EVALUATION OF CANOLA MEAL VERSUS SOYBEAN MEAL AS A PROTEIN SUPPLEMENT FOR BEEF CATTLE: EFFECTS ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, RUMEN FERMENTATION, AND NUTRIENT DIGESTION.

A Thesis Submitted to the
College of Graduate and Postdoctoral Studies
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in the Department of Animal and Poultry Science
University of Saskatchewan
Saskatoon, SK
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ABSTRACT

The objective of this research was to determine the effect of canola meal (CM) as a protein supplement for beef cattle on growth performance, rumen fermentation, and nutrient digestion compared to soybean meal (SBM) and wheat dried distillers' grains with solubles (WDDGS). A 95-d backgrounding trial (Trial 1) and a 61-d backgrounding, 147-d finishing trial (Trial 2) were used to evaluate performance and carcass characteristics of feedlot cattle fed CM vs. SBM with or without WDDGS. In Trial 1, cattle fed SBM had greater ADG ($P < 0.05$) relative to cattle fed SBM+WDDGS but also numerically the highest feed cost of gain compared to the other three treatments. No other treatment differences were noted in Trial 1. In Trial 2, no treatment differences ($P > 0.05$) were detected for overall ADG, DMI, or gain : feed. Numerically, cattle fed SBM had the highest feed cost of gain with cattle fed WDDGS the lowest. Cattle fed SBM+WDDGS had the poorest fat deposition ($P < 0.05$) compared to cattle fed CM+WDDGS and WDDGS. However, no treatment differences were noted in final carcass value. A third trial using omasal, rumen, and fecal collections in heifers fed CM or SBM with or without WDDGS in a 4 x 4 Latin square was carried out to determine the effect of protein supplement on rumen fermentation, apparent and true ruminal nutrient digestibility, and total tract nutrient digestibility. Heifers fed WDDGS had lower ($P < 0.05$) DM, OM, and N intake than those not fed WDDGS. Heifers fed CM had the highest ($P < 0.05$) DM, OM, and N apparently and truly digested in the rumen compared to heifers fed SBM, and inclusion of WDDGS tended ($P < 0.10$) to decrease N truly digested in the rumen. There were no treatment differences ($P > 0.05$) noted in DM, OM, CP, ADF, or NDF digestibility. The results of all three trials indicate that CM is not different than SBM as protein supplement for feedlot cattle and that the inclusion of WDDGS did not improve feedlot performance, rumen fermentation, or nutrient digestibility.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisor, Dr. John McKinnon, for all his guidance, patience, and support throughout the last few years. I would also like to thank the rest of my committee, Drs. Tim McAllister, Tim Mutsvangwa, and Greg Penner, and my committee chair and alternate chair, Drs. Fiona Buchanan and Bernard Laarveld for all their helpful advice in completing my research trials and finishing my thesis. Thank you also to John Campbell for taking the time to be my external examiner.

I would also like to thank my fellow graduate students, JK Nair, Federico Anez, Elisabeth Guidotti, Eranga De Seram, Jordan Johnson, Faustin Joy, Tonderai Chambwe, and Audrey Makumure for all their help with bunk shovelling mornings at the feedlot and/or late night omasal samplings. Thanks also goes out to Daal Damiran for all his wisdom and assistance throughout the trials and to my undergraduate student helpers, Teagan Oleksyn, Kimberly Lysyshyn, and Tiandra Ewanchuk for helping feed heifers and making it possible for me to get a couple hours of sleep during sampling periods in the metabolism trial. I would also like to send a huge thank you to the staff of BCRU, Teresa Binetruy, Brian Klassen, Shane Klepak, Waylon Gilbertson, and Roland Klaasen, for their excellent care of the steers in the feedlot trials. Thanks also goes to Mike Dugan and Dave Rolland at Agriculture and Agri-Food Canada for their expert assistance with FAME analysis, to Myles Stocki for the isotope analysis, and to SaskCanola for awarding me with the Dr. Roger Rimmer Award for Excellence in Graduate Research.

Lastly, I would like to thank all my family and friends for doing their best to keep me sane as I finished this degree.

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LIST OF ABBREVIATIONS

AD	Atypial Diene
ADF	Acid detergent fiber
ADG	Average daily gain
ADIN	Acid detergent insoluble nitrogen
BCFA	Branched Chain Fatty Acid
CLA	Conjugated Linoleic Acid
CLnA	Conjugated Linolenic Acid
CM	Canola meal
CP	Crude protein
D	Potentially degradable fraction
DM	Dry matter
DMI	Dry matter intake
EE	Ether extract
FAB	Fluid associated bacteria
FC	Fiber carbohydrates
FP	Fluid phase
G:F	Gain : feed
iADF	Indigestible acid detergent fiber
iNDF	Indigestible neutral detergent fiber
Kd	Degradation rate
Kp	Passage rate
LPP	Large particle phase
MUFA	Monounsaturated Fatty Acid
N	Nitrogen
NAN	Non-ammonia nitrogen
NANBN	Non-ammonia non-bacterial nitrogen
NDF	Neutral detergent fiber
NDIN	Neutral detergent insoluble nitrogen
NE_g	Net energy of gain
NE_m	Net energy of maintenance
NFC	Non-fiber carbohydrates

OM	Organic matter
OMTDR	Organic matter truly digested in the rumen
OTD	Omasal true digesta
PAB	Particle associated bacteria
PP	Particulate phase
PS	Protein source
PUFA	Polyunsaturated Fatty Acid
RDP	Rumen degradable protein
RUP	Rumen undegradable protein
S	Soluble fraction
SFA	Saturated Fatty Acid
SBM	Soybean meal
SD	Standard deviation
SE	Standard error
SPP	Small particle phase
U	Undegradable phase
VFA	Volatile fatty acid
WDDGS	Wheat dried distillers' grains with solubles

1.0 GENERAL INTRODUCTION

Canola has grown to become one of the more important crops in Canada, with its production generating almost one quarter of all Canadian annual farm cash receipts and contributing $26.7 billion to the Canadian economy (Canola Council of Canada 2017a). In 2017 Canadian plants crushed 8.4 million tonnes of canola seed, producing 3.7 million tonnes of oil and 4.7 million tonnes of canola meal (**CM;** Canola Council of Canada 2017a). Exports of CM have been growing steadily throughout the last decade. In 2016 Canada exported over 4 million tonnes of CM, most of which went to the USA (Canola Council of Canada 2017b). The main use for CM is as a protein supplement in livestock diets; it is a very good protein supplement because it has a relatively high crude protein and essential amino acid content (Canola Council of Canada 2017c).

Soybean meal (**SBM)** has long been the most popular protein source worldwide for poultry, swine, and dairy cattle due to its relatively high protein and energy content, low fibre, and lack of anti-nutritional factors (United Soybean Board 2006). However, in North America, SBM is beginning to lose traction as the most popular protein source due to cost increases and the emergence of more profitable oilseed crops (United Soybean Board 2006). Soybeans produce around 140 kg of oil per acre while sunflowers and canola can produce roughly 320 and 410 kg of oil per acre, respectively. This places a lower value on soybean as an oilseed while others gain more market share (United Soybean Board 2006).

The development of the biofuel industry has resulted in a growing supply of ethanol by-products, such as wheat dried distillers' grains with solubles (**WDDGS;** Beliveau and McKinnon 2008). Wheat dried distillers' grains with solubles are high in protein, digestible rumen undegradable protein (**RUP)**, and energy, although it is low in some essential amino acids (Beliveau and McKinnon 2008; Chibisa et al. 2012).

Canola meal has become a popular protein supplement with North American dairy producers and nutritionists, due to its availability, low cost, and ideal balance of amino acids. It has been noted that CM can be included in dairy diets at up to 20% (DM) and maintain or increase DMI (Mutsvangwa 2017). Diets containing CM have RUP values as good or better than

SBM, a better amino acid profile, and improved fibre digestibility; all these factors lead to an improvement in milk yield up to 1.4 kg/d (Mutsvangwa 2017).

While it has become important to dairy producers, the use of canola meal in feedlot rations has not been as well studied. Some studies have found improved amino acid flow and DMI compared to other protein supplements (Stanford et al. 1996; Agbossamey et al. 1998; Li et al. 2013), but few improvements have been seen in growth performance and carcass yield and quality. There have also been few studies directly comparing rumen fermentation, true ruminal digestibility, and microbial protein production in cattle fed CM vs. SBM. As well, there has been little work comparing CM or SBM to WDDGS in feedlot rations, particularly the effects of including WDDGS as a RUP source with CM or SBM on growth, carcass quality, rumen fermentation, and microbial protein production. The objective of this literature review is to provide an overview of nitrogen metabolism in ruminants and current research regarding the use of canola meal and other protein supplements for beef cattle.

2.0 LITERATURE REVIEW

2.1 Nitrogen Utilization in Ruminants

2.1.1 Rumen Microbial Nitrogen Dynamics

The majority of absorbable crude protein supplied to ruminants is supplied by the microorganisms within the rumen (Bach et al. 2005). Microbes attach to incoming feed particles and begin to degrade and ferment the feed; providing peptides, free amino acids, ammonia, and energy for microbial growth (Bach et al. 2005). The microbes eventually flow out of the rumen to act as a protein source for the animal (Bach et al. 2005). Nitrogen inputs for ruminal microorganisms are provided by dietary protein, recycled urea, and endogenous nitrogen (Bach et al. 2005). The first stage of ruminal fermentation often begins with bacterial attachment to feed particles, this process allows the microorganisms to break down feed particles and use the feed nitrogen and carbohydrates to grow and produce microbial protein (Bach et al. 2005).

Many factors affect the efficiency of microbial protein production including the presence of amino acids and peptides, organic matter digestibility, passage rate, and rumen pH (Hanigan et al. 1998; Bach et al. 2005; BCNRM 2016). Having an adequate supply of rumen degradable protein (**RDP**) to provide peptides and amino acids to microorganisms will improve microbial protein efficiency. Fiber digesting bacteria and other microbes can produce protein from non-protein nitrogen, however, in order to do so they require the branched-chain volatile fatty acids that occur as a result of feed fermentation and amino acid deamination (BCNRM 2016). The amount of organic matter fermented in the rumen can contribute to microbial growth; a greater amount of digestible organic matter in the rumen may increase microbial protein production through increased microbial growth efficiency (Galyean and Tedeschi 2014; BCNRM 2016). Feed particle passage rate has been shown to be inversely related to microbial protein production, although this change can be small and represents a small portion of microbial protein flowing out of the rumen (Bach et al. 2005).

2.1.2 Feed Nitrogen Characteristics- The Cornell Net Carbohydrate and Protein System

The Cornell Net Carbohydrate and Protein System (CNCPS) is a mathematical model developed to evaluate diet and animal performance using basic principles of rumen function, microbial growth, feed digestion and passage, and animal physiology (Fox et al. 2004). The system was originally published in a series of four papers (Fox et al. 1992; Russell et al. 1992; Sniffen et al. 1992; O'Connor et al. 1993) and has been updated since then (Van Amburgh et al. 2009, 2015; Higgs et al. 2015). The model contains sub-models including: maintenance, growth, pregnancy, lactation, feed intake and composition, rumen fermentation, intestinal digestion, metabolism, and nutrient excretion (Fox et al. 2004).

In CNCPS, feed carbohydrate and protein content are broken down into fractions based on rumen degradability to more accurately predict rumen fermentation (Tylutki et al. 2008) . Carbohydrates are defined as either fiber (FC) or non-fiber (NFC) carbohydrates and are broken down into eight fractions (Tylutki et al. 2008). Acetic, propionic, and butyric acids are classified as the CA1 fraction, lactic acid is the CA2 fraction, organic acids are the CA3 fraction and sugars make up CA4 (Tylutki et al. 2008). Starch is classified as the CB1 fraction, soluble fiber is CB2, available NDF is CB3, and unavailable NDF is the CC fraction (Tylutki et al. 2008). The expansion of carbohydrates into eight fractions allows for a more accurate description of feed characteristics and how they relate to rumen fermentation (Tylutki et al. 2008). For example, in the previous system, organic acids and sugars were classified as the same fraction, but sugars are used more efficiently for microbial growth than organic acids, making their classification not biologically correct (Tylutki et al. 2008). Protein is divided into PA1, PA2, PB1, PB2, PB3, and PC pools. The PA pool is rapidly degradable non-protein nitrogen, PA1 being the nitrogen that enters the rumen and is completely degraded into ammonia and PA2 being the small peptides and free amino acids (Higgs et al. 2015). The B pools are partially degradable protein fractions, PB1 has a rapid degradation rate and is nearly completely digested in the rumen, PB2 is the partly degraded fraction calculated from CP – (PA+PB1+PB3+PC), PB3 is the slowly degraded fraction calculated by the difference from NDIP-ADIP (Fox et al. 2004). The PC pool is the ADIP, and is assumed to be unavailable in the rumen (Fox et al. 2004).

