry matter, and titanium oxide content,

and ileal digesta samples were analyzed for viscosity using the method outlined in Bedford, N.R., and Classen, H.L., 1993.

Steam Exploded Flax and Canola Seed Digestibility Study – Laying Hens

This study was conducted to determine whether steam explosion would increase the digestibility of linseed and canola by decreasing the anti-nutritional factors such as mucilage or increase access to nutrients through modifyication the fibre and its structure. The Lohmann LSL-lite laying hens were housed in conventional cages holding six birds each. The cages were located in the laying barn of the Poultry Research Centre, on the Campus of the University of Saskatchewan. This facility is set up as a conventional 3-tiered cage system housing 6000 commercial hens. The room provided the birds with the right temperature, ventilation and correct lighting which was based on standard operating procedures with the bird's genetic recommendation. Temperature was kept at 18-20℃ _and a relative humidity of 60-70%. The lighting program for a 19-week-old bird is 9 hours of light, for 20 weeks 10 hours of light, for 21 weeks 11 hour and for 22 weeks of age 12 hours of light.

The study was a 21-day trial, starting at 19 weeks of age, the birds started the experimental diets on day 0 and fed the same feed for the entire trial. On day 19, 20 and 21 of the trial total excreta were collected from the birds. Aluminum trays were placed under each cage, samples were collected from each cage four times, after each collection the trays were cleaned and put back under the cages.

Diets

Canola and Linseed products were included at 20%, a corn and soybean meal basal diet was used to calculate energy and digestibility of the meal. Both seeds were prepared using the same treatments: untreated, water treated, and steam explosion. The untreated diet included the ingredient untouched, the water treated diet was prepared by adding the same amount of water added through the steam chamber and mixed in a cement mixer for 5 minutes. It was then left to dry for two weeks before grinding. The steam exploded treatment was prepared using a high-

pressure device under 180 PSI for 5 minutes. The product was then spread out and left to dry for two weeks prior to grinding. The experimental design was two seeds (canola, linseed), with three treatments (untreated, water treated, steam explosion), replicated five times (A-E), with each replication being fed to 2 cages holding six birds each for a total of 12 birds per replicate. The trial consisted of 420 birds total, 360 on the experimental diets and 60 birds on a control diet. The 60 bird on the control diet didn't start until the third week, instead they stayed on the regular layer hen diet.

Data Collection

Throughout this 21 day schedule each day at 8 am the birds were fed and provided fed *ad libitum*. On day 0, 7, 14, and 21 the birds were weighed to ensure the birds were maintaining a normal weight. Feed consumption was also measured weekly. Egg production was recorded daily after 1:00 pm, the number of eggs laid in each cage was recorded and the eggs were checked for abnormalities. These abnormalities included cracked, broken, double yolk, soft eggs and abnormal. Egg specific gravity was measured by floating the eggs in different concentration of salt baths starting at 1.06-1.10. During the final egg data collection one egg per cage on the third week was analyzed to measure omega-3 levels as affected by treatment. On day 19, 20 and 21 excreta was collected using aluminum trays placed under the cages in the morning and in the evening by taking a handful of material into a labeled poly bags, which were then taken to be frozen at -20℃. All the samples collected were dried for 4 days at 55℃. After drying, the samples were ground through a 1 mm screen prior to analysis. The samples were analysed for gross energy, crude protein, dry mater and AIA. Digestibility of the drymatter, protein, energy were determined. Apparent Metabolizable energy was calculated using this data.

8. Results and Discussion

System design and limitations

The steam explosion system installed for this research was purchased as part of a prior project investigating treatment of wheat DDGS, however due to changes in program funding and escalating costs of installation, the unit was never installed in the engineering labs. The system design is based

on previous designs used by other scientists conducting research on high fibre products. It essentially consists of a water heater, water softener, steam generator, pressure vessel which has a large manual in the top to load product, two steam inlets to pressurize the vessel approximately ¼ and ¾ up the sides, an air activated valve at the bottom to which a pipe is attached that leads to a large cyclone that has a vent to the outdoors and a bottom opening for the product to fall. Upon installation, the system was tested on ground wheat straw using conditions found in the literature and the resulting product showed obvious signs of fibre disruption as described in prior work. The first task was to install the system, identify and test processing parameters which appears to function appropriately in the system. To do this we focused was on using canola meal and looking at functional characteristics of the process and using fibre analysis methods to determine if changes to fibre may be occurring.

Steam explosion of Oil Seed Meals

The first step was to treat canola meal pellets as received from a commercial solvent extraction plant. Using the similar treatment conditions as those used for wheat straw, the process did not work on canola meal pellets. The pellets formed a hard-dry mass at the exit of the reaction vessel and plugged the unit. The system was dismantled and cleaned out to determine the cause of the plug. The first observation was the product was very dry and appeared to bake onto the surface of the vessel. The product was exceedingly hard and packed at the exit valve and many of the pellets remained intact. It was hypothesized that the pellets prevented steam absorption and therefore the future processing should be completed on ground meal. It was also hypothesized that most of the water from the steam was condensing on the outer walls of the vessel and creating a moisture gradient decreasing from the wall inward, resulting in untreated product that was too dry to flow out of the vessel. The vessel was insulated with fiberglass insulation to prevent condensation along the walls. In addition, the vessel was preheated by filling with steam in order to prevent localized condensation. These steps appeared to alleviate some of the issues with plugging and used for the remaining experiments.

The next step was to investigate processing time at various processing times (1, 3 and 5 minutes). Although it is expected the treatment duration can be very short in a continuous flow type of system, in a batch system it was determined it took a period of time for the steam pressure to achieve equilibrium and therefore all future experiments were conducted with a minimum of 2 minutes processing time.

Pressure in the vessel was regulated by adjusting the target pressure in the steam generator and compensating for the initial pressure drop upon vessel filling but this resulted in a delayed equilibrium. In the later experiments, the steam pressure in the steam generator was set much higher than the target (typically 150 psi higher than the target) and a manual valve was used to maintain pressure in the vessel and this allows for a more rapid stabilization of pressures and made it possible to reduce processing time in the remaining experiments.

Based on the results of experiment 2, conditions which would be considered low and high intensity (30% water, 5 minutes) 130 and 165 psi, respectively, were used to process meal for a digestibility study at the University of Alberta and funded by the Canola Council Science cluster project. Six hundred kg of each treatment plus untreated meal were shipped to the University of Alberta in November, 2018. Several options for efficiently drying the product was explored and it was found the fluidized bed drier installed in the CFRC extrusion line worked well. Steam was used to heat incoming air to 80°C and the air flow was balanced to allow optimal drying and continuous flow of product at approximately 200 kg/hour. Under these conditions the product dried efficiently and there were no obvious signs of heat damage during drying. Results of the chemical analysis are discussed later in this report but fiber analysis results were inconsistent between replications and did not follow expected outcomes based on degree of treatment.

The next experiment evaluated the impact of incremental changes in pressure at 30% moisture on canola meal. Meal was treated for 5 minutes between 100 and 300 psi in 20 psi increments. The process appeared to work but at lower pressures an obvious delay between valve opening and decompression of the product indicating the product may be sticking to the wall of the vessel. The experiment was repeated but at 20% moisture but the lowest pressure possible was 200 psi as the vessel would plug below this level as well. The results of fibre analysis are shown in Figures 4, 4 and 6 below. NDF appears to increase with steam explosion treatment but a portion of the NDF fraction is highly insoluble protein and the content of this protein is increased with treatment as shown in figure 5. This is due to an increase in temperature with pressure as the two variables are directly related. Beyond 100 psi the effects on NDF did not follow a predictable pattern making it difficult to interpret these results.

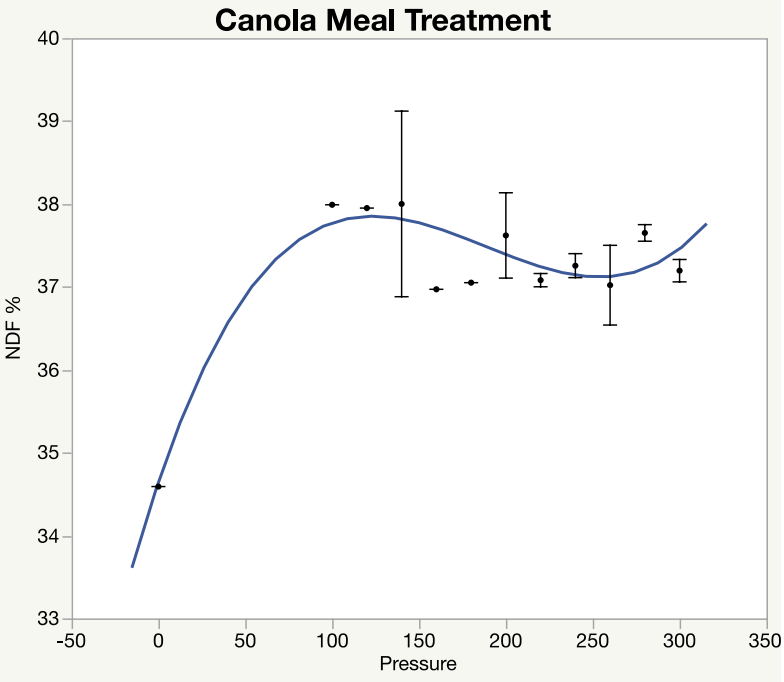

Figure 4. Effect of steam explosion treatment of solvent extracted canola meal with 30% added moisture for 5 minutes on NDF content (% DM)

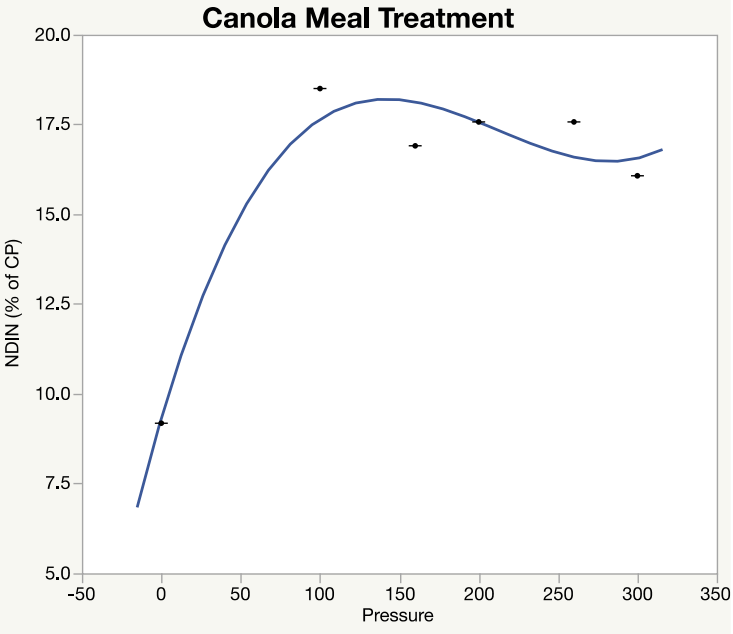

Figure 5. Effect of steam explosion treatment of solvent extracted canola meal with 30% added water for 5 minutes on NDIN (% of N) content

The effects of steam explosion treatment of canola meal on the content of ADF is shown in Figure 6 below. Similar to the NDF data, the values did not follow a predictable trend and made it difficult to predict the effects of steam explosion. It was hypothesized that one possible source of inconsistency could be cross contamination in the system. The unit is a closed system with the only accessible openings being the loading valve at the top of the reaction vessel and the exit for the product at the bottom of the cyclone. Initially it was assumed there was enough steam going through the system at the time of decompression that it would "flush" the system out. It was decided a lockable small access door should be installed in the top of the cyclone so it can be inspected and cleaned if necessary between treatments. It was immediately obvious that product was sticking to the walls of the cyclone and contaminating future treatment materials. A new protocol was devised where the cyclone is washed out with a pressure washer between treatments to prevent this cross-contamination issue.

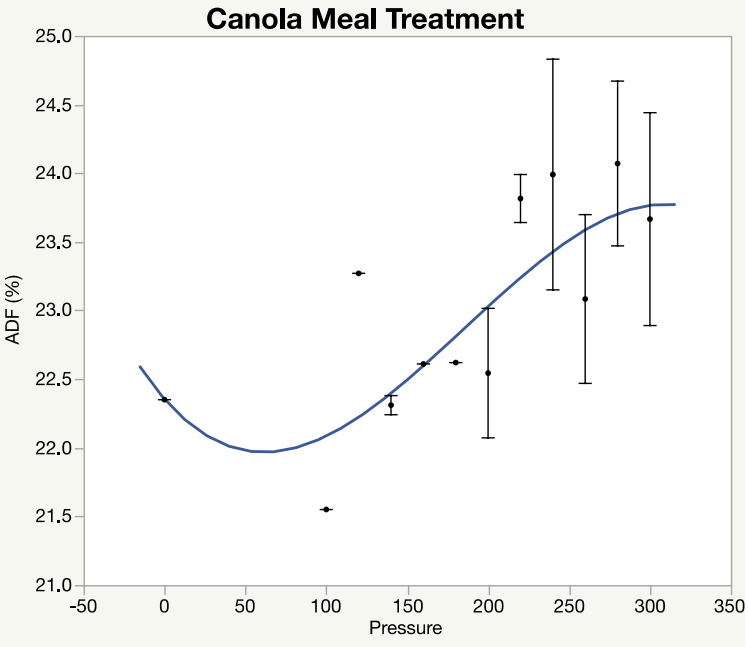

Figure 6. Effect of steam explosion treatment of solvent extracted canola meal with 30% added moisture for 5 minutes on ADF (% DM) content

It was also hypothesized that the other source of variation could be an issue with steam penetration and heat transfer in the system. The vessel has two ports for steam addition, one about ¼ way up the vessel and the other ¾ up from the bottom. The bottom quarter is funnel shaped as it narrows significantly at the bottom. It appears that dry product on the bottom below the valve packs down and does not get

properly heated by the steam but material above this entry point is vigorously mixed and interacts with steam during injection. Alternative methods of injecting steam were explored and it was decided to extend the steam inlet line inside the vessel down to approximately 4 cm above the outlet valve and pointing towards the valve. This system was used in later experiments and alleviated the plugging issue. It was hypothesized that increasing the moisture content of the meal would allow proper heat transfer so the last experiment was conducted with the product with relatively liquid consistency. Treatments consisted of 1.5, 2 and 2.5 X water to meal proportions (weight for weight basis) and treated for 4 minutes at 50, 100 and 150 psi. The effects of steam explosion of canola meal under higher moisture contents are shown in Figures 7 and 8 below. The NDF data is still confounded by the fact that NDF increases with temperature due to denaturation of protein while the content of this fibre fraction excluding protein may be declining. One of the primary targets of the process is to degrade hemi-cellulose and this is a key fraction found in NDF so alternative measures of effects on hemi-cellulose were examined and was the focus of the next stages of this project.

ADF content of canola meal appeared to be reduced at the highest added moisture content but the opposite trend was evident at the lowest moisture content, suggesting the hypothesis of lack of heat transfer and steam explosion at the bottom portion of the vessel may be an issue. This would suggest that the cellulose and lignin content of oilseed meals can be reduced by steam explosion but that the vessel must be designed differently than those used for high fibre crop residues.

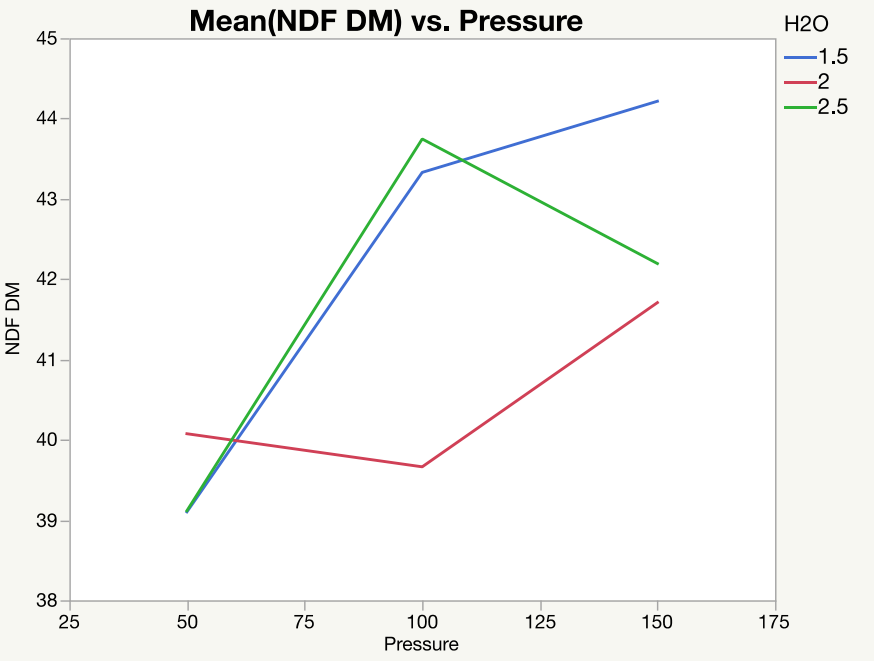

Figure 7. Effect of steam explosion treatment on solvent extracted canola meal with 1 to 2.5 X added water for 4 minutes on NDF (% DM)

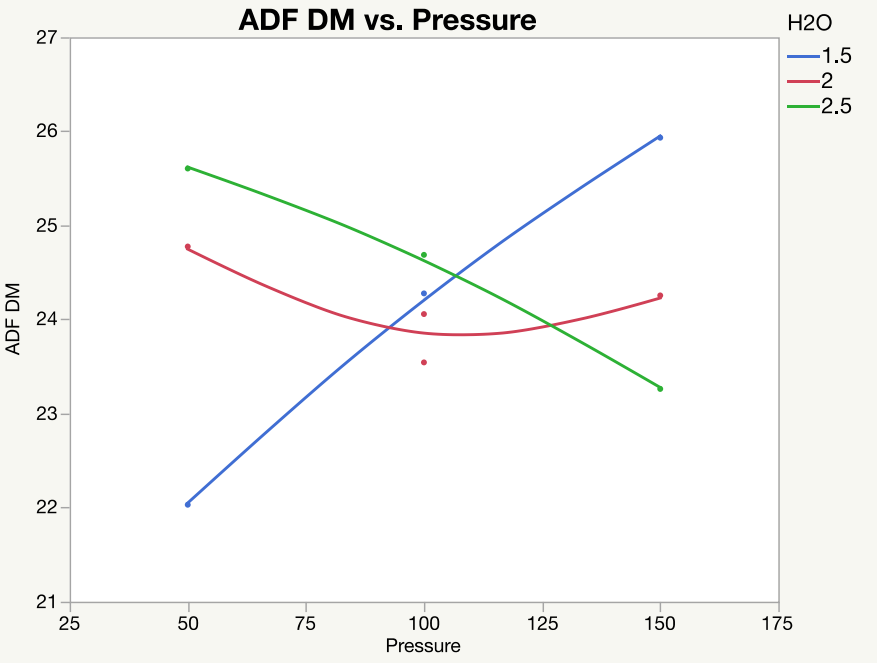

Figure 8. Effect of steam explosion treatment on solvent extracted canola meal with 1 to 2.5 X added water for 4 minutes on ADF (% DM)

In the initial stages of this research the focus was on treating solvent extracted canola meal but with the primary objective of modifying the fibre and minimizing the negative impacts on the protein and other nutrients in the product. Several attempts were made to modify fiber in canola meal using steam explosion. Several challenges were encountered with excess water absorption by protein being the most challenging. For steam explosion to work effectively, water must be absorbed into the fibre either during presoaking or while under pressure at high temperatures. Steam explosion of dry meal was not effective as the condensation of the steam while heating the product and pressurizing the vessel was not sufficient to hydrate the product and resulted in plugging at the outlet. Canola meal was then mixed with various amounts of water ranging from 1.5 to 3 g of water/g of meal. This created a very wet product that was difficult to handle and dry but in addition, the water was preferentially absorbed by the non-fibrous portions of the meal and little appeared to be absorbed by the fiber. As a result the fiber content was not altered by the process and protein quality as measured by Neutral Detergent Fibre Insoluble Nitrogen (NDIN) was diminished.

Steam Explosion of Whole Seed

The next step was to determine if steam explosion could be used on whole seed rather than meal. One of the challenges experienced was the high water holding capacity of the meal which we felt would prevent water absorption by the fibre and limit the impact of steam explosion. However, the most indigestible fiber on oilseeds such as canola and flax are in the outermost surface of the seed where water and steam would be able to interact. Therefore, it was hypothesized that steam treatment of whole seed prior to extraction might be an efficient way to increase the digestibility of the meal. It may have the added benefit of rupturing oil bodies and cell walls resulting in more efficient oil extraction. Whole canola seed was made up to 20% water and treated at 100, 200 and 300 psi for 5 minutes. The seed processed well with no obvious signs of adhering to the system or excessive water absorption during the process. Many of the hulls appears to dislodge from the seed and there appeared to be evidence of fiber modification. The effects of steam treatment of canola seed on NDF and ADF (% of Dry Matter) are shown in Figures 9 and 10, respectively. Based on this data it would appear that steam explosion significantly reduced NDF and ADF content of the seed, however the untreated seed appeared to have abnormally high levels of fibre and it is believed this is due to incomplete fat extraction during the fibre analysis. However, it is hypothesized that the steam explosion process ruptured the cell wall

cells of the seed and therefore enhanced the fat extraction process. Future studies incorporate an ether extract process following steam explosion to prevent any issue of fat interference in the assay. However, the results suggest that steam explosion prior to oilseed extraction may enhance oil extraction efficiency as well as nutritional value.

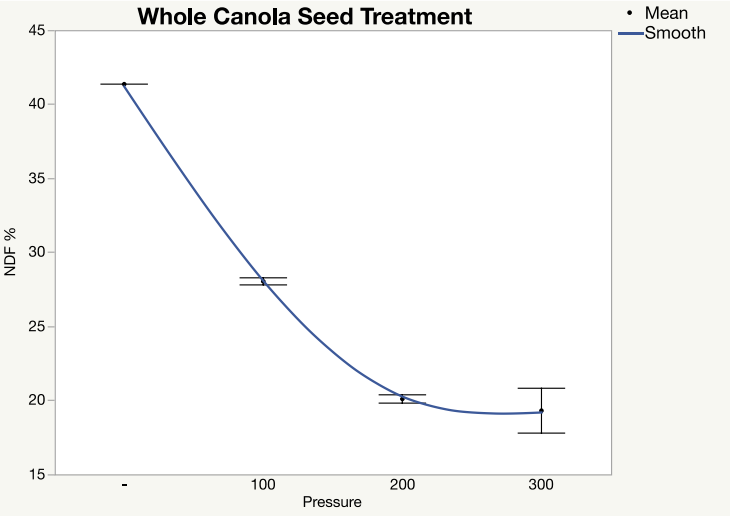

Figure 9. Effect of Steam Explosion of Canola Seed with 20% added moisture for 5 minutes on NDF (% DM)

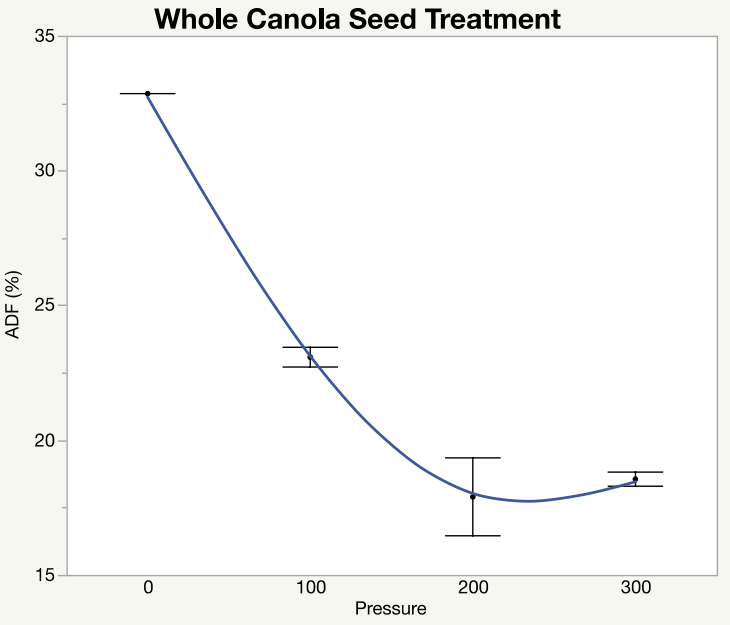

Figure 10. Effect of Steam Explosion Treatment of Canola Seed with 20% added moisture for 5 minutes on ADF (% DM)

Flax seed was also treated in a similar manner (100, 200 and 300 psi for 5 minutes) but the level of water used had to be increased to 30% due to the water absorption by the mucilage concentrated on the outer surface of the seed. Mixing 20% water with the seed resulted in thick mass that would not flow through the system effectively. There was clear visual evidence of dislodging of the hull and possibly changes to the fibre structure of the hull but mucilage created a sticky product that was difficult to handle and even clean up. The remaining experiments, we did not add additional water to the seed prior to steam explosion and this mitigated most of the issues with handling the flax seed. The effects of steam explosion of flax seed on NDF and ADF content are shown in figures 3 and 4, respectively. Similar to the results for Canola meal, it appears the fat in the seed may be interfering with the fibre analysis and may be overestimating the effect of steam explosion on fibre content of the seed.