There are two levels of CNCPS which can predict nutrient supply to the animal (Tylutki et al. 2008). The first level uses empirical equations to predict TDN and metabolizable protein from the feed, whereas the second level uses data from the feed to predict nutrient supply (Tylutki et al. 2008). The CNCPS also estimates microbial growth in the rumen (Fox et al. 2004). The rumen microbes are categorized as FC and NFC fermenters although there may be some crossover of function between the two (Fox et al. 2004). Bacteria that ferment FC generally degrade cellulose and hemicellulose, grow slowly, and utilize ammonia as their main nitrogen source while NFC fermenters degrade starch, pectin, and sugars, grow rapidly, and can use ammonia or amino acids as their nitrogen source (Fox et al. 2004). In newer models, the role of endogenous protein is acknowledged, decreasing the calculated need for feed nitrogen for microbial production (Van Amburgh et al. 2009). In the most recent model it was demonstrated that microbial protein production was more sensitive to the rate of starch digestion rather than feed protein degradability (Higgs et al. 2015).

Intestinal digestion is predicted by CNCPS using experimentally measured digestibility coefficients and assuming that the small intestine lacks the ability to digest cellulose and hemicellulose (Fox et al. 2004). In order to account for hindgut fermentation, protein and carbohydrate fractions are assigned an intestinal digestibility value; PB1, PB2, and PB3 are assigned 100, 100, and 80% respectively, CB2 is 20%, and CB1 depends on grain type but ranges from 30-85% (Fox et al. 2004).

2.1.3 Nitrogen Recycling to the Rumen

In order to meet microbial protein requirements when feed nitrogen is limiting, ruminants are able to recycle urea from the liver back into the rumen to continue microbial protein synthesis (Kennedy and Milligan 1980; Reynolds and Kristensen 2008). The process begins with the absorption of ammonia across the epithelium of the rumen and other sections of the gastrointestinal tract into the portal vein, the ammonia is then removed by the liver and converted into urea (Reynolds and Kristensen 2008). On average, two thirds of the urea produced in the liver is recycled to the rumen, approximately 50% of which is used for microbial protein synthesis, the remainder of the urea is excreted via the kidneys (Reynolds and Kristensen 2008). The two main pathways that urea is returned to the rumen are through the saliva and the blood

(Reynolds and Kristensen 2008). Upon entering the rumen, urea is degraded by microbial urease to produce ammonia which can be used for microbial protein production (Kennedy and Milligan 1980; Reynolds and Kristensen 2008). It has been estimated that saliva contains 60% of the urea relative to blood, this coupled with the fact that the amount of saliva entering the rumen is largely determined by forage to concentrate ratio and DMI, makes salivary urea transfer more consistent than urea transfer through the blood (Kennedy and Milligan 1980). Urea transfer to the rumen through the blood is dependent on multiple factors, including ruminal NH_3-N concentration, rumen VFA concentration, plasma urea concentration, rumen osmolality, and rumen pH (Reynolds and Kristensen 2008). Facilitative urea transporter (**UT**) proteins in the ruminal epithelia allow the rapid movement of urea down a concentration gradient into the rumen from the blood (Walpole et al. 2015). The major transporters involved with urea transfer into the rumen are UT-B and aquaporins (Lu et al. 2014; Walpole et al. 2015). Ruminal NH_3-N concentration has an inhibitory effect on urea transfer due to competition within the transporters with affinity for both urea and NH_3-N, reduced urease activity, and intracellular acidification (Lu et al. 2014; Walpole et al. 2015; Mutsvangwa et al. 2016).

Microbial production of protein using ammonia is an energy dependent process, the amount of fermentable carbohydrate in the rumen is positively associated with urease activity and urea retention in the rumen (Reynolds and Kristensen 2008; Walpole et al. 2015). It has been demonstrated that urea transfer into the rumen is increased when fermentable carbohydrates are increased in the diet due to upregulation of UT-B in response to elevated VFA levels and lower pH (Lu et al. 2014; Walpole et al. 2015). In theory, being able to synchronize the degradation of dietary carbohydrate and nitrogen would be beneficial to microbial protein production but this is difficult to accomplish. In practice, changing dietary carbohydrate and protein levels to alter degradation rates often changes substrate composition so that synchrony still doesn't result (Reynolds and Kristensen 2008).

2.1.4 Post Ruminal Nitrogen Dynamics

Once digesta flows out of the rumen and into the abomasum, enzymes are secreted to lyse bacteria and digest the microbial and feed protein (BCNRM 2016). Polypeptides and proteins flow into the small intestine where they are broken down to amino acids and peptides, which are

absorbed into the portal vein. (BCNRM 2016). The liver then removes the majority of the amino acids from the portal vein and uses them as precursors for protein synthesis (Seal and Reynolds 1993). Amino acids utilized for protein synthesis contribute to protein needs for maintenance, growth, gestation, and lactation (Hanigan et al. 1998). Approximately 20-35% of the essential amino acids absorbed post-ruminally are catabolized by splanchnic tissue with considerable variation, altering the availability of these amino acids for other uses by the animal (Hanigan et al. 1998; Lapierre et al. 2006).

Ruminants are inefficient in converting feed nitrogen to animal protein due to losses from fecal and urinary nitrogen, ruminal ammonia production, and maintenance requirements (Lapierre and Lobley 2001). Nitrogen retained and used for growth in beef cattle is often less than 20% of nitrogen consumed (Cole et al. 2006), the amount of nitrogen retained by the animal is dependent on the protein level of the diet as well as the degradability of the protein (Dong et al. 2014). Decreasing the amount of protein in the feed decreased the N inputs which in turn lessens the nitrogen being excreted (Cole et al. 2006). Optimizing the amount of crude protein provided to the animal and the ratio of RDP to RUP can maximize performance and minimize nitrogen waste by the animal (Cole et al. 2006).

2.2 Protein Requirements of Ruminants

2.2.1 Crude Protein

Predicting crude protein and amino acid supply in non-ruminants is relatively simple as their intake of a given nutrient is the same as the supply of nutrients for absorption; this is not the case for ruminants. In ruminants, nutrients available for absorption in the small intestine differ from the nutrients in the diet and any free amino acids are degraded rapidly in the rumen; this makes formulating rations for ruminants on a crude protein basis difficult compared to nonruminants (Lapierre et al. 2006). Because of rumen fermentation, the value of a protein supplement is not determined just by the amount of crude protein present, but rather by the rate and extent of degradation of the protein in the rumen and the composition of the RDP and RUP fractions of the feed (Schwab et al. 2003). Since the amount of digestible protein provided to the ruminant animal is dependent on endogenous nitrogen sources and microbial protein as well as

undegraded feed protein, it is important that the protein requirements of cattle be looked at in terms of metabolizable protein (Lapierre et al. 2006; BCNRM 2016).

2.2.2 Metabolizable Protein

When supplementing protein to ruminants, two major goals should be kept in mind: 1) meeting the RDP requirements for the microbes and 2) meeting the metabolizable protein requirements for the animal's maintenance and production (Das et al. 2014). Metabolizable protein consists of RUP, microbial crude protein, and endogenous protein at the duodenum that is available for use by the animal (Lapierre et al. 2006). Metabolizable protein availability to the ruminant can be estimated through carbohydrate and CP content of the feed, DMI, degradation rate of the feed, passage rate, RDP and RUP content, rate of microbial protein synthesis, and the composition of microbial population (Das et al. 2014).

While the contribution of each of the three fractions of total duodenal protein flow is directly related to DMI and diet composition, microbial protein is often the largest portion and makes up 50-80% of the MP flowing out of the rumen, approximately 80% of which is amino acids (Bach et al. 2005; Lapierre et al. 2006). The rate of microbial protein synthesis is determined by the availability of nitrogen and energy to the rumen microbes (Cooper et al. 2002; Schwab et al. 2003). A deficiency in RDP or fermentable carbohydrate will result in decreased growth and activity of microbes, leading to a lower contribution of microbial protein to MP (Schwab et al. 2003; Das et al. 2014).

Because the majority of the microorganisms use attachment to feed particles to digest protein, the type of protein in the feed and its interactions with other nutrients can have an impact on the microbial population (Bach et al. 2005). Rumen passage rate can also have an effect on microbial protein synthesis, as the longer a feed stays in the rumen, the longer it can ferment and promote microbial growth (Bach et al. 2005).

Undegraded feed protein is the second largest fraction of MP (Lapierre et al. 2006). The nutritive value of metabolizable protein supplied from undegraded feed is affected by the passage rate and rate and extent of degradation as well as the chemical composition of the feed (Schwab et al. 2003). Feeds that are rapidly degraded or that have slow passage rates will contribute less RUP to MP than feeds that degrade slowly or pass through the rumen quickly

(Schwab et al. 2003). The endogenous nitrogen fraction of MP flowing into the duodenum mainly comes from sloughing of cells, enzymes, and blood (Lapierre et al. 2006).

Requirements for metabolizable protein change with the age and growth stage of cattle; as they mature and their growth shifts more towards fat deposition, the requirement for metabolizable protein decreases (Cole et al. 2006). When finishing beef steers were phase fed different levels of crude protein, it was demonstrated that in the first 112d of the feeding period, growth of feedlot cattle was more limited by MP rather than metabolizable energy. However, during the last 56 days on feed, the growth of cattle was limited by metabolizable energy rather than protein, regardless of what protein level they were fed (Cole et al. 2006).

Horton et al. (1992) found that steers fed backgrounding diets based on corn silage with no protein supplementation had significantly lower performance than those supplemented with different protein sources including urea, dehydrated alfalfa, and SBM; suggesting their MP requirement was not being met by corn silage alone. The group with no supplementation had lower DMI, CP digestibility, and lower weight gain throughout the backgrounding period (Horton et al. 1992). When these cattle were switched to a common diet (13.4% CP) for finishing, the cattle fed protein supplements continued to have higher ADG although the calves fed no protein supplementation did have some compensatory gain (Horton et al. 1992). Calves receiving protein supplements in the backgrounding period went on to have higher yielding carcasses, larger *Longissimus dorsi* area, and a higher marbling score suggesting that increasing MP during backgrounding can have long term positive effects on performance (Horton et al. 1992).

2.2.3 Amino Acids

Although the protein requirement for ruminants is defined in terms of metabolizable protein, the true requirement is for the amino acids supplied in the metabolizable protein (BCNRM 2016). Ruminants are not often thought of as having a dietary requirement for essential amino acids due to microbial protein providing a similar amino acid profile that is required by the animal (Merchen and Titgemeyer 1992; Hanigan et al. 1998). In instances where microbial protein production is limited or when amino acid requirements are high, microbial amino acid supply may not be enough (Merchen and Titgemeyer 1992). This can occur when an

animal is increasing protein deposition during periods of high growth and less nitrogen is available to be recycled back to the rumen for microbial protein production or when a diet is too high in RDP and microbial protein is the only source of amino acids (Merchen and Titgemeyer 1992; Wilkerson et al. 1993; Titgemeyer et al. 2012). In non-ruminants, growth can be described in energy-dependent and protein-dependent phases so that when energy is limiting, the animal will not respond to increased protein supply and vice versa (Titgemeyer and Löest 2001). In ruminants, there is little data on the existence of these interactions because manipulating dietary energy will impact metabolizable protein supply because of ruminal fermentation (Titgemeyer and Löest 2001). Studies that have accomplished manipulation of metabolizable energy and protein have not observed the protein- and energy-dependent phases of growth seen in non-ruminants. This interaction between protein and energy and its effects on affect protein deposition makes predicting amino acid requirements difficult (Titgemeyer and Löest 2001).