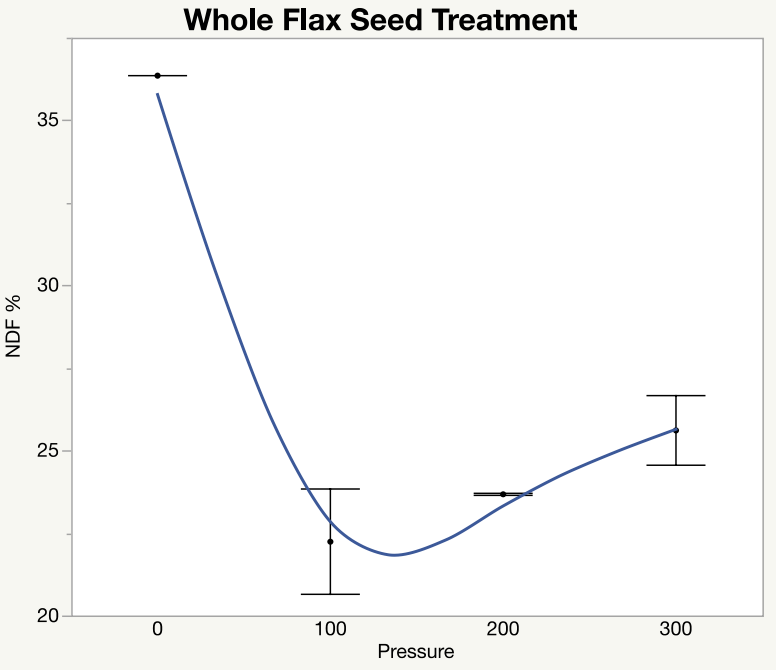

Figure 11. Effect of Steam Treatment of Flax Seed for 5 minutes at 30% added moisture on NDF (% DM) content

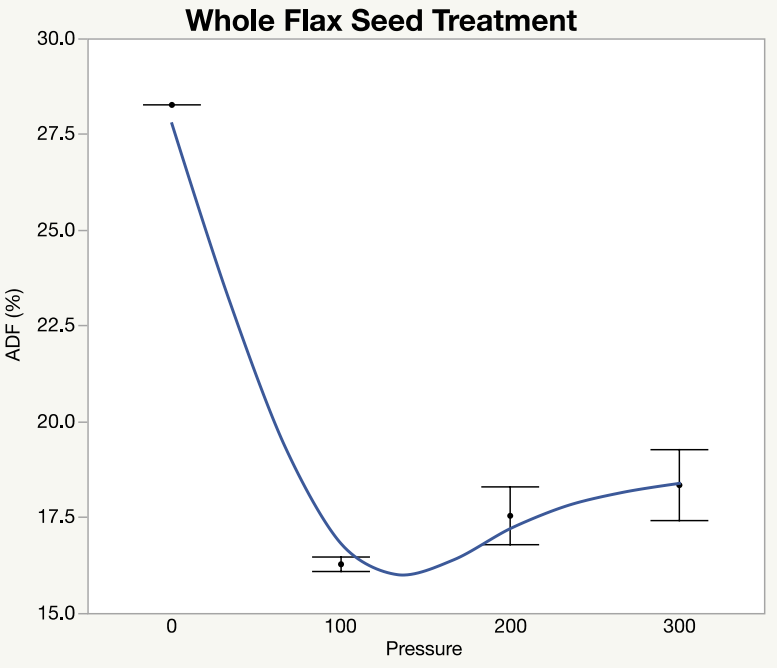

Figure 12. Effect of Steam Treatment of Flax seed for 5 minutes at 30% added moisture on ADF (% DM)

Steam Explosion of Whole Seed

This experimental consisted of treating 2 kg samples of canola seed in a 3x3 factorial, 3 different pressures (50, 100 and 150 PSI for 5 minutes) by 3 water levels (1.5, 2.0 and 2.5 times the seed content, soaked for 24 hours) (Table. 5).

Table 5. Steam explosion conditions used to treat whole seed and the resulting Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF) on a dry matter basis.

Product	H2O	Pressure	ADF DM	NDF DM
Canola seed – control untreated	0	0	22.3	34.6
Canola seed	1.5	50	22.0	39.1
Canola seed	1.5	100	24.3	43.3
Canola seed	1.5	150	25.9	44.2
Canola seed	2	50	24.8	40.1
Canola seed	2	100	24.1	38.7
Canola seed	2	150	24.3	41.7
Canola seed	2.5	50	25.6	39.1
Canola seed	2.5	100	24.7	43.7
Canola seed	2.5	150	23.3	42.2

Effect of Steam Explosion Pressures on Fibre Composition of Whole Canola Seed

The ADF and NDF content of soaked canola seed treated by steam explosion from 50 to 150 psi with 1.5 to 2.5: water to meal ratio is shown in Table 5. Steam explosion treatment had little impact on ADF and appeared to increase the NDF content of the seed, this was unexpected and may indicate the process is still damaging the protein reducing solubility of some fractions such that it remains in the NDF fraction similar to what was observed when treating canola meal. The ADF content was unaffected by steam explosion under these conditions. Canola hulls are highly lignified and it is possible that the maximum conditions tested where not sufficient to penetrate or modify this lignin. Visually the seeds appeared to unaffected by the process other than a portion of the hulls being dislodged from the seed by the process. Based on this information, a decision was made to switch focus to treating high fibre hull fractions so more extreme conditions can be used without fear of negatively affecting the protein quality in the seed.

Canola and Camelina Hulls

Since there was no reductions in fibre content when treating whole canola seed (Table 5), a decision was made to treat hull fractions which would have a higher surface area and reduce the proportion of the seed exposed to the treatments. To do this, a modified method of removing the hulls from whole seed was developed and used to produce high fibre fractions prior to steam explosion treatment. The seed cotyledons was separated from the hulls in both canola and flax seeds by passing them through a roller mill equipped with smooth rolls (Figure 13). The gap between the rolls was set to slightly less than the average thickness of the seeds to be processed and the product passed through the unit twice. For camelina, the gap was set at 0.015 mm and canola the gap was set at 0.03 mm. As the seeds passed through the rolls, it ruptures the hull releasing the cotyledons from within. The objective was to set the gap small enough to crack the hull but minimize damage to the cotyledons within. Some smaller seeds escaped cracking, those were separated during air fractionation and processed through the mill after the gap between the rolls was further reduced. Camelina seeds cracked easily and the hulls separated from the cotyledons, however the canola hulls appeared to adhere to the cotyledons and the hulls resisted cracking. To improve hull fracturing and reduce cotyledon adherence to hulls, the canola seed was dried using a fluidized bed dryer to 10% moisture at 70 C prior to rolling and fractionation. After drying, the canola hulls cracked and separated from the majority of the cotyledons. Flax seed proved more challenging as the thin flat shape of the seeds made it difficult to crack the seeds in the roll without grinding the entire seed into a powder.

Figure 13. A custom roller mill equipped with smooth roles used to crack Canola, camelina and flax seeds during dehulling.

The canola and camelina hulls are very light relative to the seeds and the cotyledons therefore it was decided to separate them using air fractionation. Initial testing was conducted in a small air fractionation unit located in the Engineering labs (Figure 14) and this proved highly effective (Figure 15) but too small for the purposes of this study but proved the principle. To create the larger quantities of hull fraction required for this research an ISM 10 Fractionating aspirator was rented locally (Figure 5) and the cracked seeds fed through the system with the feed gate set at position 1 and the airspeed set at 6% for camelina and 10% for canola hulls. This equipment effectively separated the lightest portion (mostly hulls) from the heaviest portions cotyledons (Figure 16) and seeds. The seeds were processed again as described. The hull fraction was further purified , through the use of a custom sieve which removed the majority of the remaining cotyledons from the hulls (Figure 17).

Figure 14. Small Carter Day laboratory air fractionator used for initial dehulling experiments.

Figure 15. Fraction of cracked camelina seed after fractionation on a Carter Day lab scale air fractionator.

Figure 16. ISM 10 Fractionating aspirator used to produce bulk of hulls for steam treatment.

Figure 17. Canola cotyledons and hull fractions after air fractionation.

Figure 18. Custom sieve box used to separate hulls from cotyledons following air fractionation.

Figure 19. Dehulled camelina and camelina hulls.

Steam Treatment of Canola Hulls

The effect of time and pressure during steam explosion on the ADF and NDF content of canola hulls was determined in 3 X 3 CRBD experiment with 3 pressures (160, 180 and 200 psi) X 3 times (2, 5 and 10 minutes) with each treatment replicated 3 times using 5 kg of hulls. The steam explosion system installed at the Canadian Feed Research Centre and used in this research is shown in Figure 9. A portion of the wet product from steam explosion process adhered to the walls of the cyclone, so a trap door was installed and used to access the unit for washing between samples using a pressure washer.

A representative sample was taken from each batch, oven dried and ground in a Retch grinder through a 1 mm screen prior to analysis for NDF and ADF using an Ankon fibre analysis system.

Based on data from the canola hull trial, it was decided to focus on pressure only for the camelina hulls and therefore the treatments applied were 160, 180 and 200 psi for 5 minutes, each treatment was replicated 3 times and the quantity of product was increased to 6 kg per run.

Digestibility Study in Broiler Chickens

A digestibility study using broiler chickens was conducted to determine the effect of steam explosion on digestibility of nutrients in the canola and camelina hull fractions as well as the cold pressed seed before and after dehulling. The initial study showed significant reductions in NDF in camelina hulls but the canola hulls showed little response. Therefore a decision was made to increase the severity of the treatments in an attempt to improve the hulls. The pressure was increased to 250 psi for all treatments. In addition, pre-treatments were added to further enhance the process, this included soaking in water or 3% NaOH solution (2.5:1 solution to hull ratio by weight) at room temperature for 24 hours prior to steam explosion. The presoaking resulted in very wet products following steam explosion and attempts were made to collect as much solid and liquid as possible prior to drying in a fluidized bed dryer set at 80 C. However, a portion of the soluble nutrients were likely lost in the handling and transfer. Unfortunately, due to the nature of the product which partially adhered to the wall of the cyclone and the loss of products in the large drying system, it was not possible to get a accurate mass balance on the process.

To determine the impact of dehulling on the digestibility of meals, the whole expelled meals and dehulled expeller meals were also included in the digestibility trial. The majority of the oil was extracted using a Komet CA-85 expeller press set at speed 3.5, with the external heating element on the barrel turned on to maximize oil extraction rate (Figure 10).

Figure 20. Expelling of dehulled camelina using a Lab scale Komet oilseed press.

The digestibility study in broiler chickens was conducted in the metabolic cages from 1 to 21 days using Ross 708 broiler chicks and all the environment was maintained in accordance with good animal care guidelines and within the recommendations of Avigen. From day 1 to 14 the animals were fed with a standard starter diet. From 15 to 21 days the birds were provided experimental diets. Water and feed were provided *ad libitum*. Titanium dioxide was added as a indigestible marker at 0.3% of the diet. The test ingredients were to be included in the diets at 6 and 12% inclusion levels. These levels were chosen as CFIA restricts the use of camelina to 12% in broiler diets. Canola hulls were included at the same levels so a single basal diet could be used in the trial. Unfortunately, there

was insufficient camelina hulls to include the steam explosion treatments at 6 and 12% so were only included at the latter level. A basal diet was also included which did had the same ingredients as the experimental diets minus the test ingredients, this will be used to calculate the digestibility of the test ingredients. The design was a 2x2x6 factorial, with 2 different seeds (canola and camelina), 2 inclusions (6 and 12%) and 6 different processes (Whole expelled seed, dehulled expelled seed, hulls not treated, hulls steam treated, hulls presoaked in water and treated, and hulls presoaked in NaOH and treated, Table 6).

Table 6. Dietary treatments in the broiler chicken digestibility study

Treatment number	Meal Type	Fraction	Product Name	Inclusion Level
1	Camelina	Expeller meal	CMEX	6
2	Camelina	Expeller meal	CMEX	12
3	Camelina	Dehulled expeller meal	CMDEX	6
4	Camelina	Dehulled expeller meal	CMDEX	12
6	Camelina	Hulls	CMH	12
8	Camelina	Exploded hulls	CMHEX	12
10	Camelina	Hulls soaked water exploded	CMHSOWEX	12
12	Camelina	Hulls soaked base exploded	CMHSOBEX	12
13	Canola	Expeller meal	CEX	6
14	Canola	Expeller meal	CEX	12
15	Canola	Dehulled expeller meal	CDEX	6
16	Canola	Dehulled expeller meal	CDEX	12
17	Canola	Hulls	CH	6
18	Canola	Hulls	CH	12
19	Canola	Exploded hulls	CHEX	6
20	Canola	Exploded hulls	CHEX	12
21	Canola	Hulls soaked water exploded	CHSOWEX	6
22	Canola	Hulls soaked water exploded	CHSOWEX	12
23	Canola	Hulls soaked base exploded	CHSOBEX	6
24	Canola	Hulls soaked base exploded	CHSOBEX	12

25	Basal	Basal	0

Fecal samples were collected on days 20 and 21 and dried and ground prior to analysis. Birds were dissected and organ weights and sizes determined on day 21. Digesta from the distal ileum was collected and pooled from every bird per replication within treatment and frozen. These samples will be analysed for amino acid digestibility if the fecal digestibility indicate significant improvements in protein digestibility.