In order to provide an ideal mix of essential amino acids to ruminants and maximize growth, one or more of three strategies can be used: 1) maximize production of microbial protein by providing enough RDP, 2) use an RUP source that provides adequate levels of essential amino acids, or 3) feed rumen protected amino acids (Merchen and Titgemeyer 1992). Using an undegradable protein source that is high in limiting amino acids, or a combination of protein sources that meets limiting amino acid requirements can improve production when amino acids are limiting (Huuskonen et al. 2014).

Amino acids that can be limiting in ruminants are methionine, leucine, lysine, threonine, and histidine (Merchen and Titgemeyer 1992; Titgemeyer et al. 2012; Maxin et al. 2013a). These amino acids only become limiting when the animal is at maximum performance, in other words - when both the energy consumed and the genetics of the animal are not limiting its gain (Titgemeyer and Löest 2001).

In a three-step process to determine amino acid requirements of double-muscled Belgian Blue bulls, it was found that increasing the supply of digestible methionine improved nitrogen utilization (Froidmont et al. 2000). This suggests a positive interaction between methionine and other limiting amino acids for use in protein deposition (Froidmont et al. 2000). Methionine may also be used for other functions, such as a methyl donor or a precursor to cysteine, which may contribute to inefficiencies in depositing methionine in protein tissues (Froidmont et al. 2000).

In an experiment where steers were abomasally infused with 2 levels of leucine (0 or 4 g/d), a basal mix of all other essential amino acids above their requirements, and one of three energy sources, it was found that nitrogen retention was improved with increased leucine supply (Titgemeyer et al. 2012). Leucine has been established as a regulator of protein synthesis in monogastrics, given its function as a regulator of the growth regulating pathway, mTOR (Titgemeyer et al. 2012). In the case of leucine deficiency, mTOR cannot fully respond to the energy being supplied for protein deposition (Titgemeyer et al. 2012). This makes leucine an important amino acid for implanted finishing cattle as they are often on high energy diets and are gaining weight rapidly and have high demands for protein deposition (Titgemeyer et al. 2012).

2.2.4 Protein Degradability in the Rumen

A shortage of RDP can lead to a reduction in microbial fermentation of carbohydrates, synthesis of microbial protein, and feed intake (Li et al. 2013; Huuskonen et al. 2014). However, excess RDP causes inefficiency in the use of feed protein (Das et al. 2014). To avoid excess nitrogen loss, getting the balance of ruminal RDP supply and RDP requirement right, is important (Bach et al. 2005). The requirement for RDP is related to microbial yield in the rumen, and the BCNRM (2016) suggests that the requirement for RDP is 1.18 times the predicted microbial protein synthesis.

The degradability of protein can have a significant effect on the growth performance of cattle fed high forage diets (Stock et al. 1981; Cecava and Parker 1993; Titgemeyer and Löest 2001). In one study when cattle were grazed on grass or fed grass hay, a RUP supplement improved their performance slightly (Titgemeyer and Löest 2001). In the same study, cattle that were fed a grass silage had significantly improved growth performance when supplemented with a RUP source. It was suggested that this was because grass silage is high in non-protein nitrogen and low in pre-formed protein and energy, resulting in reduced microbial protein production (Titgemeyer and Löest 2001). In another study, steer calves were fed high forage diets with protein supplements including urea and a source of RUP (Stock et al. 1981). Calves that were supplemented with a RUP source had higher ADG and were more efficient than those supplemented with just urea (Stock et al. 1981).

Although supplementing RUP has been shown to improve backgrounding performance, there has been little work done to establish its effect on finishing performance. When finishing steers were fed diets with different protein supplements varying in the level of RUP, it was reported that the steers with higher RUP diets had increased daily gain (Sindt et al. 1993). This response was greatest during the first 41 days of the finishing period, likely because during the transition onto a finishing diet, rations are typically higher in forage and forage sources are typically lower in RUP (Sindt et al. 1993). It was also suggested that the rate of protein deposition is decreased with increased body weight as fat deposition begins to increase (Sindt et al. 1993). As mentioned earlier, energy becomes more limiting as cattle go further into finishing rather than metabolizable protein, thus the requirement for RUP decreases with advancing maturity.

Similar results to Sindt et al. (1993) were seen when growing and finishing lambs were fed diets that included one of five protein supplements varying in degradability. It was found that level of RUP in the diet had no effect on growth, feed efficiency, or carcass characteristics (Beauchemin et al. 1995b). Instead it was suggested that energy content of the feed had more effect on finishing performance than level or degradability of protein (Beauchemin et al. 1995b).

2.3 Canola Meal compared to Soybean Meal and Wheat Dried Distillers' Grains with Solubles

2.3.1 Nutrient Composition of Canola Meal

Multiple factors can influence the amount of nutrients available in canola meal, including the content of fiber, protein, and oil (Bell 1993). The chemical composition of seed and therefore the meal is impacted by growing conditions, storage, and processing methods (Bell 1993; Newkirk et al. 2003). Excess moisture, frost damage, and heat-stress from storage can all affect the composition of the seed (Bell 1993). Seed size, ratio of hull to embryo, colour, and composition of hull are affected by growing conditions and can change the chemical composition of the seed and therefore the amount of energy, fibre, and protein in the meal (Bell 1993). Heat and pressure during processing can affect protein degradability and amino acid content (Newkirk et al. 2003).

2.3.1.1 Protein

As seen in Table 2.1, the average crude protein value of CM is 39.0 ± 3.6%. The actual crude protein content can vary from as low as 31.5% (Paz et al. 2014) to 44.0% (Mulrooney et al. 2009) depending on growing conditions and processing. Compared to SBM, CM is lower in crude protein with SBM ranging from 44 (Banaszkiewicz 2011) to 54% (Broderick et al. 2015). Canola meal has a similar crude protein level to WDDGS, with reported crude protein values ranging from 32% (Mulrooney et al. 2009) to 43% (McKeown et al. 2010).

Two important characteristics influencing the degradability of a protein source are physical characteristics of the protein and processing (Kendall et al. 1991). One major factor influencing the degradability of CM is the presence of hulls which limit OM degradability and likely contribute to CM's higher RUP value relative to low fiber protein sources such as SBM (Kendall et al. 1991; Boila and Ingalls 1992). Rates of nitrogen degradation in CM have been found to vary from 5.4 to 10.4%/h for CM (Stanford et al. 1995, 1996; Broderick et al. 2015).

The RUP values reported for CM in recent studies range from 32.1% of total CP (Paz et al. 2014) to 52.5% (Maxin et al. 2013b) with an average of 41.4%. The range of RUP values is lower for SBM with the lowest reported as 29% (Brito et al. 2007) and the highest at 41.9% (Stanford et al. 1995). Compared to CM and SBM, there are fewer studies reporting RUP values for WDDGS, the lowest value reported is 39.2 (Maxin et al. 2013b) and the highest is 54.4% (Nuez-Ortin and Yu. 2010).

While microbial protein is the most significant source of protein and amino acids for ruminants, having the correct quantity and proportions of essential amino acids in the feed is important to achieve maximum production potential (BCNRM 2016). Broderick et al. (2015) noted that lactating dairy cows tend to respond positively when fed a rumen protected methionine source, suggesting that methionine is a limiting amino acid for dairy cattle. Methionine is also one of the first limiting amino acids in growing beef cattle (Wilkerson et al. 1993). As seen in Table 2.2, CM has been found to have a superior amino acid balance relative to SBM and WDDGS; it has higher levels of rumen escape methionine and threonine than SBM, and higher levels of most rumen escape essential amino acids than WDDGS (Boila and Ingalls 1992; Maxin et al. 2013b).

Table 2.1. Nutrient profiles of canola meal (CM), soybean meal (SBM), and wheat dried distillers' grains with solubles (WDDGS).

	CM[1]	SBM[2]	WDDGS[3]
(% DM; Mean ± SD)			
Crude Protein	39.2 ± 3.3	50.2 ± 3.1	38.1 ± 3.0
Rumen Undegradable Protein (% of CP)	41.4 ± 8.9	36.7 ± 5.9	46.2 ± 7.7
Organic Matter	91.8 ± 0.7	93.1 ± 0.7	95.0 ± 0.7
Neutral Detergent Fiber	26.3 ± 4.0	10.0 ± 4.3	38.6 ± 8.2
Acid Detergent Fiber	17.7 ± 2.7	6.8 ± 3.1	12.9 ± 2.1
Ether Extract	3.7 ± 0.8	1.3 ± 0.7	5.2 ± 2.2
Starch	1.2 ± 0.4	4.2 ± 2.3	3.2 ± 0.8
Calcium	0.9 ± 0.2	0.4 ± 0.1	0.1 ± 0.1
Phosphorus	1.1 ± 0.0	0.4 ± 0.3	0.9 ± 0.1

[1]Values averaged from: Bell 1993; Rule et al. 1994; Beauchemin et al. 1995; Stanford et al. 1995; 1996; Brito et al 2007; Bach et al. 2008; Mulrooney et al. 2009; Li et al. 2013; Yang et al. 2013; Maxin et al. 2013a; Paz et al. 2014; Broderick et al. 2015.

[2]Bell 1993; Rule et al. 1994; Stanford et al. 1995; 1996; Maiga et al. 1996; Brito et al. 2007; Bach et al. 2008; Banaszkiewicz 2011; Maxin et al. 2013a; Paz et al. 2014; Broderick et al. 2015.

[3]Beliveau 2008; Mulrooney et al. 2009; McKeown et al. 2010; Nuez-Ortin and Yu 2010; Walter et al. 2010; Li et al. 2012; Li et al. 2013; Maxin et al. 2013a; Yang et al. 2013

Table 2.2. Amino acid content of canola meal (CM), soybean meal (SBM), and wheat dried distillers' grains with solubles (WDDGS) prior to and after rumen incubation

	Amino Acid Content (g/100 g CP; Mean ± SD)					
	Un-incubated			Rumen Escape		
	CM[1]	SBM[3]	WDDGS[5]	CM[2]	SBM[4]	WDDGS[6]
Arginine	6.1 ± 0.1	7.4± 0.0	4.7 ± 1.0	5.8 ± 0.6	5.9 ± 0.5	5.2
Histidine	3.2 ± 0.4	2.7 ± 0.1	2.3 ± 0.2	2.6 ± 0.2	2.6 ± 0.1	2.0 ± 0.1
Isoleucine	3.8 ± 0.3	4.5 ± 0.1	4.0 ± 0.8	3.9 ± 0.2	3.9 ± 0.6	4.2 ± 0.9
Leucine	6.4 ± 0.6	7.9 ± 0.4	8.4 ± 2.0	7.6 ± 0.3	8.2 ± 0.2	8.2 ± 0.5
Lysine	5.0 ± 0.5	6.2 ± 0.2	2.7 ± 0.8	5.1 ± 0.7	5.4 ± 0.5	3.1 ± 0.5
Methionine	2.2 ± 0.8	1.4 ± 0.3	1.8 ± 0.4	3.3 ± 0.9	1.7 ± 0.2	2.3 ± 0.1
Phenylalanine	3.9 ± 0.3	5.1 ± 0.1	4.9 ± 0.4	4.8 ± 0.7	5.4 ± 0.1	4.5 ± 0.1
Threonine	4.1 ± 0.3	3.5 ± 0.2	3.4 ± 0.6	5.0 ± 0.4	2.6 ± 1.8	3.6 ± 0.0
Valine	4.5 ± 0.3	4.6 ± 0.0	5.0 ± 1.1	4.9 ± 0.6	4.1 ± 0.7	3.4 ± 3.3

[1]Values averaged from: Kendall et al. 1991; Boila and Ingalls 1992; Li et al. 2013; Canola Council of Canada 2015.

[2]Cooperative Extension UC Davis; Boila and Ingalls 1992; Maxin et al. 2013a; Canola Council of Canada 2015.

[3]Kendall et al. 1991; Maiga et al. 1996; Karr-Lillienthal et al. 2005.

[4]Cooperative Extension UC Davis; Maiga et al. 1996; Maxin et al. 2013a.

[5]Widyaratne and Zijlstra 2007; Abdelqader 2012; Li et al. 2012; Li et al. 2013; Maxin et al. 2013a.