Effect of Steam Explosion Pressures on Fibre Composition and pH of Canola Hulls

The effect of steam explosion at 160-200 psi from 2 to 10 minutes on NDF and ADF content is shown in Table 7. Similar to the affect in seed, NDF content of the hulls increased with treatment and ADF remained unaffected. The pH of the hulls were reduced by steam explosion, indicating that some of the hemicellulose may have been degraded to organic acids. Neither pressure or time affected the fibre content or the pH. Based on this information, it was decided to use higher pressures with addition pre-treatments to effectively delignify the canola hull prior for the digestibility study. The pressure was increased to 250 psi and two pre-treatments (soaking in water or 3% NaOH solution) for 24 hours prior to steam explosion in an attempt to soften or dissolve the lignin in the hull.

Table 7. Main effects of Steam Explosion at 0, 160, 180, 200 psi and 2, 5 and 10 minutes on Acid Detergent Fibre (ADF), Neutral Detergent Fibre (NDF), and NDIN of canola hulls.

Treatment	NDF (%)	ADF (%)
Control – untreated hulls	43.9	50.4
Pressure (psi)		
160	51.1	50.6
180	51.1	49.5
200	50.0	50.1
Time (min)		
2	50.7	49.8
5	50.8	49.7
10	49.6	50.7
SEM	1.3	0.9

Table 8 . Effects of Steam Explosion at 0, 160, 180, 200 psi for 2, 5 and 10 minutes on the pH of canola hulls.

Pressure (psi)	Time (Minutes)	pH
0	0	7.54
160	2	4.27
160	5	4.44
160	10	4.59
180	2	4.11
180	5	4.60
180	10	4.06
200	2	4.65
200	5	4.62
200	10	4.50

Effect of Steam Explosion and dehulling on the digestibility of canola and camelina hulls and seed by broiler chickens.

Table 11 shows the NDF content of the test ingredients examined in the broiler digestibility study. Steam explosion at 250 psi decreased the NDF content from 50.5 to 43.7 indicating the process was more successful than past attempts at lower pressures. Pre-treatments by either soaking or NaOH treatment appeared to increase the NDF content. Given the large quantities of water in the pretreated meals, the product was very wet after steam explosion and it was not possible to collect and dry all of the free liquid as some stuck to the wall of the cyclone and was washed out between batches. This likely resulted in a loss of nutrients that were solubilized by the pre-treatment and steam explosion combinations thereby making it appear NDF increased in the remaining fraction.

As expected the NDF content of camelina hulls was significantly reduced by steam treatment (Table 11) suggesting digestibility by broiler chickens should be improved. Similar to canola, pre-soaking in

water increased NDF content but to a lesser extent in camelina. This too may be due to loss of soluble materials during the collection and drying process following steam explosion.

Table 11. NDF content (% DM basis) of steam exploded hulls, hulled and dehulled expeller meals from camelina and canola tested in the broiler digestibility trial.

Seed type	Product	Treatment	NDF (% DM)
Canola	Hulls	Untreated	50.5
	Hulls	Steam explosion	43.7
	Hulls	Water + Steam explosion	49.5
	Hulls	NaOH + Steam exploded	55.6
	Expeller meal	Hulled	21.8
	Expeller meal	Dehulled	11.1
Camelina	Hulls	Untreated	68.0
	Hulls	Steam explosion	31.4
	Hulls	Water + Steam explosion	42.5
	Hulls	NaOH + Steam exploded	33.0
	Expeller meal	Hulled	21.7
	Expeller meal	Dehulled	15.9

Inclusion of steam exploded canola hulls in the diet at 6% inclusion level significantly reduced the AME, dry matter digestibility and Energy digestibility and tended to decrease it when included at 12% inclusion level (Table 12). Pre-treating with water and base tended to reverse some of the losses in digestibility but the difference was not statistically different. The reasons for a loss in drymatter and energy utilization after steam explosion is not apparent at this time. It may be possible that degradation products of lignin during the process impaired digestion. It is interesting that steam explosion caused the greatest reduction in NDF but also had the greatest negative impact on digestibility. Based on this evidence it would suggest significant modification of canola hulls by extreme hydrothermal treatments can have negative consequences on digestibility.

Table 12. Effect of treatments on the digestibility of diets containing canola hulls in broiler chickens of dry matter (DM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) and apparent metabolizable energy (AME) on a DM basis

Treatment	AME (kcal/kg)	Gross Energy	DM
	6% Inclusion		
Canola Hulls	3442[a]	71.6[a]	66.4[a]
Steam Exploded[a]	2631[b]	54.1[b]	45.2[b]
Steam Exploded + water[b]	3098[ab]	63.3[ab]	55.8[ab]
Steam Exploded + base[c]	3156[ab]	64.4[ab]	57.1[ab]
SEM	172	3.5	4.3
P Value	0.0313	0.0239	0.0237
	12% Inclusion		
Canola Hulls	3303	67.6	61.9
Steam Exploded[a]	3127	63.4	58.2
Steam Exploded + water[b]	3218	65.0	59.3
Steam Exploded + base[c]	3349	68.0	62.1
SEM	78.8	1.6	1.90
P Value	0.2428	0.1771	0.3909

Values in the same column with different letters are significantly different at P<0.05

[a]Hulls steam exploded at 250 PSI for five minuets

[b]Hulls soaked in water at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours

then steam exploded at 250 PSI for five minuets

[c]Hulls soaked in NaOH at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minuets

The Effect of Pressure During Steam Explosion Treatment on the Nutritional Value of Camelina Hulls

Chemical Composition of Camelina Hulls and Steam Exploded Camelina Hulls

The chemical composition of the camelina hulls treated by steam explosion at 160, 180, 200 PSI is presented in table 12. The untreated camelina hulls had an NDF and hemicellulose content of 79.39% and 49.07% respectively. These values decreased considerably to 42.47%, 40.26%, 40.42%, NDF and 9.21%, 6.86%, and 7.63%, hemicellulose after steam explosion at 160, 180, 200 PSI respectively. Additionally, steam explosion at 160, 180, and 200 PSI decreased the pH from the initial measurement of 9.46 to 4.16, 4.40, 4.12 respectively. The content of NDIN also decreased from 15.9% (69.2% CP) in the untreated camelina hulls to 8.32% (51.4% CP), 7.72% (47.65% CP), and 7.57% (46.73% CP), after steam explosion at 160, 180, 200 PSI respectively. The ADF content of the untreated camelina hulls was 30.32%, and after steam explosion at any of the tested pressures, the value increased to approximately 33%. Between the three steam explosion pressures tested (160, 180, 200 PSI) the resulting ADF, NDF, hemicellulose, NDIN, and pH values were similar, and that the NDF, hemicellulose, pH and NDIN decreased and ADF slightly increased.

Table 12. Effects of steam explosion at 0, 160, 180, 200 PSI on acid detergent fibre (ADF), neutral detergent fibre (NDF), neutral detergent indigestible nitrogen (NDIN), and pH of camelina hulls (As fed)

Treatment	Pressure (PSI)	ADF (%)	NDF (%)	Hemicellulose[b]	NDIN (%)	NDIN (%CP)	pH
None	0	30.32	79.39	49.07	15.9	69.23	9.46
Exploded[a]	160	33.26	42.47	9.21	8.32	51.36	4.16
Exploded	180	33.40	40.26	6.86	7.72	47.65	4.40
Exploded	200	32.79	40.42	7.63	7.57	46.73	4.12

[a]Steam exploded for 5 minutes

[b]Calculated by NDF-ADF

The Effect of Steam Explosion on The Nutrient Utilization of Camelina Hulls in Boiler Chickens

Analyzed nutrient composition of camelina experimental ingredients

The chemical composition varied significantly between ingredients (table 13). All of the ingredients except CMHSOBEX yielded gross energy above 5000 kcal/kg with CMHEX being the highest (5730.62 kcal/kg). Steam explosion increased the CP content in CMHEX and CMHSOWEX ingredient but slightly decreased it in the CMHSOBEX ingredient. Adding a pretreatment before steam explosion caused the ether extract content to decrease, but without the pretreatment and only steam explosion, the ether extract content increased, when compared to the CMH ingredient. The ether extract was considerably lower in the CMHSOBEX ingredient (10.29%) when compared to the other steam exploded ingredients (CMHEX: 22.48% and CMHSOWEX: 17.18%) and CMH ingredient (20.95%). The content of TDF and insoluble fibre in the steam exploded ingredients (CMHEX, CMHSOWEX, CMHSOBEX) was significantly higher than the CMH ingredient. Additionally, the content of soluble fibre was increased in the steam exploded ingredients that were pretreated (CMHSOWEX and CMHSOBEX) when compared to the CMH ingredient (11.63% and 15.17% vs 6.26% respectively). Conversely, steam explosion without a pre-treatment resulted in a decrease in soluble fibre (2.03% vs 6.26%). The steam exploded ingredients (CMHEX, CMHSOWEX, CMHSOBEX) were significantly decreased in NDF, with CMHEX and CMHSOBEX being the most reduced, yielding values that were decreased by over 50% when compared to the CMH ingredient. The ADF content also decreased after steam explosion with the greatest reduction in the CMHSOBEX ingredient. The CMHSOBEX ingredient contained 4.61% sodium, which was significantly higher than the other two steam exploded ingredients (CMHEX and CMHSOWEX) which contained 0.07%, and 0.22% respectively. The elevated sodium content indicates the sodium from the sodium hydroxide pre-treatment was retained during steam explosion.

Table 13. Analyzed nutrient composition of camelina experimental ingredients (DM basis)

	CMH[c]	CMHEX[d]	CMHSOWEX[e]	CMHSOBEX[f]
Gross energy (kcal/kg)	5291.23	5730.62	5347.59	4830.83
Dry matter	93.91	96.04	95.63	96.18
Crude protein	17.89	20.92	19.81	16.12
Ether extract	20.95	22.48	17.18	10.29
TDF[g]	45.22	60.21	72.59	68.22
Insoluble fibre	38.97	58.17	60.96	53.04
Soluble fibre	6.26	2.03	11.63	15.17
NDF[h]	68.04	31.35	42.51	33.01
ADF[i]	40.68	36.32	33.73	27.02
Calcium	0.44	0.54	0.55	0.31
Phosphorus	0.29	0.38	0.36	0.24
Potassium	1.06	1.29	1.15	0.89
Magnesium	0.22	0.27	0.27	0.10
Sodium	0.04	0.07	0.22	4.61
Copper (ppm)	14.16	17.04	19.69	4.47
Iron (ppm)	72.36	120.29	518.42	215.49
Zinc (ppm)	15.86	28.80	51.30	12.07
Manganese (ppm)	18.50	27.83	35.08	13.40

Values in the same column with different letters are significantly different at P<0.05

[c]Hulls

[d]Hulls steam exploded at 250 PSI for five minuets

[e]Hulls soaked in water at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minuets

[f]Hulls soaked in NaOH at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minuets

[g]Total dietary fibre

[h]Neutral detergent fibre

[i]Acid detergent fibre

Camelina Treatments on Performance of Broiler Chicks

Camelina treatments were analyzed on broiler performance for feed intake, body weight gain (BWG), and feed efficiency which is illustrated in table 13. The was no significant difference in feed intake and feed efficiency between the birds fed any of the diets. Additionally, there was also no significant difference in BWG between the CMHEX, and CMHSOWEX diets. However, the BWG of the birds consuming the CMH diet (396.32g) and the CMHEX diet (474.21g) was significantly different ($p<0.05$). Similarly, the birds fed the CMH diet had a numerically lower feed intake, and consequently, a less efficient feed conversion ratio than birds fed the CMHEX diet (645.55g vs 658.95g, feed intake, and 1.63 vs 1.39, feed efficiency).

Table 13. Overall effect of camelina treatments at 12% inclusion on the performance of broiler chicks (day 14-20 and 21)

Treatment	Feed Intake (g)		BWG (g)		Feed Efficiency (F:G)	
	Mean	Std Error	Mean	Std Error	Mean	Std Error
CMH[c]	645.55	17.36	396.32b	14.86	1.63	0.025
CMHEX[d]	658.95	17.36	474.21a	14.86	1.39	0.025
CMHSOWEX[e]	630.43	17.36	448.93ab	14.86	1.40	0.025
CMHSOBEX[f]	590.08	17.36	413.12b	14.86	1.43	0.025
Basal	637.42	30.17	484.77ab	25.83	1.31	0.044

Values in the same column with different letters are significantly different at $P<0.05$

[c]Hulls

[d]Hulls steam exploded at 250 PSI for five minuets

[e]Hulls soaked in water at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minuets

[f]Hulls soaked in NaOH at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minuets

Camelina Treatments on Organ Weights of Broiler Chicks

Camelina treatments were analyzed for their effects on organ weights in broiler chicks (table 14). The CMEX and CMDEX diets yielded numerically the smallest cecas when compared to the other treatments (CMH, CMHEX, CMHSOWEX, and CMHSOBEX). However, the cecas of the birds fed the CMHSOBEX diet was larger than the cecas of the birds fed the CMEX and CMDEX diets (0.44% of BW vs 0.33% of BW and 0.32% of BW, respectively, $p<0.05$). In contrast, there were no differences amongst any of the diets on gizzard and proventriculus weights.