[6]Li et al. 2012; Maxin et al. 2013a.

Canola meal often improves the amino acid profile of diets compared to SBM and WDDGS due to its higher level of rumen escape amino acids (Brito et al. 2007; Mulrooney et al. 2009; Maxin et al. 2013a). Brito et al. (2007) found that the omasal outflow of essential amino acids was numerically greatest for lactating cows fed diets supplemented with CM compared to cows fed diets supplemented with SBM, cottonseed meal, and urea. When CM was compared to SBM, WDDGS, and high protein DDGS as protein supplements for lactating cows, cows fed CM had the highest plasma concentration of essential amino acids (Maxin et al. 2013a). However, when using CM as a protein supplement in backgrounding diets compared to corn and wheat dried distillers' grains with solubles, Li et al. (2013) found that the flow of essential amino acids out of the rumen of backgrounding beef heifers was either equal to or less than that of WDDGS, even though CM originally had higher levels of essential amino acids.

2.3.1.2 Fiber

Canola seeds have a small surface area which contributes to proportionately more hull in CM than in most other protein sources; hulls represent approximately 30% of the weight of CM (Bell 1993; Newkirk et al. 2003). This, combined with the fact that canola seed is often not dehulled prior to oil extraction and reduced efficiency of processing, leads to CM being higher in fiber, especially ADF, than other common protein supplements (Newkirk et al. 2003). The average level of NDF for CM as seen in Table 2.1 is 26.3 ± 4.0% and the average level of ADF is 17.7 ± 2.7%. These values are higher than reported for SBM (NDF: 10.0 ± 4.3%; ADF: 6.8 ± 3.1%) due mostly to the proportion of hulls in the meals and the high proportion of starch in SBM (Maxin et al. 2013a). Compared to WDDGS (NDF: 38.6 ± 8.2%; ADF: 12.9 ± 2.1%), CM has a lower level of NDF but a higher level of ADF. In the production of WDDGS, starch from the wheat is used for fermentation, resulting in a high protein, high NDF product that is rapidly fermented (Beliveau and McKinnon 2009). Compared to CM, however, WDDGS has less lignin than CM, leading to a lower ADF content.

2.3.1.3 Energy

Canola meal is most often used as a protein supplement although its energy value cannot be ignored (Bell 1993). Gums, oil, and phospholipids left in the meal after solvent extraction can increase the energy content of CM (Bell 1993). The energy content of CM is typically lower than that of other protein supplements due to its higher proportion of hulls and lower proportion of starch compared to SBM and WDDGS (1.2 ± 0.4% vs. 4.2 ± 2.3 and 3.2 ± 0.8%) (Bell 1993). The low fiber, high protein *Brassica juncea* contains more digestible energy than *Brassica napus* and could be used as a higher energy, higher protein alternative relative to *Brassica napus* (Bell 1993; Nair et al. 2016). However, He et al. (2013) found that replacing up to 30% of the barley grain in a finishing diet with CM from either *Brasssica juncea* or *Brassica napus* had no effect on growth or carcass quality. Cattle fed diets with 30% of the barley grain replaced with CM had a higher DMI and therefore a lower gain to feed, regardless of the variety (He et al. 2013). This study showed no significant differences in the feed value of the brown seeded and yellow seeded canola despite the lower fiber value of *Brassica juncea* (He et al. 2013). They concluded that replacing 15% of barley grain with canola meal of either variety would meet finishing animal's energy requirements (He et al. 2013). Nair et al. (2015) found somewhat similar results when replacing 15 or 30% of barley grain in backgrounding and 10 or 20% of barley grain in finishing diets with *Brassica napus* or *Brassica juncea*. In this trial, it was found that increasing the level of canola meal of either variety in the diets resulted in reduced growth performance and carcass quality, indicating that CM is not an adequate substitute for cereal grains over the entire feeding period (Nair et al. 2015). In a companion study, the same authors found that the level and type of CM in the diet did not affect apparent total tract nutrient digestion, energy availability, VFA concentration, or rumen pH in cattle fed backgrounding diets (Nair et al. 2016). However, they did note increased rumen ammonia concentrations and increased nitrogen excretion in the diets where 20% of barley grain DM was replaced with CM, suggesting a decrease in nitrogen efficiency in cattle fed higher levels of CM (Nair et al. 2016).

While CM may be an adequate replacement for up to 15% of the barley grain in a finishing diet, other protein supplements have been found to be more suitable replacements. Multiple studies have replaced barley grain with WDDGS or corn DDGS in both backgrounding and finishing rations and found positive results. Beliveau and McKinnon (2008) replaced barley

grain at intervals up to 32% with WDDGS during backgrounding and up to 23% during finishing. These authors found that during backgrounding, DMI and ADG displayed a cubic response to increasing WDDGS in the diet, with maxima at 27.2% and 30.8% WDDGS respectively. In contrast, feed efficiency exhibited a quadratic response with the poorest efficiency being at 13.1% WDDGS (Beliveau and McKinnon 2008), suggesting that WDDGS is a good replacement for barley grain during backgrounding. Despite the improvements in DMI, ADG, and feed efficiency seen in the backgrounding period, no effects of WDDGS inclusion were seen during finishing. When Walter et al. (2010) fed WDDGS or corn DDGS to finishing steers at either 20% or 40% of dietary DM, they also saw no effects on ADG however a quadratic increase in gain : feed was noted in steers fed corn DDGS and a linear reduction in days on feed was noted for those fed WDDGS. Dressing percentage was also linearly increased for steers fed WDDGS and in a quadratic matter for those fed corn DDGS (Walter et al. 2010). Similarly, Amat et al. (2012) noted that when 17% of the barley grain was replaced with corn DDGS, WDDGS, or a blend of the two from backgrounding to finishing, steers fed DDGS had improved ADG and DMI compared to the control. However, in a backgrounding trial by the same authors, no differences were noted in ADG, DMI, or feed efficiency (Amat et al. 2012). Taken together, these studies suggest that either WDDGS or corn DDGS can be an adequate replacement for barley grain in backgrounding and finishing diets up to a level of ##%% and are a more appropriate energy source than CM.

2.3.1.4 Minerals

As seen in Table 2.1, CM is a good source of minerals, containing more calcium than both SBM and WDDGS (0.9 ± 0.2% vs. 0.4 ± 0.1 and 0.1 ± 0.1%, respectively) as well as more phosphorus (1.1 ± 0.04% vs. 0.4 ± 0.3 and 0.9 ± 0.13, respectively). Like most plant based feeds, the mineral concentration of CM can be quite varied. In a four year survey of four locations, it was found that CM of different cultivars had significant variation in mineral levels (Bell et al. 1999). This variation is likely due to genetic makeup of the cultivar affecting soil mineral uptake and physical soil composition affecting the uptake of minerals by the plant (Bell et al. 1999). Sulfur is another important mineral to consider when formulating diets, the BCNRM (2016) recommends that sulfur accounts for less than 0.5% of total DMI. While CM has a higher sulfur

content than SBM (0.86 vs. 0.42%; Bell 1993), it is lower than the average sulfur level of WDDGS (1.0%; Amat et al. 2012). The sulfur content of WDDGS is higher than most other protein sources (Amat et al. 2012). When feeding corn DDGS with a sulfur content of 1.01%, Buckner et al. (2008) found total dietary sulfur levels reached 0.6% for cattle fed 50% corn DDGS. Five steers fed this diet experienced symptoms of sulfur toxicity after 22 days on feed (Buckner et al. 2008).

2.3.2 Production of Canola Meal

The original method of canola crushing used pressure to expel the oil from the seed. This method starts with cleaning the seed and briefly conditioning it to raise the temperature to 105-108°C (Bredeson 1983).The seed is then flaked using rollers, cooked for 30 minutes at 135°C and then fed into a screw-press and extruded . This method of canola processing resulted in CM with a high residual oil content. To get around this issue, crushing plants began using solvent extraction to recover more of the high quality oil (Shi and Bao 2008).

Direct solvent extraction has been used by soybean crushers for many years before being introduced in Canada for use in canola crushing. This process did not expel the seed after flaking and cooking and used the solvent to extract oil (Shi and Bao 2008). While the method worked for crushing soybeans, the flaked canola seed tended to break apart into fine particles so expelling was introduced back into the solvent extraction process (Youngs 1965).

Most canola currently grown in Canada is processed through the prepress solvent extraction process (Figure 2.1; Canola Council of Canada 2015). This process begins with cleaning and flaking the seed (Newkirk 2002; Canola Council of Canada 2015). The flakes are then passed through a series of cookers to prepare them for expelling (Newkirk et al. 2003; Canola Council of Canada 2015). The cooking cycle usually lasts 15 to 20 minutes with temperatures ranging between 80 and 105°C. After cooking, the canola flakes proceed to the pressing stage where a series of screw presses or expellers remove most of the oil and form a cohesive particle that remains intact during hexane extraction (Newkirk et al. 2003; Canola Council of Canada 2015).

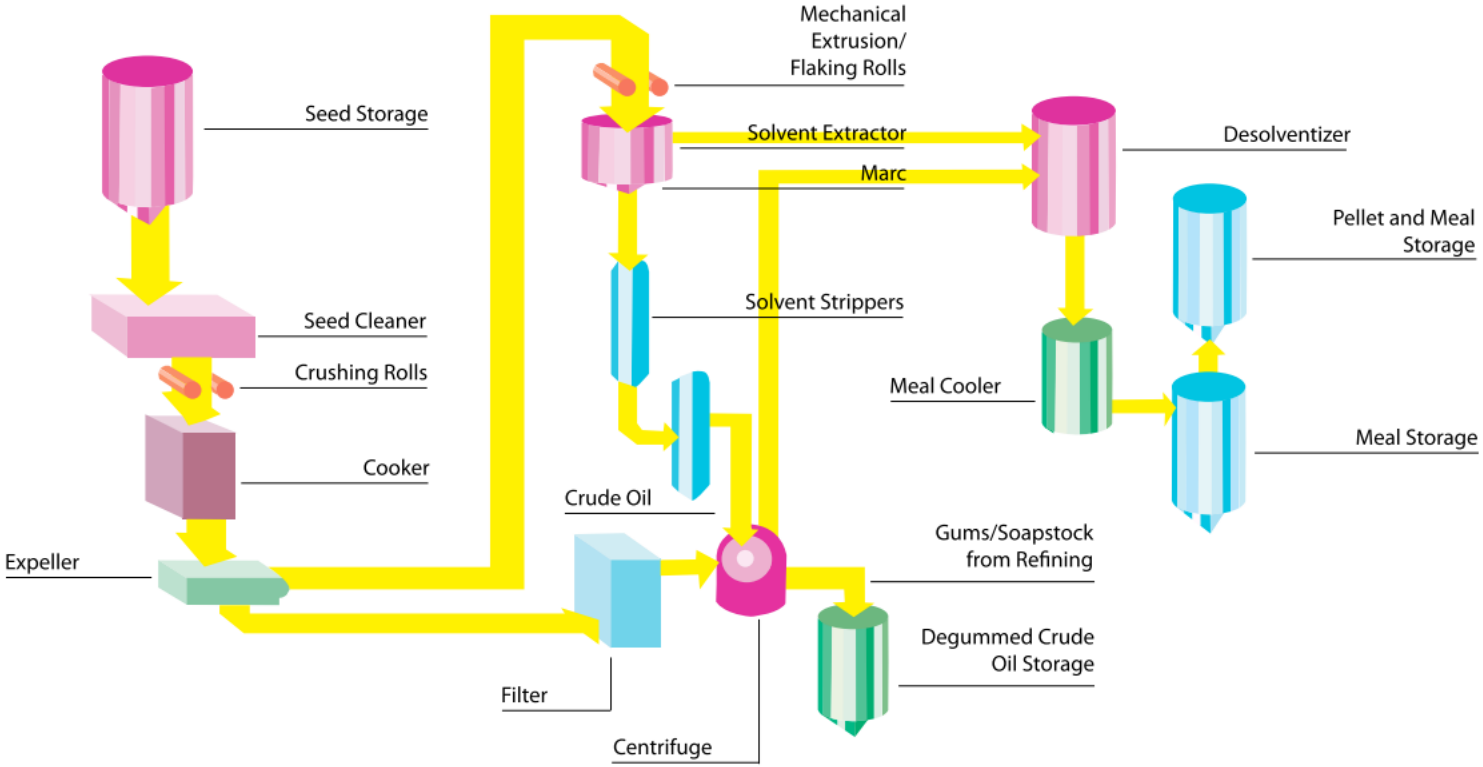

Figure 2.1. Schematic of prepress solvent extraction process. (Canola Council of Canada 2009).