Table 14. Overall effect of camelina treatments at 12% inclusion on organ weights related to body weight of broiler chicks (day 14-20 and 21)

Treatment	Proventriculus (% of BW)		Gizzard (% of BW)		Ceca (% of BW)	
	Mean	Std Error	Mean	Std Error	Mean	Std Error
CMH[c]	0.50	0.027	1.61	0.085	0.37ab	0.023
CMHEX[d]	0.49	0.027	1.73	0.085	0.36ab	0.023
CMHSOWEX[e]	0.48	0.027	1.70	0.085	0.40ab	0.023
CMHSOBEX[f]	0.53	0.027	1.69	0.085	0.44a	0.023

Values in the same column with different letters are significantly different at $P<0.05$

[c]Hulls

[d]Hulls steam exploded at 250 PSI for five minuets

[e]Hulls soaked in NaOH at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minuets

[f]Hulls soaked in NaOH at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minuets

Effect of Camelina Treatments on Digestibility in Broilers

The effects of camelina treatments on broiler fecal digestibility of DM, CP, NDF, ADF, and AME are presented in table 15. The AME varied considerably between each of the diets. The basal diet had the

highest AME being 3571.20 kcal/kg, the CMH diet had the lowest being 2523.20kcal/kg, and the steam exploded diets were intermediate. However, of the three steam exploded diets (CMHEX, CHMSOWEX, CMHSOBEX), the CMHSOBEX diet yielded the highest AME with a value of 3221.80 kcal/kg. The DM digestibility was the highest in the basal diet with a value of 69.91% and lowest in the CMH diet with a value of 49.04%, and the three steam exploded diets yielded a DM digestibility in-between them. Amongst the steam exploded diets, the DM digestibility was highest in the CMHSOBEX diet (61.46%). Similar to the results of the DM digestibility, The CP digestibility was the highest in the basal diet (68.59%), lowest in the CMH diet (55.90%) and the steam exploded diets were intermediate.

The NDF and ADF digestibility was unusual since most of the diets yielded negative values. However, both the NDF and ADF parameters followed similar trends to one another between each of the diets. The basal diet had the highest NDF and ADF digestibility of 33.23% and 39.40% respectively, and the CMH diet had the lowest NDF and ADF digestibility of -56.44% and -78.27% respectively. The NDF and ADF digestibility were improved after steam explosion, but most improved in the CMHSOBEX die when compared to the CMH diet (-22.60% vs -56.44%, NDF, respectively, and -29.29% vs -78.27% ADF, respectively).

Similar to the AME of the diets, the AME of the ingredients also varied significantly between the treatments, with some treatments yielding negative values. The CMHSOBEX ingredient yielded the highest AME with a value of 1574.60kcal/kg, and the CMH ingredient yielded the lowest AME with a value of -5162.20kcal/kg. The AME digestibility of the CMH, CMHEX, and CMHSOWEX ingredients were negative whereas, the CMEX, CMDEX, and CMHSOBEX ingredients yielded positive AME values. Furthermore, steam explosion at any of the treatments (CMHEX, CMHSOWEX, CMHSOBEX) significantly ($p<0.05$) improved the AME of the hull when compared to the CMH ingredient.

The *pri-priori* contrast test was performed on three comparisons: CMH vs CMHEX, CMH vs CMHEX, CMHSOWEX, and CMHSOBEX, and CMEX vs CMDEX. The test revealed the CMHEX diet had a higher AME and DM, CP, NDF, and ADF digestibility when compared to the CMH diet ($p<0.05$). Additionally, all of the steam exploded treatments (CMHEX, CMHSOWEX, CMHSOBEX) increased AME and DM, CP, NDF, and ADF digestibility when compared to the CMH diet ($p < 0.05$). It also revealed there were no differences between the CMEX and CMDEX diets on AME and DM, CP, NDF, and ADF digestibility.

Table 15. Effect of camelina treatments on broiler fecal digestibility of dry matter (DM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) and apparent metabolizable energy (AME) on a DM basis

	Diet (DM basis)					Ingredient (DM basis)
	Mean					
Treatment	AME (kcal/kg)	DM (%)	CP (%)	NDF (%)	ADF (%)	AME (kcal/kg)
Basal	3571.20a	69.91a	68.59a	33.23a	39.40a	
CMH[c]	2523.20d	49.04d	55.90b	-56.44d	-78.27c	-5162.20d
CMHEX[d]	3065.40bc	56.62bcd	62.57ab	-14.14b	-26.80b	-645.80bc
CMHSOWEX[e]	2958.60c	51.33cd	60.69ab	-44.83cd	-60.69c	-1533.00c
CMHSOBEX[f]	3331.80ab	61.46ab	60.98ab	-22.60bc	-29.29b	1574.60ab
Pooled P-value	0.0001	0.0001	0.0032	0.0001	0.0001	0.0001
Contrast P-value						
CMH vs CMHEX[g]	0.0001	0.0115	0.0264	0.0001	0.0001	0.0001
CMH vs CMHEX, CMHSOWEX, and CMHSOBEX[h]	0.0001	0.003	0.0247	0.0002	0.0001	0.0001
CMEX vs CMDEX[i]	0.5663	0.4555	0.3373	0.8279	0.8592	0.5634

Values in the same column with different letters are significantly different at P<0.05

[c]Hulls

[d]Hulls steam exploded at 250 PSI for five minuets

[e]Hulls soaked in water at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minuets

[f]Hulls soaked in NaOH at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minuets

[g]Hulls versus hulls steam exploded at 250 PSI for five minuets

[h]Hulls versus hulls steam exploded at 250 PSI for five minutes, hulls soaked in water at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours
then steam exploded at 250 PSI for five minutes, and hulls soaked in NaOH at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours
then steam exploded at 250 PSI for five minuets

Discussion

Effect of Steam Explosion Pressures on Fibre Composition of the Camelina Hull

The chemical contents of the camelina hulls after steam explosion in the present study were comparable to studies that observed steam explosion effects on other fibrous material such as corn stover (Gutiérrezt et al. 2012) and wheat straw (He et al. 2015). The camelina hull is extremely fibrous which makes it highly resistant to digestion in a monogastric diet. Steam explosion can alter the structure of the biomass within the hull as well as the chemical composition (Sarkar et al. 2012). The results of this study show that steam explosion at 160, 180, or 200 PSI for five minutes can significantly change the chemical composition of the camelina hull. The most notable change, being the decrease in NDF and hemicellulose. The decrease in NDF and hemicellulose observed in this experiment is similar to those observed by Gutiérrezt et al. (2012), He et al. (2015), and (Kim et al. 2005) in other fibrous material treated by steam explosion. The degradation of hemicellulose was also observed in the study by Li et al. (2015), which explained the substantial decrease to be a result of the fibrous structure degrading and releasing hemicellulose, resulting in hemicellulose hydrolysis into oligosaccharides disaccharides, monosaccharides and organic acids (Kim et al. 2005). The decrease in pH after steam explosion also indicates hemicellulose hydrolysis into organic acids. Gutiérrezt et al. (2012) explain that during the steam explosion process, hemicellulose is degraded and acetyl groups attached to xylose are released and converted to acetic acid (Gutiérrezt et al. 2012). This study did not look at how much organic acids formed, but Iroba (2014) explains that the longer the retention time, the more hemicellulose hydrolysis, thus organic acid formation. However, too long of a retention time could induce the undesired formation of inhibitory substances like furfurals from the cellulose and hemicellulose polymers (Iroba 2014). In addition to the decrease in NDF, hemicellulose, and pH observed after steam explosion, there was also a significant decrease in NDIN. It is unusual that the content of NDIN after steam explosion had

decreased since thermal processing typically denatures and insolubilizes proteins, which should increase the content of NDIN. However, the decrease suggests there was protein encapsulated in the hull fibre, and steam explosion was able to release some of that protein.

Table 16. Effects of steam explosion at 0, 160, 180, 200 PSI for 5 min on acid ADF, NDF, NDIN, CP and pH of camelina hulls (DM basis).

Pressure (PSI)	ADF (%)	NDF (%)	Hemicellulose[1]	NDIN (%)	CP (%)	NDIN[2] (% CP)	pH
0	30.3	79.4	49.1	15.9	17.9	88.9	9.46
160	33.3	42.5	9.21	8.32	19.0	43.9	4.16
180	33.4	40.3	6.86	7.72	20.5	37.6	4.40
200	32.8	40.4	7.63	7.57	20.0	37.9	4.12

[1]Calculated by NDF-ADF.

[2] Calculated by (NDIN/CP)*100.

Table 17. Diet composition for camelina hull digestibility study

Ingredients and chemical composition of starter and experimental diets (as fed).

	Starter	Basal	Camelina
Ingredients (%):			
Corn grain ground	55.8	58.2	51.2
SBM-50% wo hull sol	37.7	33.9	29.9
DiCalcium Phosphate	1.78	1.90	1.67
Calcium Carbonate	1.18	1.59	1.40
Canola Oil	2.00	2.27	2.00
Poultry Vit/Min Pre- Mix[1]	0.50	0.57	0.50
Salt (Sodium Chloride)	0.34	0.50	0.44
Titanium oxide (TiO_2)	-	0.34	0.30
dI-Methionine	0.34	0.32	0.28
Lysine HCl	0.24	0.23	0.20
Choline Chloride	-	0.11	0.10
L- Threonine	0.11	0.09	0.08
Camelina test ingredient	0	0	12
Calculated composition (%):			
Metabolic Energy (Kcal/kg)	3000	3011	2796
Crude Protein	24.1	22.4	21.5
Ether Extract	4.36	4.66	6.51
Crude fiber	2.53	2.46	2.17
Calcium	0.96	1.14	1.00
Available Phosphorus	0.48	0.49	0.44
Methionine + Cystine	1.09	1.02	0.90

[1]Supplied per kilogram of feed: vitamin A, 2,200,000 IU; vitamin D, 440,000 IU; vitamin E, 6,000 IU; menadione, 400 mg; thiamine, 300 mg; riboflavin, 1,200 mg; pyridoxine, 800 mg; vitamin B12, 4 mg; niacin, 12,000 mg; pantothenic acid, 2,000 mg; folic acid, 120 mg; biotin, 30 mg, copper, 2,000 mg; iron, 16,000 mg;manganese, 16,000 mg; iodine, 160 mg; zinc, 16,000 mg; selenium, 60 mg; calcium carbonate, 100,000 mg; antioxidant, 125 mg; wheat midds, 754,546.

Table 18. Analyzed nutrient composition of camelina experimental ingredients (DM basis).

Nutrient composition (% as fed)	Camelina Ingredient			
	Hulls[1]	Exploded hulls[2]	Water treatment[3]	NaOH treatment[4]
Gross energy (kcal/kg)	5291	5731	5348	4831
Dry matter	93.9	96.0	95.6	96.2
Crude protein	17.9	20.9	19.8	16.1
Ether extract	21.0	22.5	17.2	10.3
TDF	45.2	60.2	72.6	68.2
Insoluble fibre	39.0	58.2	61.0	53.0
Soluble fibre	6.26	2.03	11.6	15.2
NDF	68.0	31.4	42.5	33.0
ADF	40.7	36.3	33.7	27.0
Calcium	0.44	0.54	0.55	0.31
Phosphorus	0.29	0.38	0.36	0.24
Potassium	1.06	1.29	1.15	0.89
Magnesium	0.22	0.27	0.27	0.10
Sodium	0.04	0.07	0.22	4.61
Copper (ppm)	14.2	17.0	19.7	4.47
Iron (ppm)	72.4	120	518	216
Zinc (ppm)	15.9	28.8	51.3	12.1
Manganese (ppm)	18.5	27.8	35.1	13.4

[1]Hulls.

[2]Hulls steam exploded at 250 PSI for five minutes.

[3]Hulls soaked in water at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minutes.

[4]Hulls soaked in NaOH at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minutes.

Table 19. Overall effect of camelina treatments at 12% inclusion on the FI, BWG and FCR of broiler chicks (day 14-20 and 21).

Treatment	FI (g)		BWG (g)		FCR	
	Mean	Std Error	Mean	Std Error	Mean	Std Error
Basal	637	29.2	485[a]	21.4	1.31[c]	0.019
Hulls[a]	646	29.2	396[a]	21.4	1.63[a]	0.019
Exploded hulls[b]	659	29.2	474.2[a]	21.4	1.39[bc]	0.019
Water treatment[c]	630	29.2	448.9[a]	21.4	1.40[b]	0.019
NaOH treatment[d]	590	29.2	413.1[a]	21.4	1.43[b]	0.019
P Value	0.545		0.036		<0.0001	

[a-c] Means within a column with uncommon superscripts differ significantly ($P \leq 0.05$).

[1] Hulls.

[2] Hulls steam exploded at 250 PSI for five minutes.

[3] Hulls soaked in water at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minutes.

[4] Hulls soaked in NaOH at 2.5:1 ratio by weight (solution : product) and soaked for 24 hours then steam exploded at 250 PSI for five minutes.

Table 20. Effect of camelina treatments at 12% inclusion on proventriculus, gizzard and ceca weights as a percentage of bird weight (day 14-20 and 21).

Treatment	Proventriculus (% of BW)		Gizzard (% of BW)		Ceca (% of BW)	
	Mean	Std Error	Mean	Std Error	Mean	Std Error
Hulls[1]	0.50	0.025	1.61	0.079	0.37	0.024
Exploded hulls[2]	0.49	0.025	1.73	0.079	0.36	0.024
Water treatment[3]	0.48	0.025	1.70	0.079	0.40	0.024
NaOH treatment[4]	0.53	0.025	1.69	0.079	0.44	0.024
P Value	0.529		0.736		0.092	

[ab] Means within a column with uncommon superscripts differ significantly ($P \leq 0.05$).

[1] Hulls.

[2] Hulls steam exploded at 250 PSI for five minutes.

[3] Hulls soaked in water at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minutes.

[4] Hulls soaked in NaOH at 2.5:1 ratio by weight (solution : product) and soaked for 24 hours then steam exploded at 250 PSI for five minutes.

Table 21. Effect of camelina treatments on broiler fecal digestibility of DM, CP, NDF, ADF and AME (DM basis).

Treatment	Diet (DM basis)					Ingredient (DM basis)
	AME (kcal/kg)	DM (%)	CP (%)	NDF (%)	ADF (%)	AME (kcal/kg)
Basal	3571[a]	69.9[a]	68.6[a]	33.2[a]	39.4[a]	3354[a]
Hulls[1]	2523[c]	49.0[d]	55.9[b]	-56.4[d]	-78.3[c]	-5162[c]
Exploded hulls[2]	3065[b]	56.6[bcd]	62.57[ab]	-14.1[b]	-26.8[b]	-646[b]
Water treatment[3]	2959[b]	51.3[cd]	60.7[ab]	-44.8[cd]	-60.7[c]	-1533[b]
NaOH treatment[4]	3332[ab]	61.5[ab]	61.0[ab]	-22.6[bc]	-29.3[b]	1575[ab]
Pooled P-value	<0.0001	<0.0001	0.001	<0.0001	<0.0001	<0.0001
Contrast P-value						
Hulls vs Steam exploded	0.0001	0.012	0.026	0.0001	0.0001	0.0001
Hulls vs Steam exploded, Water treatment, and NaOH treatment	0.0001	0.003	0.025	0.0002	0.0001	0.0001

[a-d] Means within a column with uncommon superscripts differ significantly ($P \leq 0.05$).

[1] Hulls.

[2] Hulls steam exploded at 250 PSI for five minutes.

[3] Hulls soaked in water at 2.5:1 ratio by weight (solution: product) and soaked for 24 hours then steam exploded at 250 PSI for five minutes.

[4]Hulls soaked in NaOH at 2.5:1 ratio by weight (solution : product) and soaked for 24 hours then steam exploded at 250 PSI for five minutes.

Steam explosion at any of the pressures tested resulted in a slight increase in ADF. He et al. (2015) reported an increase in ADF after steam explosion at 2.0 Mpa (approximately 250 PSI) in wheat straw and rice straw, but a decrease in corn straw. They explained that steam explosion of corn straw

could decrease its content of cellulose by breaking the lignocellulosic complex causing the cellulose, hemicellulose, and lignin matrix to depolymerize. The study by Kim et al. (2005) looked at the effects of steam explosion at various pressures on the chemical composition of rice straw. The content of ADF decreased at 12 kgf cm^{-2} (approximately 170 PSI), but increased linearly at 16 kgf cm^{-2}, 20 kgf cm^{-2}, 24 kgf cm^{-2}, and 28 kgf cm^{-2} (approximately 227, 228, 341, 398 PSI respectively). The findings in both studies suggest that steam explosion pressure plays a key role in the resulting chemical composition and that the higher the pressure, the more ADF created. Also, the higher pressures may enhance chemical reactions involving soluble carbohydrates, proteins, and phenolics which can contribute to the increase in acid detergent lignin (ADL) and consequently ADF (Kim et al. 2005). It may be that in this study, the pressures tested were high enough to cause the proposed mechanism to occur, thus explaining the increased ADF content after steam explosion. It is also possible that as the hemicellulose hydrolyzed, the proportion of cellulose increased (Kim et al. 2005) or that steam explosion increased the solubility of some of the constituents which were lost in the liquid created during processing resulting in increased ADF content.

Analyzed nutrient composition of camelina experimental ingredients

The gross energy and ether extract content was lower, and the sodium content was higher in the CMHSOBEX ingredient when compared to the other two steam exploded ingredients. These results indicate that saponification likely occurred when the presoaked sodium hydroxide hulls were steam exploded. Saponification is the process where triglycerides react with NaOH to produce soap (Theodorou et al. 2007). Either the soap was lost to the walls of the cyclone after steam explosion, and it was not recovered, or the ether extract content of the CHMHSOBEX ingredient was underestimated since soap not well extracted during the ether extract assay, which would explain the low ether extract value observed. After steam explosion, the NDF content of the CMHEX and CMHSOBEX ingredients had decreased more than the CMHSOWEX ingredient. Since the product was soaked in water before steam explosion the material being steam exploded was very saturated and gelatinous due to the mucilage surrounding the hull. The mucilage substance likely hindered the saturated steam from fully penetrating the biomass in the reactor; therefore, not all of the fibrous structure was degraded, and some of the hemicelluloses remained intact. Alkaline pretreatment such as NaOH is an identified mechanism to turn the lignocellulosic biomass into reducing sugars (Loow et al. 2016) and using it in combination with steam explosion was thought to enhance the breakdown of the lignocellulosic matrix and increase

hemicellulose hydrolysis. However, there was no difference in NDF content between CMHEX and CMHSOBEX, which is likely due to the mucilaginous substance created when soaking the hulls in the NaOH and its adverse effect on steam penetration. The content of ADF was significantly lower in the CMHSOBEX ingredient indicating the NaOH was able to break down the cellulose or lignin more than steam explosion on its own. It is more likely that the lignin was degraded in the process as cellulose is normally preserved in alkaline pretreatment (Chen et al. 2013) and lignin is known to be solubilized by it (Silva et al. 2018). However, looking into the content of cellulose and lignin before and after steam explosion would provide useful insight into which constituent was primarily affected by an alkaline pretreatment.

Steam explosion of camelina hulls decreased soluble fibre, but steam explosion of camelina hulls soaked in water or NaOH increased soluble fibre. The presoaking before steam explosion may be the reason for the increase in soluble fibre. When the camelina hulls were saturated by either water or NaOH, a thick gel formed. The gel was a result of the saturation of the mucilage on the hulls, which may have been more stable and less affected by steam explosion explaining the increase in soluble fibre content observed in both soaked ingredients. The content of Insoluble fibre increased in all of the steam exploded ingredients, which is likely the result of a combination of events. After steam explosion, some material was lost to the edges of the cyclone as well as during handling, and if the majority of the material that was lost was soluble fibre, then the remaining material would be more concentrated in insoluble fibre. Secondly, the resulting product after steam explosion was hard to filter because of the mucilage gel which likely yielded in inaccurate TDF analysis results. Although the TDF results are interesting, since there was such difficulty filtering the product, there can only be speculation as to why TDF, insoluble fibre, and soluble fibre content increased after steam explosion. Conversely, the study by Huffman (2003) noted a significant increase in cellulose after the steam explosion of straw at 220°C (approximately 140 PSI) which may correspond to the substantial increase in insoluble fibre after steam explosion observed in this study. However, the study did not mention the mechanism behind the increase. Viewing the material after steam explosion under a scanning electron microscope may provide more insight into what physical changes happen to the cellulose, hemicellulose and lignin fractions after steam explosion, therefore providing more support for the analyzed TDF values.

Camelina Treatments on Performance of Broiler Chicks

The birds that consumed the CMHEX diet had a higher BWG than the birds consuming the CMH diet. The increased gain is likely a result of increased feed consumption and digestibility. Steam explosion likely enhanced the palatability, possibly by deactivating the glucosinolates, of the ingredient and the birds were more inclined to eat it. Glucosinolates are unpalatable and have been reported to decrease feed intake (Acamovic et al. 1999). They are also heat-liable; therefore, at high enough temperatures they may be inactivated (Gu et al. 2011), which likely happened as an outcome of steam explosion. Also, the birds that consumed the CMHEX diet had a higher BWG than the birds consuming the CMHSOBEX diet. In addition, the birds that consumed the CMHSOBEX diet also ate less than the birds consuming the CMHEX diet. The chemical analysis of the CMHSOBEX ingredient (refer to table 4.2) revealed it was very high in sodium. Also, the birds that consumed the CMHSOBEX diet exhibited watery feces. Taking both factors into consideration, it is likely those birds were experiencing a mild form of salt toxicity (Porter 2018), which probably decreased their feed intake thus body weight gain.

In a poultry diet, dietary fibre is considered a diluent that at high enough quantities can have negative repercussions on feed intake and nutrient digestibility (Mateos et al. 2012), which may also explain the reduced BWG, feed intake and feed conversion ratio from the birds consuming the untreated hull diet (CMH). However, adding steam explosion treatment with and without pretreatment was able to improve the feed intake, BWG, and feed efficiency ratio. The improvement in bird performance when compared to the birds fed the CHM diet, indicates steam explosion was an effective method to break down the camelina hull fibre and release encapsulated nutrients and make them digestible to the bird.

Camelina Treatments on Organ Weights of Broiler Chicks

The ceca in the birds consuming the CMHSOBEX diet was significantly bigger than the birds consuming CMEX and CMDEX diets and numerically larger than the cecas of the birds consuming the other steam exploded diets. Ceca size would be largest in a diet that increases fermentation. Since the CMHSOBEX diet yield the largest ceca, this indicates it had more small or soluble indigestible components that could enter the ceca and be fermented. Hulls have significantly more indigestible fibre than the expeller meals, so a larger ceca was expected. The size of the ceca was numerically larger in all of the treatments involving hulls when compared to the two expeller meal treatments, but only the CMHSOBEX treatment was statistically significant ($p<0.05$). The sodium hydroxide treatment likely solubilized or aided in the

degradation of the hull during steam explosion resulting in more fermentable material entering the ceca than the other treatments. Increasing fermentation in broilers may be advantageous as recent research has outlined the inclusion of moderate amounts of fibre to be beneficial for improving digestive organ development (Mateos et al. 2012).

Effect of Camelina Treatments on Broiler Fecal Digestibility

The basal diet yielded the highest AME, and DM, CP, NDF, and ADF digestibility between all of the treatments. It was expected that the addition of camelina, especially the hulls which are highly fibrous to the diet, would reduce the amount of available energy and digestibility of a corn-soybean diet, which is highly digestible. The AME was the lowest in the CMH diet and negative in the CMH ingredient. The negative AME value of the CMH ingredient indicates that not only are the hulls not digestible, but the hulls are impairing the digestion of other nutrients in the diet. This antinutritional effect may be a result of the mucilage that surrounds the hull. Wet mucilage forms a viscous substance that is likely encapsulating the nutrients that are inside the hull as well as other nearby nutrients that are coming from other sources in the diet, thus inhibiting their absorption by the bird. However, steam explosion with and without pretreatment improved the AME of the diets as well as the AME of the ingredients. The improvement indicates steam explosion has a positive effect on reducing the antinutritional effect observed with the CMH ingredient. It is possible that steam explosion is removing some of the mucilage surrounding the hull and reducing its negative impact on the absorption of other nutrients in the diet. Of the steam exploded diets, the CMHSOBEX diet had the highest AME. In addition, the AME of the CMHSOBEX ingredient was no longer a negative value. This indicates that a portion of the hulls became digestible and that the hulls were no longer affecting the nutrient absorption of other sources in the diet. It is possible that the NaOH was able to neutralize the agent within the hulls causing the antinutritional effect, or that the agent was washed out through saponification. It is also possible that if the antinutritional effect of the hulls was a result of mucilage, the NaOH treatment was able to breakdown/remove all of the mucilage. Between the two expeller meals, the AME was slightly higher in the CMDEX diet when compared to the CMEX diet. This is expected since dehulling removed the majority of the hull and fibre components yielding a meal that was high in energy and protein and low in fibre.

The CP digestibility was the highest in the basal diet and adding any of the camelina treatments to the diet had reduced the CP digestibility. The study by Aziza et al. (2013) reported a decreased in CP

digestibility after incorporating 10% camelina meal which agrees with this study where a decrease in CP digestibility was seen with the inclusion of 12% camelina meal. Glucosinolates and other antinutritional factors present in camelina such as NSPs and phenolic compounds (phenolic acids and tannins) have been identified to decrease CP digestibility since they can react with proteins, enzymes, or essential amino acids and form complexes that negatively affect digestibility and nutrient utilization by poultry (Aziza et al. 2013). The trypsin inhibitors in camelina may also explain the decrease in CP digestibility. The CMH diet was the lowest in CP digestibility; however, treating the hulls with steam explosion increased CP digestibility. It is possible that the hull fibre was preventing the protein inside the hulls from being accessed by the bird, and by treating the hulls with steam explosion, it broke down some of the fibre and released encapsulated nutrients. It is also possible that since trypsin inhibitors are heat labile (Avilés-Gaxiola et al. 2018), they were inactivated by steam explosion, which would explain the increase in CP digestibility in the steam exploded diets.