Since the amount of heat put into pressing the canola is minimized, potential heat damage to the protein in canola meal is minimized (Newkirk et al. 2003). Hexane is used to extract the remaining oil in the canola presscake, leaving a hexane saturated canola meal (Newkirk et al. 2003; Canola Council of Canada 2015). The solvent is removed from the meal through heating to 95 – 115°C on a series of steam plates and by injecting steam through the meal. Once desolventized, the meal is cooled, dried, granulated to a uniform consistency using a hammer mill and sometimes pelleted (Newkirk et al. 2003).

2.3.3 Effects of Processing

As there are many stages of canola processing where heat is applied, protein damage could occur at multiple steps (Bell 1993). In cases where excessive heat has been applied to the canola, the Maillard reaction can reduce the availability of protein and amino acids within the meal (Bell 1993). While this protein damage is not ideal for monogastric livestock, it can prove beneficial to ruminant diets if controlled by limiting the RDP portion of CM (Bell 1993).

There have been multiple processing strategies examined to reduce the ruminal protein degradability of CM so that more protein escapes to the abomasum for digestion. Heating CM at high temperatures was found to be an effective way to reduce protein degradability by utilizing changes in protein structure and through the formation of linkages with carbohydrates via the Maillard reaction (McKinnon et al. 1991). Heating at 145° for 10, 20, or 30 minutes decreased crude protein degradability from 59.6 to 14.8, 15.7, and 10.5% while heating at 125°C for the same periods decreased crude protein degradability to 27.7, 21.9, and 22.7% (McKinnon et al. 1991). Both temperatures are effective at reducing ruminal degradability, but it was suggested that the larger relative increase in ADIN from heating CM at 145°C could also decrease protein digestibility in the small intestine (McKinnon et al. 1991). A combination of heating CM for 1 hour at 100°C with 5% lignosulfonate, a product containing lignosulfonic acid, hemicellulose, and reducing sugars, by weight was found to decrease the protein degradability of CM by 52%, however, when fed to nursing beef calves, there were no differences in growth rates (Beauchemin et al. 1995a). When CM was processed with 5% lignosulfonate and heated at 100°C for 120 minutes, rumen degradability of protein dropped from 71.3 to 29.9% and an improvement in milk yield was noted (Wright et al. 2005).

2.4 Value of Canola Meal as a Protein Source in Ruminant Diets

2.4.1 Value of Canola Meal Compared to Other Protein Sources in Dairy Rations

In western Canada and some parts of the USA, CM has become the principal protein source for dairy cattle because of its availability, high protein quality, and palatability (Mutsvangwa 2017). As a result, CM has been relatively well studied in dairy cattle, with the majority of studies agreeing on maintenance or improvements in DMI and milk yield from feeding cows CM compared to other common protein supplements (Huhtanen et al. 2011; Mutsvangwa 2017).

When CM was compared to SBM, WDDGS, and high protein dried distillers' grains with solubles in lactating cow rations, there were no differences found in milk yield, energy corrected milk, or DMI (Maxin et al. 2013a). There was a slight milk fat depression in cows fed diets supplemented with WDDGS, likely due to the higher fat content of WDDGS (Maxin et al. 2013a). This study also found that CM had the best amino acid profile of all protein sources; cows fed CM had the highest plasma concentration of all essential amino acids except leucine, suggesting that CM offered a superior profile of essential amino acids (Maxin et al. 2013a). It was concluded from this study that CM supplemented diets were highest in metabolizable protein value, while SBM was deficient in methionine and WDDGS was deficient in histidine (Maxin et al. 2013a).

Broderick et al. (2015) compared CM to SBM at two different protein levels with alternating rumen protected methionine and lysine for lactating cows. They found that replacing SBM with CM at both the low (14%) and high (16.5%) protein levels improved nitrogen utilization, DMI, milk yield, and true protein yield in the milk (Broderick et al. 2015). Feeding rumen protected methionine in all diets increased milk yield, due to its role as a limiting amino acid (Broderick et al. 2015). Using the NRC (2001) model to predict amino acid supply, they reported that CM delivered 4g d^{-1} more methionine than SBM at the low protein level and 5g d^{-1} more methionine at the high protein level and that the methionine to lysine ratio was improved from 3.55 to 3.2 (Broderick et al. 2015). Based on this, it can once again be suggested that CM has a preferred amino acid profile as compared to SBM and improves production in dairy cattle.

A similar experiment was carried out comparing CM to WDDGS at two different protein levels (Mutsvangwa et al. 2015). No interactions were found between protein source and protein level (15 vs 17%) and there were no effects were seen of protein source on DMI or milk yield.

However, milk yield was numerically greater for cattle fed CM compared to WDDGS (Mutsvangwa et al. 2015). Protein source also had no effect on omasal flow of N, microbial protein, or RDP level in the diet, however omasal flows of lysine and histidine tended to be greater in cows fed CM (Mutsvangwa et al. 2015). There was no protein source effect on omasal flow of methionine, likely explaining the lack of a significant difference in milk yield, as methionine and lysine are co-limiting amino acids for milk production (Mutsvangwa et al. 2015).

In a meta-analysis, Huhtanen et al. (2011) concluded that CM is at least as good as SBM as a protein supplement for lactating cows. In most cases, CM improved DMI and milk yield compared to SBM and provided a more balanced supply of amino acids to the small intestine, however, there were no differences in the amount of omasal RUP flow between the two protein sources (Huhtanen et al. 2011).

Contrary to the results of Maxin et al (2013), Chibisa et al. (2012) found that replacing CM with WDDGS at up to 20% of the diet improved milk yield and DMI. They determined that the omasal flow of non-ammonia nitrogen increased as level of WDDGS increased, due to the high RUP content of WDDGS (Chibisa et al. 2012). A deficiency of lysine was anticipated in cows fed diets containing WDDGS, but none was noted, suggesting that the high RUP value of WDDGS compensated for amino acid deficiencies and supplied similar levels of lysine as CM (Chibisa et al. 2012).

2.4.2 Value of Canola Meal Compared to Other Protein Sources in Backgrounding and Finishing Rations

Compared to dairy cattle, the value of canola meal compared to other protein sources is relatively less studied in backgrounding and finishing cattle. When compared to WDDGS, corn DDGS (**CDDGS**), and fractionated corn DDGS (**FDDGS**) in a backgrounding trial, cattle fed diets supplemented with CM had the highest DMI compared to cattle supplemented with the other three protein sources and a non-supplemented control (Yang et al. 2012). Cattle fed CM had a higher ADG and larger final body weight compared to cattle fed WDDGS and control, with cattle fed the other two protein supplements being intermediate (Yang et al. 2012). A metabolism trial using the same treatments found that duodenal flow of microbial nitrogen was improved with CM or WDDGS compared to CDDGS, FDDGS, and the control. This may have been the result of better synchronization of carbohydrate and nitrogen digestion in the rumen (Li

et al. 2013). Contrary to previous work with dairy (Maxin et al. 2013), Li et al. (2013) found that the flow of essential amino acids into the duodenum in heifers fed WDDGS and CM were similar for most amino acids, with WDDGS having a higher flow of histidine and leucine. FDDGS had the highest flow of essential amino acids compared to the other protein supplements, while the control had the lowest (Li et al. 2013). Although essential amino acid flows were different for all the amino acids, there were no differences in post-ruminal digestion for any of the essential amino acids except valine (Li et al. 2013). Post-ruminal digestion of valine was highest in heifers fed FDDGS and lowest in those fed CDDGS, with the other two protein supplements and the control being intermediate (Li et al. 2013).

In 3 backgrounding trials at three locations, five protein supplements (fish meal, CM, SBM, corn gluten meal and blood meal combination, and meat meal) were compared to determine the effects of RUP on growth performance (Veira et al. 1995). No effect on DMI was seen, while cattle fed fish meal had the highest live weight gains and cattle fed meat meal having the lowest and cattle fed CM, SBM, and corn gluten meal/blood meal combination being intermediate (Veira et al. 1995). There were no differences seen in feed efficiency or nitrogen digestibility between any of the protein treatments (Veira et al. 1995). The same treatments were compared in a backgrounding to finishing trial, where cattle received one of 5 treatments or a control for backgrounding and then half of the protein supplemented cattle had protein supplementation removed for finishing, while the other half had the protein supplementation level cut in half (Petit and Veira 1994). Once again there were no differences seen in DMI between treatments (Petit and Veira 1994). During backgrounding, steers fed CM had the lowest ADG compared to other treatments while over the entire feeding period, cattle fed all protein supplements had similar rates of gain (Petit and Veira 1994). The feed to gain ratio was highest for steers fed fish meal or CM compared to the other protein supplements (Petit and Veira 1994). Cattle fed fish meal finished the fastest with cattle fed the other protein supplements finished at an intermediate time, but were no treatment differences seen in carcass yield or carcass quality (Petit and Veira 1994).

In a comparison between CM, SBM, and lupin seeds as protein supplements for finishing lambs, it was found that lupin seeds had higher dry matter, crude protein, and energy digestibility. Feeding lupin seeds also resulted in higher nitrogen retention than CM and SBM while SBM had the highest ADF digestibility (Stanford et al. 1996). Intake and feed conversion

of all lambs were similar, however lambs fed CM had the highest ADG and lambs fed SBM had the lowest. Lambs fed lupin seeds did not differ in these parameters afrom those fed the other two protein sources (Stanford et al. 1996). Somewhat similar to these results, an Australian study found that lambs fed CM had the highest ADG, DMI, and feed efficiency compared to lambs supplemented with lupin seeds or urea, however no differences were seen in carcass yield or carcass quality (Wiese et al. 2000).

Lignosulfonate treated CM and untreated CM were compared to lignosulfonate treated and untreated SBM in a lamb digestibility growth trial (Stanford et al. 1995). This trial found no differences between untreated CM and SBM in dry matter, fiber, or energy digestibility, however SBM had a higher nitrogen digestibility (Stanford et al. 1995). Lambs fed untreated CM had higher DMI than lambs fed untreated SBM, but both treatments had similar ADG and feed efficiency (Stanford et al. 1995). Lambs fed CM had more fat depth over the ribeye and more kidney fat compared to SBM, although there were no other treatment differences noted in carcass yield or quality (Stanford et al. 1995).

2.5 Sampling Techniques and Estimation of Diet Digestibility

Understanding the site and extent of diet digestibility can help to improve understanding of the differences occurring in performance of animals, particularly in relationship to responses to protein supplementation (Titgemeyer 1997). There are several techniques used to estimate apparent ruminal digestibility and total tract digestibility and determining the most accurate method can be somewhat difficult (Rotta et al. 2014).

2.5.1 Apparent Rumen Digestibility Techniques

2.5.1.1 In Situ Fermentation

In situ techniques can be useful in estimating ruminal degradation of feed due to its relative ease to perform and the ability to estimate and include degradation rates (Von Keyserlingk and Mathison 1989; Weiss 1994). There are multiple factors that need to be accounted for to ensure accuracy in the prediction of rumen degradability of feed, including bag size, pore size and uniformity, fabric type, bacterial contamination, and variability within samples (Weiss 1994). The accuracy of the in situ technique can be improved if the incubation time used is based on the plateau in digestion (Weiss 1994). An in situ incubation time of 72

hours is needed for higher forage diets to accurately predict crude protein degradability while 48 hours is sufficient for high concentrate feeds (Weiss 1994).