The NDF and ADF digestibility were the highest in the basal which indicates the basal diet was highly fermentable. Oddly, the ADF digestibility of the basal diet was nearly 40%, which is unusual for poultry species since they have limited fermenting ability which is why the ADF digestibility is typically assumed to be zero. Adding any camelina treatments to the diet impaired digestibility of the fibre and prevented fermentation specifically in treatments containing hulls. The NDF and ADF analysis may have been affected by the presence of mucilage, which hindered the fibre washing, making it appear there were more NDF and ADF than there was. Since steam explosion likely reduced the mucilage content, the analysis of those diets was probably less affected. It may also be possible that the camelina hulls have antimicrobial properties which would explain why it's inclusion into the diet greatly impedes fermentation. The study by Dai et al. (2017) identified the potential antimicrobial activity of camelina seed on ruminal bacterial community composition, and that it increased propionate-producing bacteria, suppressed ruminal bacteria associated in biohydrogenation, and decrease cellulolytic bacteria. More research into the potential antimicrobial effects of the camelina seed and hull and its regard to what microbes it may be restricting would provide more insight into hindered NDF and ADF digestibility observed in this study.

Conclusion and Recommendations Camelina Hull Processing

The inclusion of camelina by any treatment into the broiler diet reduced AME and DM, CP, NDF, and ADF digestibility when compared to the basal diet. The addition of hulls impaired energy utilization and

digestibility the most meanwhile, steam explosion was able to improve it. Steam explosion was able to improve the nutrient composition of the camelina hull primarily by reducing the hemicellulose fraction. The NaOH pretreatment before steam explosion was the most effective treatment at breaking down the lignocellulosic biomass when compared to the other steam exploded treatments. The CMHSOBEX ingredient was significantly decreased in NDF and ADF, and the CMHSOBEX diet increased the fecal AME and DM digestibility when compared to the other steam exploded diets.

The nutrient composition of the CMDEX diet was slightly better than the CMEX diet since it was lower in fibre and higher in gross energy and CP. However, there was no statistical difference between the CMEX and CMDEX diets on AME and fecal digestibility of DN, CP, NDF, and ADF.

The camelina seed mucilage proved to be a challenge through the analysis portion of this project which is why it would be valuable to look at preprocessing techniques to reduce the mucilage content. Steam explosion proved to be an effective mechanism to reduce some of the camelina fibre; however, it can be expensive. A similar mechanism to steam explosion is a steam conditioner, which is often used in pelleting. Research into different steam conditioning pressures at different retention times on camelina fibre may be beneficial as this process may be more practical and as effective as steam explosion at reducing fibre. A longer bird trial may also be beneficial to assess the effects of feeding broilers camelina better. In this study, the birds fed camelina products appeared to be eating and gaining equal to, or more than the basal diet fed birds. However, fecal digestibility analysis suggests negative digestibility impacts of camelina, which may have been seen if the birds were fed the experimental diets longer. Additionally, since antibiotic use for livestock in Canada requires a prescription from a veterinarian, it would be beneficial to find an effective alternative that does not require veterinary intervention. For that reason, research into the possible antimicrobial effects of camelina seeds and hulls on fermentation may also be beneficial.

Impact of dehulling canola and camelina on energy utilization and digestibility of meals in broiler diets

Camelina and canola are oilseed crops that are members of the Brassicaceae family (Acamovic 1999). Brassica crops are known for their high oil content and protein-rich meal (Ussetti Mohottalalage 2016). A disadvantage of brassica crops is their high fibre content, mucilage and antinutritional compounds such as glucosinolates (Acamovic 1999). Camelina and canola meal both contain approximately 12% crude fibre (Pekel et al. 2015; Canola Council 2009). Poultry have limited enzymes that can degrade fibre; therefore, the dietary fibre remains indigestible and cannot be used for energy (Sinha et al. 2011). For that reason, adding fibre to poultry diets will reduce the apparent digestibility, thus having negative impacts on growth (Sinha et al. 2011). The high fibre content of camelina and canola meal is due to the presence of the hulls that are included in the meal (Yuan 2014). The hull contains the major insoluble fibre fractions as well as mucilage (Ussetti Mohottalalage 2016; Ding 2015). Since the fibre cannot be broken down, that portion remains indigestible and cannot be used for energy (Sinha et al. 2011). The mucilage in camelina results in a gel that coats the seed as it passes through the body, preventing the absorption of nutrients that are encapsulated in the seed (Rajapakse 2015). When these crops are incorporated in broiler diets, the high content of mucilage can increase the amount of stool and absorption of water, thus affecting nutrient absorption (Rajapakse 2015; and Duranti 2012). Removal of the seed hull removes the majority of the fibre, which is expected to improve the value of the seed meal and the nutritional value in animal feed (Yuan 2014). Therefore, this study was conducted to determine if dehulling canola and camelina improves the digestibility and energy utilization of the meal in broiler diets.

MATERIALS AND METHODS

All experimental procedures were approved by the University of Saskatchewan Animal Ethics Board and conducted in accordance with the guidelines set by the Canadian Council on Animal Care. Ingredient processing and diet formulation were conducted at the Canadian Feed Research Centre (North Battleford, SK). Canola and camelina seeds were used for this study. The camelina seed (variety Midas) was obtained from Landis producer Co-op Ltd, located in Landis, SK and the canola seed (Liberty Canola L157H) was sourced from a farm near North Battleford, SK. Whole and dehulled expeller meal were generated from both the camelina and canola. The seeds were passed through a reduction roller mill (diameter 10", length 6", differential speed ration 2:1, roll weight 50 kg, 0.015 mm (camelina) and 0.8 mm (canola) gap) to remove the hulls. Prior to rolling, the canola seed was dried to approximately 8% moisture. The seeds were processed at these conditions twice to enhance separation. Following rolling, the products were separated using and ISM 10 Fractionating Aspirator (Flaman's Agriculture, Saskatoon SK). After separation, the hull fractions were further purified using a custom sieve box (hole size of 4/64" and hole separation of 4mm), which removed the remaining cotyledon. These steps resulted in partially dehulled camelina and canola seeds. The whole and dehulled seeds were expelled using a KOMET CA-85 oil expeller press. The resulting meals were mixed and added to the experimental diets at a 12% inclusion level. The diets were prepared as crumbled pellets containing the camelina or canola ingredient, and corn (approximately 55%) and soybean (approximately 30%). The diets were formulated to meet the dietary requirements of Ross 708 birds, and titanium dioxide was added as an indigestible marker. The basal diet which did not include either of the experimental ingredients, was corn-soybean based and was not isocaloric.

A total of 100 d-old male Ross 708 chicks were used for this experiment. The birds were randomly assigned to 47 cages (50 cm x 50 cm). The experiment was a complete randomized block design with five experimental diets. Each diet was replicated five times, with four birds per replication. The chicks were fed a corn-soybean based starter diet for the first 14 days of the trial. On d-14, the chicks were weighed and randomly assigned to one of five experimental diets: basal, whole camelina meal (12%

inclusion), dehulled camelina meal (12% inclusion), whole canola meal (12% inclusion), and dehulled canola meal (12% inclusion). Feed and water were provided *ad libitum* through feeders and nipple drinkers.

Feed was weighed on d-14 and again at the end of the trial (d-20 and 21) to determine feed intake (FI). Bird weight was recorded on d-14, and then on d-20 and 21 to determine body weight gain (BWG). Excreta samples free from feathers, feed and dust, were collected every 12 h during the last three days of the trial. The collected excreta samples were stored at -20°C. The samples were then dried on trays at 55°C for 72 to 84 h. The dried samples were ground and analyzed for titanium dioxide. On d-20 and 21, the birds were euthanized via a T-61 intravenous injection. The empty weight of the proventriculus and gizzard were recorded. Chemical analysis of the diet and excreta for AME, CP, neutral detergent fibre (NDF), acid detergent fibre (ADF), and titanium dioxide was performed.

The digestibility and performance data were analyzed by ANOVA using JMP Statistical Discovery Software from SAS (version 12; SAS Institute, Inc, Cary, NC, USA). A least square fit model was used and included seed type, treatment and the interaction between seed type and treatment. Mean separation was conducted using Tukey HSD method for means that showed significance ($P < 0.05$). Means were considered to be significantly different if $P \leq 0.05$, and tendencies are discussed when $0.1 \leq P \leq 0.05$.

RESULTS

Table 22 summarizes the analyzed nutrient composition of the experimental ingredients. The ether extract content of canola increased from 21.58% in the whole canola meal to 25.09% in the dehulled canola meal. The NDF of camelina decreased from 21.7% to 15.9% in the whole and dehulled meal. Similarly, the NDF of canola decreased from 21.81% to 11.07% in the whole and dehulled meal. The insoluble and soluble fibre content of camelina and canola decreased slightly in the dehulled meal.

There was no effect of treatment, inclusion level or feed type on the BWG, FI and FCR of the birds. The initial average bodyweight of the birds was 445.9 g (±77.34) and the final average bodyweight was 951.1 g (±53.81). The average FI was 617.5 g (±60.68) and the average FCR was 1.25 (±0.058). The basal diet had a CP digestibility of 68.4% (±2.51), a GE digestibility of 75.4% (±1.11), DM digestibility of 69.9% (±1.06), and an AME of 3571 kcal kg^{-1} (±52.7).

Table 23 summarizes the effect of dietary treatment on digestibility and energy utilization. There was an overall effect of dehulling in both the camelina and canola, but no significant interaction between the ingredients and treatments. The AME of the whole and dehulled canola and camelina meals were 3182, 3249, 3416 and 3711 kcal kg^{-1} respectively. The CP (dry matter basis) of the whole and dehulled canola and camelina meals were 56.8, 59.5, 63.8 and 68.9% respectively. Canola meal (whole and dehulled) had significantly higher GE digestibility than camelina meal ($P = 0.0004$), and the dehulled meals had significantly higher GE digestibility than the whole expeller meals ($P = 0.029$). The DM and CP digestibility were also significantly higher in canola meal than camelina meal ($P = 0.005$ and $P = 0.0005$). The DM digestibility was significantly higher in the dehulled expeller meals ($P = 0.029$). There was a tendency for the CP digestibility to be higher in the dehulled meals ($P = 0.055$). The digestibility of NDF and ADF did not show statistical significance and therefore are not presented in the table.

DISCUSSION

The 12% inclusion used in this study is relatively low and can make the observation of significant effects challenging to achieve. This inclusion level was used because that is the maximum level of camelina allowed to be included in poultry diets as set by the Canadian Food Inspection Agency (2017). This inclusion is what would be used in commercial diets; therefore, it is beneficial to observe the effects at this level. The reduction in fibre observed following dehulling (Table 22) was expected given that the majority of the fibre is located in the hull of the seed (Ussetti Mohottalalage 2016). It was also expected that the whole expeller meal diets would have a lower digestibility and energy content because of the high

fibre content of the hulls. The reduced digestibility and AME of the whole ingredients indicate that the hulls are indigestible and likely impair the digestion of other ingredients in the diet. This antinutritional effect may a result of the mucilage that surrounds the hull encapsulating nutrients. The CP digestibility was significantly lower in the camelina diet (10%) compared to the canola diet (Table 23). These results agree with Aziza et al. (2013), who observed a decrease in CP digestibility following the incorporation of 10% camelina meal. Glucosinolates and other antinutritional factors present in camelina are likely responsible for the decreased CP digestibility. These compounds can react with proteins, enzymes, or essential amino acids and form complexes that negatively affect digestibility and nutrient utilization (Aziza et al. 2013). There was a tendency for the CP digestibility to increase following dehulling. The hull fibre may have prevented the protein inside the hulls from being accessed by the bird. Therefore, by removing the hulls, it removed some of the fibre and released the encapsulated nutrients. Removing the hull also results in the removal of the mucilage contained around the seed hull, which would enhance digestion and nutrient absorption of the meal (Yuan 2014). The improvement in digestibility following dehulling indicates that dehulling is a viable process for making camelina and canola more digestible in broiler diets. The results of this study demonstrate that dehulling camelina and canola seed removes the majority of the fibre components yielding a meal that is higher in energy and protein, and low in fibre.

Table 22. Analyzed nutrient composition of camelina and canola experimental ingredients (DM basis).

	Ingredient			
Nutritional composition (% as fed)	Camelina meal[a]	Dehulled camelina meal	Canola meal[b]	Dehulled canola meal
Crude protein	33.7	37.9	33.92	38.21
Ether extract	20.3	20.4	21.58	25.09
TDF	61.4	59.4	73.68	73.26
Insoluble fibre	53.9	51.8	47.05	45.37
Soluble fibre	8.05	7.61	4.755	2.832
NDF	21.7	15.9	21.81	11.07

Note: TDF, total dietary fibre; NDF, neutral detergent fibre.
[a]Whole camelina expeller meal.
[b]Whole canola expeller meal.