In a trial comparing in situ digestibility of common forages with calculated total tract digestibility from total collection, it was found that single incubation time of 24 or 36 h most accurately predicted dry matter digestibility with correlations of 0.92 and 0.89, respectively (Von Keyserlingk and Mathison 1989). It was also found that incorporating degradation and passage rates into the prediction equations improved the predictability of diet digestibility from in situ incubations (Von Keyserlingk and Mathison 1989). In another trial comparing in situ degradability with in vivo digestibility of ensiled corn and two varieties of ensiled amaranth, it was found that diet digestibility was not the same as that estimated using in situ degradability. The ensiled amaranth varieties had higher total tract digestibility in vivo than the ensiled corn, whereas the ensiled corn had a higher in situ degradability than ensiled amaranth (Karimi Rahjerdi et al. 2015). The authors suggested this was because of differences in the chemical compositions of the forages leading to digestion occurring in different parts of the digestive tract (Karimi Rahjerdi et al. 2015). Similarly, in a comparison of corn genetics and cutting height on in situ degradability and in vivo digestibility, Kennington et al. (2005) found that the in situ DM degradability did not align with in vivo DM digestibility estimates. They suggested that this was due to retention time and passage rate in the rumen affecting total tract digestion (Kennington et al. 2005). Since in situ degradability does not take into account mastication, rumination, or feed structure, it should not be used to determine total tract digestion (Weiss 1994; Kennington et al. 2005).

Compared to other methods used to determine the RUP/RDP, the in situ technique can be one of the best (Edmunds et al. 2012). Although it does have its limitations, it is highly correlated to in vivo digestibility as of the laboratory based feed evaluation techniques, it most closely mimics in vivo conditions (Edmunds et al. 2012). However, in situ determination of RUP could be overestimated by failing to account for passage rate (Schwab et al. 2003). Passage rate can be determined through one of three methods: by using the same rate for all feeds, by using one rate for forages and one for concentrates, and by calculating the passage rate based on the DMI and diet characteristics (Schwab et al. 2003). Dry matter intake, feed characteristics, and body weight are important factors that determine passage rate, and are therefore important in

determining RUP and RDP values of the feeds (Schwab et al. 2003). Using the wrong passage rate in the equations could result in an under or over estimation of RUP (Schwab et al. 2003).

2.5.1.2 Omasal Sampling

One of the more accurate ways to determine ruminal digestibility of the diet has been omasal sampling using dual or triple markers (Krizsan et al. 2010; Rotta et al. 2014). Samples of the digesta flowing past the omasal canal can be obtained via inserting a sampling device into the omasal canal from the reticulum (Huhtanen et al. 1997). There are multiple options for markers to determine the ruminal outflow using this method. Dual or triple marker methods have been found to work best to estimate ruminal outflow and digestibility, with Cr, Co, Yb, indigestible NDF (**iNDF**) or ADF (**iADF**), and acid insoluble ash all being used as markers (Rotta et al. 2014). While markers can be useful in estimating ruminal outflow, they do present some problems: incomplete recovery, variation in outflow, and unrepresentative samples are the primary issues (Titgemeyer 1997). Higher grain diets tend to have lower marker recoveries which can lead to an underestimation of ruminal outflow (Titgemeyer 1997). Errors in ruminal outflow estimation can also occur when the concentration of marker is not accurate relative to the total digesta flow or when the total concentration of marker is representative of the total flow but the digesta is not (Titgemeyer 1997). This error can occur in higher grain diets and can lead to underestimation of nutrient and microbial protein flow out of the rumen (Titgemeyer 1997).

Omasal sampling has been found to be an acceptable alternative to measuring ruminal outflow of nutrients using abomasal or duodenal cannulas (Rotta et al. 2014). In a trial comparing reticular, omasal, and abomasal sampling using single, double, or triple marker methods, Rotta et al. (2014) determined that omasal and abomasal sampling produced similar digestibility results to reticular sampling, although nutrient flows were higher than expected. Apparent digestibility of CP in the rumen should be zero or slightly negative, and these authors found that CP digestibility calculated from omasal and abomasal sampling met this target while CP digestibility calculated from reticular sampling did not. However, Hristov (2007) found that there were no differences in estimated flow of microbial nitrogen and non-ammonia nitrogen between reticular and duodenal sampling. Omasal or reticular sampling likely provides a more accurate picture of nitrogen digested in the rumen compared to duodenal or abomasal sampling due to the avoidance of abomasal degradation of microbial nitrogen and secretion of endogenous

nitrogen sources (Krizsan et al. 2010). However, as mentioned earlier, there may be some errors when using the omasal sampling technique on higher grain diets, resulting in an underestimation of nutrient flow out of the rumen (Titgemeyer 1997). It is also possible that the digesta flowing out of the omasal canal can become contaminated with ruminal contents if they are mixed prior to or while inserting the sampling device. This could result in the collection of samples that do not represent the true contents that are flowing to the omasum(Rotta et al. 2014).

The acceptable range for ruminal digestibility of nutrients can be quite wide due to variation in the types of diets being fed (Titgemeyer 1997). The range for organic matter apparently digested in the rumen can be 30-60% and organic matter truly digested in the rumen from 40 to 70% (Titgemeyer 1997). The flow of nitrogen out of the rumen should be 70 to 130% of intake, nitrogen flows greater than 100% indicate that nitrogen recycling and microbial protein synthesis is taking place. Urea recycling is particularly important when lower protein or highly fermentable diets are being fed, or when the protein is not very degradable (Titgemeyer 1997). Microbial efficiency can also vary quite a lot with values reported from 10 to 40 g microbial N /kg organic matter truly digested in the rumen (Titgemeyer 1997; Chibisa et al. 2012). Diet type and feeding levels have a major effect on the flow of these nutrients, therefore the range is quite wide (Titgemeyer 1997).

2.5.2 Total Tract Digestibility Techniques

Total collection of urine and feces is the most accurate way to determine total tract digestion of nutrients in animals (Weiss 1994). In cases where total collection of urine and feces from animals is not feasible, internal markers can be used to estimate fecal output and therefore digestibility of the diet (Huhtanen et al. 1994). An ideal marker is one that is not absorbed or affected by the digestive tract, is intimately associated with the digesta, is specific and sensitive to analysis, and doesn't affect the function of the microbiota or the gastrointestinal tract (Owens and Hanson 1992). In a comparison of total collection to the accuracy of 10 different internal markers, it was found that iNDF and iADF can be accurate at predicting diet digestibility (Huhtanen et al. 1994). The iNDF or iADF values that were most accurate were those determined using 288 h rumen incubations and nylon bags with a pore size of 6 μm (Huhtanen et al. 1994). While these markers were the most accurate compared to total collection, the recovery of the markers was still less than 100%, meaning that markers underestimated digestibility

(Huhtanen et al. 1994). These authors suggested that the underestimation of diet digestibility could have been caused by particle loss from the bags and that not grinding or coarse grinding would improve digestibility estimates (Huhtanen et al. 1994). Variations in fiber analysis can also account introduce variability into digestibility estimates (Owens and Hanson 1992). While not as accurate , iNDF or iADF are acceptable markers for estimation of fecal output because they are not absorbed or altered within the digestive tract, are natural components of digesta that require no preparation, and are easily analyzed (Owens and Hanson 1992).

2.6 Summary

Canola is economically important to Canada, as is the oil and meal and as the canola acreage continues to expand, so will the availability of canola meal as a protein supplement for beef cattle. Canola meal has been found to have a similar CP level to WDDGS and slightly lower CP level than SBM. The CP of CM has a good balance between RDP and RUP and high concentrations of rumen escape essential amino acids, especially lysine and methionine, making it favourable for dairy producers.

Canola meal has been very well researched in the dairy industry, with most studies reporting either similar or improved milk yields, milk protein, and DMI in cows fed CM compared to other protein supplements such as SBM, WDDGS, and corn DDGS. The flow of RUP and essential amino acids is also increased with CM compared to other protein supplements, contirbuting to the improved milk yield.

While CM has not been as thoroughly researched in beef cattle and lambs, there are still some positive results. The majority of studies found similar or improved DMI, nutrient digestibility, ADG, feed efficiency, and carcass quality in steers or lambs fed CM compared to other protein supplements. As SBM begins to lose market share, more research is needed to compare it to protein supplements that are growing in popularity, like CM and WDDGS, and how they influence the growth performance and carcass quality of feedlot cattle. How each protein supplement effects ruminal and total tract digestibility and ruminal microbial protein production in beef cattle is also of interest.

2.7 Hypotheses

The hypothesis of this research is that increasing the RUP of backgrounding and finishing diets by supplementing CM and/or WDDGS will improve backgrounding and finishing growth performance compared to diets containing SBM. Rumen fermentation will be largely unaffected by protein supplement, but additional RUP in diets including CM and/or WDDGS will decrease microbial protein production and increase flow of non-ammonia non-bacterial protein compared to diets containing SBM.

2.8 Objectives

The objective of this research was to evaluate canola meal as a protein supplement for beef cattle. The specific objectives of the trials were:

1. To compare the performance of growing beef cattle fed CM as a protein supplement relative to those fed SBM with or without WDDGS.
2. To determine the effect of CM vs SBM with or without WDDGS or WDDGS alone on the performance and carcass quality of finishing cattle.
3. To determine if CM supplementation either alone or in combination with a RUP source, in the form of WDDGS, improves rumen fermentation, microbial protein synthesis and intestinal amino acid supply in growing beef cattle.

3.0 THE EFFECT OF CANOLA MEAL VERSUS SOYBEAN MEAL ON GROWTH PERFORMANCE AND CARCASS QUALITY OF FEEDLOT CATTLE.

Abstract

Two trials were conducted to evaluate the performance and carcass characteristics of backgrounding and finishing cattle fed canola meal (**CM**) versus soybean meal (**SBM**) as a protein supplement with or without wheat dried distillers' grains with solubles (**WDDGS**). Trial 1 was a 95-d backgrounding program in which 398 steer calves (288 ± 17.6 kg; mean ± SD) were randomly assigned to one of 12 pens and fed one of four diets with either CM, SBM, CM+WDDGS, or SBM+WDDGS as a protein supplement. The barley silage, barley grain-based diets were formulated to 13.5% CP, with 1.52 and 0.92 Mcal kg^{-1} NE_m and NE_g, respectively. Trial 2 utilized 300 steer calves (305 ± 18.4kg) assigned to 25 pens for a 61-d backgrounding and 147-d finishing program. Backgrounding diets were identical to Trial 1 with the addition of a fifth treatment (WDDGS). The basal finishing diet was barley grain-based and formulated to 13% CP, with 1.95 and 1.30 Mcal kg^{-1} NE_m and NE_g, respectively. The five dietary treatments were CM, SBM, WDDGS, CM+WDDGS, or SBM+WDDGS. Performance data were analyzed as a completely randomized design using pen as the experimental unit. Quality and yield grades were analyzed using GLIMMIX with a binomial error structure and logit data transformation. In Trial 1, there were no differences between treatments for final BW (420.7 ± 1.8 kg; mean ± SE; $P = 0.30$), or gain-to-feed (G:F) (0.16 ± 0.003; $P = 0.60$). Compared to the other three treatments, cattle fed SBM had greater ADG ($P < 0.05$) relative to cattle fed SBM+WDDGS (1.45 ± 0.04 kg vs. 1.32 ± 0.03 kg) but also the numerical highest feed cost of gain ($1.03 kg^{-1}). In Trial 2, no treatment differences ($P > 0.22$) were detected for overall ADG (1.65 ± 0.01 kg), DMI (9.77 ± 0.07 kg), or G:F (0.17 ± 0.001). Cattle fed SBM+WDDGS had the least subcutaneous fat depth relative as compared to cattle fed CM+WDDGS (1.17 ± 0.06 cm vs. 1.46 ± 0.05 cm; $P = 0.02$) and the poorest marbling score relative to cattle fed WDDGS (398.75 ± 15.19 vs. 440.10 ± 8.20; $P = 0.05$). There was a tendency ($P = 0.09$) for greater proportion of AAA carcasses with the WDDGS treatment (66.1 ± 6.2%) while SBM+WDDGS had the least (41.4 ± 6.5%). These results indicate that CM is equal to SBM as a protein supplement for backgrounding and finishing cattle and that provision of WDDGS as a source of rumen undegradable protein did not

benefit performance, although it did reduce the cost of gain. The combination of SBM+WDDGS negatively influenced energy partitioning by reducing fat deposition.

3.1 Introduction

Canola production generates almost one quarter of the annual farm cash receipts in Canada (Canola Council of Canada 2017a), making the use of this crop and its by-products important for Canadian agriculture. In any given year, Canada produces approximately 15 million tonnes of seed and crushes approximately 10 million tonnes, producing about 5 million tonnes of CM (Canola Council of Canada 2017a). The main use for canola meal (CM) is as a protein supplement for livestock. It is palatable and has low glucosinolate levels as well as a superior balance of amino acids when compared to other protein sources such as soybean meal (Canola Council of Canada 2017b).

In dairy cattle, canola meal has been relatively well studied as a protein source for lactating cows (Huhtanen et al. 2011). Multiple studies have found either no change or an improvement in milk quality and production when canola meal is compared to other common protein supplements (Huhtanen et al. 2011). In contrast, canola meal as a protein supplement for beef cattle is not as well studied. Petit et al. (1994) found that steers fed diets supplemented with canola meal tended to have a slightly heavier carcass than those supplemented with molasses. Canola meal has previously been found to improve ADG and feed efficiency compared to WDDGS or SBM or a corn gluten meal blood meal combination (Veira et al. 1995). In trials using lambs, CM fed lambs had similar ADG, feed efficiency, carcass yield, and carcass grade to lambs fed SBM, urea, or lupin seeds (Stanford et al. 1995, 1996; Wiese et al. 2003; McKeown et al. 2010)

Feeds that are high in RUP have been found to improve nitrogen retention, nitrogen utilization, and metabolizable protein supply in growing lambs and beef steers (Cecava and Parker 1993; Atkinson et al. 2007a, 2007b), leading to an increase in growth performance. Canola meal has been known to be intermediate in RUP content, higher than SBM but lower than WDDGS (Canadian International Grains Institute 2013, Canola Council of Canada 2015). Multiple studies have looked at the effect of using WDDGS as an energy source in finishing beef cattle diets and have found that it is an effective replacement for barley grain (Beliveau and

McKinnon 2008; Walter et al. 2010). Based on this, WDDGS could have value as a source of additional RUP as well as energy in feedlot diets.

There has been no direct comparison of canola meal to soybean meal for growing and finishing cattle, nor has there been any research done to show the possible benefit of including a RUP source in combination with canola meal on growth and feed efficiency of cattle.

The objective of this experiment was to determine the effect of CM versus SBM on growth performance and carcass characteristics of feedlot steers and to determine the effect of supplemental RUP in the form of WDDGS on these parameters.

3.2 Materials and Methods

3.2.1 Animal Management

Two separate trials were conducted to evaluate the effects of CM versus SBM on feedlot performance. The first consisted of a 95 day backgrounding period and the second consisted of a 61 day backgrounding period followed by a 147 day finishing period.

For Trial 1, 398 cross-bred steer calves (288 ± 17.6 kg; mean ± standard error) were purchased and shipped to the Beef Cattle Research Unit (**BCRU**) where they each received Bimectin pour-on (Bimeda Canada, Cambridge, Ontario) to protect against lice, mites, and gastrointestinal parasites, UltraBac 7Somnubac (Zoetis Canada, Kirkland, Quebec) for protection against clostridial organisms, Bovishield Gold One Shot (Zoetis Canada, Kirkland, Quebec) to protect against IBR and BVD, Liquamyacin LA (Zoetis Canada, Kirkland, Quebec) as a metaphylactic treatment against pneumonia, and a Ralgro implant (Merck Animal Health, Kirkland, Quebec). Once processed they were stratified by weight and then randomly assigned to one of 12 pens. Each pen was randomly assigned to one of four treatments. This resulted in three pens per treatment, and 33 animals per pen in a completely randomized design.

For Trial 2, 300 cross-bred steer calves (305 ± 18.4 kg) were purchased from commercial sources and shipped to the BCRU where they were processed according to the same protocol as described for Trial 1. Once processed they were stratified by weight and then randomly assigned to one of 25 pens. Each pen was randomly assigned to one of five treatments. This resulted in five pens per treatment, and 12 animals per pen in a completely randomized design. After 57 days on feed, steers were re-implanted with Revalor G (Merck Animal Health, Kirkland,

Quebec) and after 111 days re-implanted again with Revalor S (Merck Animal Health, Kirkland, Quebec).

Prior to initiation of both trials, cattle were provided with a receiving diet consisting of 20% brome grass hay, 50% barley silage, 20% barley grain, and 10% supplement. All steers were cared for according to the guidelines of the Canadian Council on Animal Care (2009) the protocol was reviewed and approved by the University of Saskatchewan Animal Research and Ethics Board.

3.2.2 Diets and Feeding Management

Diets fed in Trial 1 are shown in Table 3.1. The backgrounding diet consisted of barley grain, brome grass hay, barley silage, a vitamin/mineral supplement, and one of the four protein treatments. These treatments included: (1) CM at 8.7% of the diet, (2) SBM at 7.0% of the diet, (3) CM+WDDGS at 4.6 and 4.8% of the diet, and (4) SBM+WDDGS at 4.2 and 4.4% of the diet (dry matter basis). The rations were formulated for 13.5% CP and 1.52 and 0.92 Mcal kg^{-1} NE_m and NE_g, respectively, which met or exceeded the National Research Council requirements for beef cattle (BCNRM 2016). All diets also contained 33 mg kg^{-1} monensin sodium (Elanco Animal Health, Calgary, AB). Treatments were designed to vary in RUP delivered in the feed by having an approximate 50:50 ratio of CM or SBM to WDDGS in two of the treatments. Ingredient RUP values for CM (48.1%), SBM (33.3%), and WDDGS (54.5%) were taken from the Canola Council of Canada (2015) and Canadian International Grains Institute (2014). The barley grain RUP content (32.8%) was taken from Prusty et al. (2014), the brome hay RUP content (39.1%) from Kononoff et al. (2007), the barley silage RUP (20.8%) from the BCNRM (2016), and the supplement RUP value (33%) was assigned based on its ingredient composition. Based on these values, target RUP content for each of the diets, as a % CP was: CM- 33.7%, SBM- 29.9%, CM+WDDGS- 35.1%, SBM+WDDGS- 32.8%. Actual RUP values for the supplements were determined by in situ incubation.

Table 3.1. Composition and analysis of diets used to evaluate the effect of canola meal (CM) versus soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS) on backgrounding growth performance.

	Treatment			
	CM	SBM	CM+ WDDGS	SBM+ WDDGS
Diet Composition (% DM basis)				
Barley Silage	33.8	33.3	31.8	32.3
Barley Grain	29.5	30.3	29.8	30.0
Brome Hay	21.2	22.4	22.0	22.1
Canola Meal	8.7	-	4.6	-
Soybean Meal	-	7.0	-	4.2
Wheat DDGS	-	-	4.8	4.4
Supplement	6.9	7.1	7.0	7.0
Diet Analysis (% DM basis)				
Crude Protein	13.0 ± 0.33	13.3 ± 0.34	13.2 ± 0.28	13.5 ± 0.34
Ether Extract	1.9 ± 0.10	2.6 ± 0.04	2.8 ± 0.02	2.6 ± 0.04
Acid Detergent Fiber	28.4 ± 0.79	28.6 ± 0.12	28.5 ± 0.46	27.8 ± 0.12
Neutral Detergent Fiber	44.7 ± 1.19	44.3 ± 0.87	44.6 ± 1.15	44.0 ± 0.87
Calcium	0.9 ± 0.06	0.8 ± 0.07	0.9 ± 0.05	0.8 ± 0.07
Phosphorus	0.3 ± 0.02	1.5 ± 0.84	0.3 ± 0.01	0.3 ± 0.01
Net Energy of Maintenance (Mcal kg^{-1})	1.4 ± 0.01	1.5 ± 0.06	1.5 ± 0.01	1.5 ± 0.01
Net Energy of Gain (Mcal kg^{-1})	0.8 ± 0.02	0.9 ± 0.03	0.9 ± 0.02	0.9 ± 0.01

Note: Ration analysis values displayed as mean ± standard error. Net Energy of Maintenance and Net Energy of Gain based on chemical analysis of feed. Supplement nutrient composition: 9.8% CP, 10.0% Ca, 0.4% P, 1.8% Na, 0.3% Mg, 0.7% K, 0.1% S, 5.3 mg Co, 201.1 mg Cu, 18.0 mg I, 91.3 mg Fe, 543.5 mg Mn, 606.5 mg Zn, 108.7 mg Fl, 43,478.3 IU Vitamin A, 5,434.8 IU Vitamin D3, 652.2 IU Vitamin E, 456.5 mg Monensin.

Diets used in Trial 2 are shown in Table 3.2 and Table 3.3. The backgrounding diets were identical to those used in Trial 1 with the addition of a 5th treatment where WDDGS was fed as the sole protein supplement at 9.52% of the diet dry matter. The finishing rations included barley grain, barley silage, a vitamin/mineral supplement, and were supplemented with one of the five protein treatments. Treatments included: (1) CM at 5.7% of the diet, (2) SBM at 4.3% of the diet, (3) WDDGS at 6.7% of the diet, (4) CM+WDDGS at 3.0% and 3.1% of the diet, respectively and (5) SBM+WDDGS supplemented at 2.4% and 2.6% of the dietary DM, respectively. The rations were formulated to 13% CP and 1.95 and 1.30 Mcal kg^{-1} NE_m and NE_g, respectively so as to meet or exceed the National Research Council requirements (BCNRM 2016) for trace minerals and fat-soluble vitamins. Diets also contained 33 mg kg^{-1} monensin sodium (Elanco Animal Health, Calgary, AB). Ingredient RUP values were the same as Trial 1, with target dietary RUP values as a % CP being CM- 34.9%, SBM- 32.0%, WDDGS- 36.6%, CM+WDDGS- 35.5%, SBM+WDDGS- 33.8%.

Cattle in both trials were fed ad libitum with feed being delivered once daily and the amount of feed delivered to each pen recorded daily. Canola meal and SBM for both trials were supplied by Federated Co-op Ltd. (Saskatoon, SK) and WDDGS were supplied by North West Terminal Ltd. (Unity, SK).

3.2.3 Feed Analysis

Every two weeks, a sample from each diet was taken, dried, and ground using a hammer mill through a 1 mm screen (Christy and Norris 8" Lab mill, Christy Turner Ltd. Chelmsford, UK). The feed bunks were cleaned every two weeks prior to weighing of the cattle and orts were weighed, dried, and discarded.

Actual dry matter intakes were determined based on dry matter delivered to the bunk and corrected for orts. Samples of silage and hay were taken every two weeks and analyzed for dry matter. Moisture content of silage and hay was used to adjust ration composition as necessary. A sample of barley grain, CM, SBM, and WDDGS was taken from each load used throughout the two trials, dried, and ground through a 1 mm screen (Retsch, Haan, Germany). Monthly composite TMR samples and samples of CM, SBM, WDDGS, and barley grain were sent to Cumberland Valley Analytical Services (Hagerstown, MD).

Table 3.2. Composition and analysis of backgrounding diets used to evaluate the effect of canola meal (CM) or soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS), or WDDGS on finishing growth performance and carcass characteristics.

	Treatment				
	CM	SBM	WDDGS	CM+ WDDGS	SBM+ WDDGS
Diet Composition (% DM basis)					
Barley Silage	33.8	33.3	31.8	31.8	32.3
Barley Grain	29.5	30.3	29.8	29.8	30.0
Brome Hay	21.2	22.4	22.0	22.0	22.1
Canola Meal	8.7	-	-	4.6	-
Soybean Meal	-	7.0	-	-	4.2
Wheat DDGS	-	-	9.5	4.8	4.4
Supplement	6.9	7.1	7.0	7.0	7.0
Diet Analysis (% DM basis)					
Crude Protein	13.5 ± 0.22	13.0 ± 0.49	13.7 ± 0.22	13.1 ± 0.55	13.6 ± 0.39
Ether Extract	2.7 ± 0.10	2.2 ± 0.06	2.1 ± 0.05	2.2 ± 0.09	2.2 ± 0.24
Acid Detergent Fiber	17.7 ± 5.42	17.0 ± 6.34	16.7 ± 5.12	16.7 ± 5.9	17.4 ± 5.65
Neutral Detergent Fiber	29.8 ± 7.6	29.5 ± 8.43	29.6 ± 6.82	29.1 ± 8.09	29.7 ± 7.63
Calcium	0.8 ± 0.12	0.6 ±0.08	0.6 ± 0.06	0.7 ± 0.10	0.6 ± 0.09
Phosphorus	0.4 ± 0.03	0.4 ± 0.03	0.4 ± 0.03	0.4 ± 0.03	0.4 ± 0.04
Net Energy of Maintenance (Mcal kg^{-1})	1.7 ± 0.13	1.7 ± 0.15	1.7 ± 0.11	1.8 ± 0.17	1.7 ± 0.14
Net Energy of Gain (Mcal kg^{-1})	1.1 ± 0.1	1.1 ± 0.13	1.1 ± 0.10	1.1 ± 0.12	1.1 ± 0.12

Note: Ration analysis values displayed as mean ± standard error. Net Energy of Maintenance and Net Energy of Gain based on chemical analysis of feed. Supplement nutrient composition: 9.8% CP, 10.0% Ca, 0.4% P, 1.8% Na, 0.3% Mg, 0.7% K, 0.1% S, 5.3 mg Co, 201.1 mg Cu, 18.0 mg I, 91.3 mg Fe, 543.5 mg Mn, 606.5 mg Zn, 108.7 mg Fl, 43,478.3 IU Vitamin A, 5,434.8 IU Vitamin D3, 652.2 IU Vitamin E, 456.5 mg Monensin.

Table 3.3. Composition and analysis of finishing diets used to evaluate the effect of canola meal (CM) or soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS) or WDDGS on finishing growth performance and carcass characteristics.

	Treatment				
	CM	SBM	WDDGS	CM+ WDDGS	SBM+ WDDGS
Diet Composition (% DM basis)					
Barley Silage	5.5	7.2	6.0	6.3	6.9
Barley Grain	83.5	83.2	82.0	82.4	82.9
Canola Meal	5.7	-	-	3.0	-
Soybean Meal	-	4.3	-	-	2.4
Wheat DDGS	-	-	6.7	3.1	2.6
Supplement	5.3	5.3	5.3	5.3	5.3
Ration Analysis (% DM basis)					
Crude Protein	12.5 ± 0.06	12.7 ± 0.29	13.2 ± 0.36	12.3 ± 0.06	12.7 ± 0.11
Ether Extract	2.0 ± 0.04	2.1 ± 0.06	2.6 ± 0.18	1.8 ± 0.28	1.9 ± 0.07
Acid Detergent Fiber	7.3 ± 0.28	7.0 ± 0.21	7.6 ± 0.31	7.0 ± 0.32	7.4 ± 0.27
Neutral Detergent Fiber	14.5 ± 0.65	14.7 ± 0.55	15.9 ± 0.36	14.3 ± 0.73	15.5 ± 0.34
Calcium	0.5 ± 0.02	0.5 ± 0.02	0.5 ± 0.02	0.5 ± 0.01	0.4 ± 0.02
Phosphorus	0.4 ± 0.01	0.4 ± 0.003	0.4 ± 0.01	0.4 ± 0.003	0.4 ± 0.004
Net Energy of Maintenance (Mcal kg^{-1})	1.9 ± 0.01	2.0 ± 0.01	2.0 ± 0.01	2.0 ± 0.01	1.9 ± 0.01
Net Energy of Gain (Mcal kg^{-1})	1.3 ± 0.01	1.3 ± 0.01	1.3 ± 0.01	1.3 ± 0.01	1.3 ± 0.01

Note: Ration analysis values displayed as mean ± standard error. Net Energy of Maintenance and Net Energy of Gain based on chemical analysis of feed. Supplement nutrient composition: 9.8% CP, 10.0% Ca, 0.4% P, 1.8% Na, 0.3% Mg, 0.7% K, 0.1% S, 5.3 mg Co, 201.1 mg Cu, 18.0 mg I, 91.3 mg Fe, 543.5 mg Mn, 606.5 mg Zn, 108.7 mg Fl, 43,478.3 IU Vitamin A, 5,434.8 IU Vitamin D3, 652.2 IU Vitamin E, 597.8 mg Monensin

Feed samples were analyzed in duplicate according to the Association of Official Analytical Chemists (2000) for DM (AOAC method 930.15), ash (AOAC method 942.05), CP using the nitrogen combustion method (AOAC method 990.02), NDF (Van Soest et al. 1991), ADF (AOAC method 973.18), EE (AOAC method 920.39), and minerals including calcium, phosphorus, magnesium, potassium, and sodium (AOAC 985.01).

3.2.4 Trial 1 Performance Data

At the beginning of Trial 1, steers were weighed on two consecutive days prior to feeding to provide an average start of trial weight. They were weighed every 2 weeks prior to the morning feeding and again on two consecutive days at the end of the trial to provide an average end of trial weight. Shrunk weights (96% of live weight) were used to calculate live weight gains. Dietary NE_g and NE_m levels were calculated based on performance data according to Zinn et al. (2002). An economic analysis was done to analyze feed cost of gain. Total feed cost per kg of feed was calculated by using feed benchmark prices from December 2016 (Alberta Pulse Growers, 2016) to determine the cost per tonne of feed (DM basis). Total feed cost per kg of feed was then multiplied by the average DMI for each pen and divided by the average pen ADG to estimate cost of gain.

3.2.5 Trial 2 Performance Data

Performance data for steers in Trial 2 was collected similarly to Trial 1. Cattle were not re-randomized between backgrounding and finishing as a systems approach was taken to evaluate the effects of these protein supplements from receiving to finishing. At the end of the finishing period, cattle were shipped to Cargill Foods (High River, AB) where the carcasses were graded using a camera grading system to determine *Longissimus thoracis* area (**LM**), subcutaneous fat thickness, marbling score, and yield grade. Dressing percentage was calculated from carcass and live weight. Feed cost of gain was calculated in the same manner as Trial 1, using the same feed prices. The final value of the finished steers was based on the live weight price for the finished steers. The price per hundred weight reported was converted to dollars per kg and then multiplied by the pen average end of trial live weight to determine the final live weight value.

To determine changes in the fatty acid composition of subcutaneous fat as a result of feeding CM versus SBM with or without WDDGS, biopsies were taken at the start and finish of Trial 2. Eight head were randomly selected from the total population within the first week on feed and a biopsy of subcutaneous fat was taken from the tail-head. The left side of the tail head was frozen with Lidocaine, a small incision was made and tweezers were used to collect 0.5 g of subcutaneous fat. Once finished, 9 steers were randomly selected from each treatment for fat sampling, with the exception of cattle fed SBM+WDDGS where 8 steers were selected due to trailer load limits. A 50 g fat sample was collected from the right side of the brisket and kept on ice while transported to the University of Saskatchewan. All fat samples were stored -20°C until analysis.

Fat samples were thawed and analyzed at the Lacombe Research and Development Centre (Lacombe, AB). Fatty acids were extracted and methylated as described by Aldai et al. (2014). Analysis of Fatty acid methyl esters (**FAME**) was completed using a gas chromatograph (CP-3800; Varian Inc., Walnut Creek, CA) with a BR2560 fused silica column (Bruker, Billerica, MA) and 8600 series auto-sampler. FAME peaks were identified using standard 603 from Nu-Check Prep, Inc. (Elysian, MN). FAME were quantified using the chromatographic peak area and internal standard based calculations. Fatty acid concentrations were calculated as a % of total FAME using a relative response factor of 1.

3.2.6 *In Situ* Trial

An *in situ* trial was done to determine the RDP and RUP values of CM, SBM, and WDDGS. The trial took place at the Rayner Dairy Research and Teaching Facility using 2 dry cows fed diets similar to the CM diet in Trial 1. One sample each of CM, SBM, and WDDGS was collected at the end of the trial to determine RUP content of each of the protein supplements. Due to the similar small particle size of the protein supplements (CM- 495.1 ± 2.3 microns; SBM- 589.8 ± 2.2 microns; WDDGS- 513.7 ± 2.1 microns), samples were not ground prior to incubation.

Seven ± 0.5 grams of CM, SBM, or WDDGS were weighed into nylon bags with a 41μm pore size. The bags were tied approximately 2 cm below the top, providing a sample to bag surface area ratio of 39 mg cm^2. Rumen incubations were performed according to the 'gradual in - all out' schedule, with bags incubated for 0, 2, 4, 8, 12, 24, and 48 h. Following incubation, bags were removed from the rumen and rinsed in cold water to remove excess ruminal contents

and then thoroughly washed in cold water. Bags were then dried at 55°C for 48 h in a forced air oven. After drying, the bags were exposed to room temperature and humidity for 24 h before being weighed. The incubations were repeated 3 times in each cow. Once bags were weighed, moisture and CP analyses were done to determine effective degradability of DM and CP.

Kinetic analyses were conducted to determine the soluble fraction (S, %), potentially degradable fraction (D, %), the undegradable fraction (U, %), the rate of degradation (Kd, $\%h^{-1}$), and lag time (T0, h) using the non-linear model of SAS version 9.4 (SAS Institute Inc. Cary, NC) using iterative least squares regression. The modified first-order equation with lag time of Ørskov and McDonald (1979)

$$R(t) = U + (100 - S - U) \times e^{-Kd \times (t - T0)}$$

was used; where R(t) is defined as the amount of material remaining after t h of ruminal incubation. Effective degradability (ED, %) of each protein supplement was calculated according to Ørskov and McDonald (1979) with an assumed passage rate of 6% h^{-1}. The effective degradability of dry matter was calculated as:

$$\%EDDM = S+D*Kd/(Kd+Kp)$$

the effective degradability of CP as:

$$\%EDCP = S+D*Kd/(Kd+Kp)$$

and the RUP content of CP as:

$$\%RUP = D * Kp/(Kp+Kd) + U.$$

3.2.7 Statistical Analysis

All performance and most carcass data was analyzed as a completely randomized design using the Mixed model procedure of SAS (version 9.4; SAS Institute Inc. Cary, NC) with pen as the experimental unit and treatment as the fixed effect. Denominator degrees of freedom were determined using the Kenward-Roger option and the Satterthwaite adjustment. Results were analyzed using the Tukey test. Significance was declared where $P \leq 0.05$ and trends declared where $P \leq 0.10$. Quality and yield grades were analyzed using the GLIMMIX macro (version 9.4; SAS Institute Inc. Cary, NC) with a binomial error structure and logit data transformation. In situ degradation parameters were analyzed as a completely randomized design using the Mixed model procedure of SAS with protein supplement as a fixed effect.

3.3 Results & Discussion

3.3.1 Diet and Ingredient Composition

Chemical composition of the CM, SBM, and WDDGS are presented in Table 3.4. The CM utilized in this study averaged 40.1 ± 0.5 % CP. Compared to CM, SBM had higher CP (50.0 ± 0.5%) whereas WDDGS was similar (39.4 ± 1.0%). The CP of CM used in this study was higher than the average (36.7%) reported by the Canola Council of Canada (2015), however, it is still within the range of reported by others (Kendall et al. 1991; Broderick et al. 2015). Both SBM and WDDGS had similar CP levels to those reported (Stanford et al. 1996; Beliveau and McKinnon 2008).

In Trial 1, all diets were formulated to be isonitrogenous and isoenergetic. As seen in Table 3.1, the dietary CP ranged from 13.0% to 13.5%, with the CM+WDDGS (13.2%) and SBM+WDDGS (13.5%) diets having slightly higher protein levels than CM (13.0%) or SBM (13.5%). The slightly higher crude protein in the diets containing WDDGS is due to the initial load of WDDGS used to formulate the diet having lower CP (36.6%) than subsequent loads, meaning it was included at a slightly higher rate than was necessary. Despite the slight variation in CP, all diets met metabolizable protein requirements for growth (BCNRM 2016) and had similar EE (2.5 ± 0.1%), NE_m (1.5 ± 0.01 Mcal kg^{-1}), and NE_g (0.9 ± 0.01 Mcal kg^{-1}) values.

Both backgrounding and finishing diets in Trial 2 were formulated to be isonitrogenous (13.5 and 13% CP, respectively), however as seen in Table 3.2, backgrounding dietary CP ranged from 13.0% to 13.7% and as seen in Table 3.3 finishing dietary CP ranged from 12.3 to 13.2 %. As in Trial 1, original WDDGS used to formulate diets had a lower CP (36.6%) than subsequent loads, so the diet containing WDDGS in