Table 23. Effect of ingredient (canola and camelina) and treatment (whole and dehulled expeller meal) on GE, DM and CP digestibility and AME (DM basis).

	Ingredient				Treatment			
Variable	Camelina	Canola	SEM	P Value	Whole[a]	Dehulled[b]	SEM	P Value
GE (%)	65.3[b]	72.0[a]	1.06	0.0004	66.8[b]	70.4[a]	1.06	0.029
DM (%)	59.3[b]	65.2[a]	1.28	0.005	60.1[b]	64.4[a]	1.28	0.029
CP (%)	58.2[b]	66.4[a]	1.34	0.0005	60.3	64.2	1.34	0.055
AME (kcal kg^{-1})	3216[b]	3564[a]	52.4	0.0002	3299[b]	3480[a]	52.4	0.027

Note: GE, gross energy; DM, dry matter; CP, crude protein; AME, apparent metabolizable energy; SEM, standard error of mean.

[ab] Means with uncommon letters within rows differ significantly ($P \leq 0.05$).

[a] Whole expeller meal.

[b] Dehulled expeller meal.

Steam explosion of canola and flax seed – effects on digestibility in laying hens and broiler chickens

Steam explosion of both flax and canola seed reduced lysine, cysteine, arginine and aspartic acid content of the products (Table 24). It was hoped that the intact seed would protect the protein in the seed from degradation but in this case it did not appear to do so. Many of the seeds ruptured upon steam explosion and it took some time for the product to cool and dry after the process. We believe the damage to the proteins occurred during this drying and cooling period. If this process were to be conducted on a commercial scale, the product would be conveyed directly to a dryer cooler and it is possible the negative effects would be lessened by this process.

Steam explosion treatment of canola and flax seed did not significantly affect digestibility in laying hens (Table 25). Laying hens contain large quantities of calcium and this can interfere with the digestibility assay using indigestible markers such as acid insoluble ash. Perhaps the reason we failed to see any treatment affects are due to this issue. In addition, laying hens have a more mature digestive tract than young broiler chickens and therefore appear to handle fibre more effectively. Since disruption of fibre was the primary focus of the treatment, this may also account for some of the lack of differences expected.

Steam explosion treatments did affect nutrient utilization in broiler chickens (Table 26). There was also a significant interaction between seed type and processing on dry matter, protein and energy utilization. Untreated flax seed had low digestibility. This is likely due to the high level of mucilage in the diet, which caused intestinal viscosity (Table 27). Since this was a digestibility study the test products were included at 20% of the diet to enhance our ability to predict the digestibility of the ingredient. Typically flax seed is limited to approximately 11% in poultry diets in an attempt to minimize the negative effects of mucilage. Steam explosion improved the digestibility of flax seed significantly. As shown earlier in this report, steam explosion of camelina hulls, which also contain significant levels of mucilage, resulted in a dramatic drop in the hemicellulose fraction. Although the NDF/ADF assays used to predict hemicellulose is not specifically designed to measure mucilage but in practice that is where this fraction tend to reside. The steam explosion of flax seed likely degraded the mucilage, similar to that observed in the camelina hull study. This is also supported by the significant drop in intestinal viscosity (Table 27). Interestingly water treatment with out steam explosion increased the viscosity. The reason for the increase is not known but it appears to have further modified the mucilage and enhanced it antinutritive properties. Steam explosion did not improve body weight, feed intake or feed to gain. The primary objective of this study was to measure digestibility study and is not optimized to observe differences in animal performance. Performance parameters are measured to ensure the birds are growing normally and consuming adequate quantities of feed to ensure reliable digestibility data, and all birds performed normally as expected.

Steam explosion reduced the digestibility of the dry matter , protein and AME of canola seed. The reason for the decline in Dry matter and AME is not known. As discussed previously, upon steam explosion, the seeds ruptured and exposed the embryo to high temperatures prior to cooling so this can explain the reductions in protein utilization. As described in an earlier section, steam explosion of canola hulls appeared to negatively affect protein and energy utilization and the results of this study are consistent with those findings. It may be possible that under the conditions used to process this seed 250 psi for 5 minutes, the lignin may have started to decompose forming antinutritional compounds. Treating with water and drying however, appeared to increase protein and energy digestibility. The difference was not statistically different but it would suggest that

soaking in water can increase digestibility of the seed by poultry. The mechanism for this is not known at this time.

Table 24. Amino acid content of treated Canola and Flax seed

Seed Type	Canola Seed			Flax Seed		
Treatment	Untreated	Water Treated	Steam Exploded	Untreated	Water Treated	Steam Exploded
Taurine	0.06	0.06	0.04	0.07	0.07	0.06
Hydroxyproline	0.23	0.23	0.23	0.18	0.15	0.20
Aspartic Acid	1.53	1.44	1.25	1.76	1.70	1.59
Threonine	0.94	0.90	0.94	0.74	0.71	0.71
Serine	0.83	0.81	0.75	0.80	0.78	0.74
Glutamic Acid	3.67	3.60	3.79	3.37	3.29	3.46
Proline	1.34	1.34	1.40	0.71	0.67	0.71
Lanthionine	0.00	0.00	0.06	0.00	0.00	0.04
Glycine	1.21	1.17	1.26	1.24	1.19	1.24
Alanine	0.99	0.96	1.07	0.90	0.87	0.94
Cysteine	0.67	0.61	0.35	0.35	0.32	0.16
Valine	1.22	1.19	1.28	1.06	1.02	1.09
Methionine	0.47	0.44	0.47	0.36	0.36	0.37
Isoleucine	0.95	0.95	1.00	0.88	0.85	0.88
Leucine	1.54	1.50	1.64	1.17	1.11	1.17
Tyrosine	0.61	0.55	0.60	0.48	0.46	0.46
Phenylalanine	0.93	0.90	0.91	0.96	0.92	0.92
Hydroxylysine	0.08	0.14	0.05	0.03	0.03	0.02
Ornithine	0.02	0.02	0.19	0.02	0.02	0.12
Lysine	1.43	1.38	0.52	0.84	0.80	0.38
Histidine	0.62	0.60	0.58	0.43	0.41	0.40
Arginine	1.36	1.32	0.38	1.78	1.71	0.97
Tryptophan	0.22	0.25	0.33	0.24	0.24	0.33
Total	20.92	20.36	19.09	18.37	17.68	16.96
Crude protein*	22.39	22.11	24.00	20.05	19.88	20.87
Available Lysine	1.40	1.35	0.22	0.81	0.78	0.12

Table 25. Digestibility of Steam Exploded Canola and Flax seed in Laying hens

		Digestibility (%)		AME kcal/kg As Fed basis
Seed	Treatment	Dry matter	Protein	
Canola	Untreated	76.23	94.21	5434
	Water	65.7	74.38	5331
	Steam Explosion	68.75	62.07	5545
Flax	Untreated	70.85	62.21	5018
	Water	71.62	86.77	5209
	Steam Explosion	68.51	72.56	5023
SEM		4.32	11.97	232
Main Effects				
Seed Type				
Canola		70.23	76.7	5437
Flax		70.33	74.68	5084
SEM		2.7	6.68	130
Process				
	Untreated	73.54	78.21	5226
	Water	68.66	80.57	5270
	Steam Explosion	68.63	67.9	5255
SEM			8.47	164.4
Probability				
Seed Type		0.97	0.75	0.06
Process		0.5	0.47	0.97
Seed X Process		0.48	0.12	0.63

Table 26. Effect of process on Nutrient Digestibility of Canola and Flax seed in broiler chickens

		Digestibility (%)		AME kcal/kg As Fed basis
Seed	Treatment	Dry matter	Protein	
Canola	Untreated	66.31[a]	70.86[a]	4877[a]
	Water	69.36[a]	81.82[a]	5354[a]
	Steam Explosion	59.92[ab]	45.86[b]	4215[b]
Flax	Untreated	23.61[c]	26.40[b]	2100[c]
	Water	28.92[c]	37.99[b]	2605[c]
	Steam Explosion	49.02[b]	44.51[b]	4249[b]
SEM		3.63	6.04	144.6
Main Effects				
Seed Type				
Canola		65.19[a]	65.06[a]	4815[a]
Flax		33.85[b]	36.30[b]	2985[b]
SEM		1.95	3.25	77
Process				
	Untreated	44.96[b]	48.63[ab]	3489[b]
	Water	49.14[ab]	59.90[a]	3980[a]
	Steam Explosion	54.47[b]	45.18[b]	4231[a]
SEM		2.57	4.27	102.2
Probability				
Seed Type		0.0001	0.0001	0.0001
Process		0.0264	0.0476	0.0001
Seed X Process		0.0001	0.0008	0.0001

[a-c]Means within a main effect or interaction not sharing a common superscript are significantly different ($P \leq 0.05$).

Table 27. Effect of seed type and processing on Ileal viscosity, body weight, feed intake and feed to gain ratio in 21 day old broiler chicks.

		Day 21		Day 7-21	
Seed	Treatment	Viscosity (cP)	Body Weight (g)	Feed Intake (g)	Feed to Gain (g:g)
Canola	Untreated	1.79[c]	1023	919	1.30
	Water	2.04[c]	1000	954	1.30
	Steam Explosion	3.27[c]	1006	1000	1.32
Flax	Untreated	21.69[ab]	906	937	1.43
	Water	26.78[a]	977	905	1.42
	Steam Explosion	7.52[bc]	886	980	1.35
SEM		3.64	33	27.8	1.42
Main Effects					
Seed Type					
Canola		2.26[b]	1010[a]	958	1.31[b]
Flax		17.48[a]	923[b]	941	1.40[a]
SEM			19	16	0.015
Process					
	Untreated	10.32[ab]	965	928	1.36
	Water	13.03[a]	991	929	1.36
	Steam Explosion	5.92[b]	943	990	1.34
SEM		2.41	23	19.7	
Probability					
Seed Type		0.0001	0.0035	0.4592	0.0002
Process		0.0302	0.343	0.055	0.6268
Seed X Process		0.0123	0.333	0.51	0.1478

Project Conclusions

Canola and Camelina can be dehulled with relative ease using smooth rolls in a roller mill combined with air fractionation and this results in improved nutritional profile. It is necessary to dry canola to 10% in order to achieve effective dehulling. The system as configured does not work for flax seed.

Steam explosion of oilseed meals such as canola meal is not affective due to the high levels of water absorbed during the process. High temperature extrusion with a single screw extruder may be a more effective method of hydrothermally treating canola meal or similar product. High temperatures reduced protein utilization and heat sensitive amino acids such as lysine and cysteine so if the process were to be used it needs to be short duration with rapid cooling and drying incorporated into the process.

The extensive lignification of canola hulls make them resistant to delignification and fiber modification using steam explosion. Pre-treatment of hulls by either soaking in water or NaOH solution for 24 hours did not appear to improve the effectiveness of steam explosion and has negative consequences due to excess water handling and drying. In addition, high temperatures encountered in this process appeared to produce antinutritional compounds which are possibly degradation products of lignin. These appeared to reduce digestibility of the energy and dry matter as a whole.

Camelina hulls were significantly improved by steam explosion as was flax seed, resulting in dramatic reductions in hemicellulose. Steam explosion reduced intestinal viscosity and increased nutrient utilization of the products. Based on these findings we would recommend hydrothermal treatments be developed for camelina and flax to improve the nutritive value for poultry.

9. List any technology transfer activities undertaken in relation to this project:

Newkirk, R.W., 2020. Feed Processing For Optimal Animal Health and Performance. Animal Nutrition Conference of Canada. Due to Covid19 the conference to be held in Winnipeg, Mb was replaced by a virtual conference. Presentation given June 9, 2020 via Webinar.

Le Thanh, B.V., Wang, L. F., Beltranena, E., **Newkirk, R.W**., and Zijlstra, R. T. 2019. Nutrient and energy digestibility of steam-exploded canola meal in cannulated grower pigs. ASAS Midwest Meeting, Omaha, NE, March 11-13, 2019

Sanchez-Zannatta, J. J., Thanh, Bich Van Le ; Wang, L.F. ; Beltranena, E. ; **Newkirk, R. W.**; Zijlstra, R. T. 2019. Diet nutrient digestibility and growth performance in weaned pigs fed steam-exploded canola meal. ASAS Midwest Meeting, Omaha, NE, March 11-13, 2019

Franco. A. and **Newkirk, R.W.** 2018. Enhancing the digestibility of canola hulls through dehulling and steam-explosion. 1st International Feed Technology Conference. Cologne, Germany, June 12-13, 2019.

Franco. A. and Newkirk, R.W. 2018. Improvement of the nutritional value of the canola hulls through fibre fractionation with a hydrothermal treatment. Canadian Lipid & Bioresource Conference 2018. Saskatoon, SK, Sept 9-11, 2018.

Franco. A. and **Newkirk, R.W.** 2018. Enhancing the digestibility of canola hulls through dehulling and steam-explosion. International Rapeseed Congress. Berlin, Germany, June 16-19, 2018.

10. Identify any changes expected to industry contributions, in-kind support, collaborations or other resources.

11. Appendices: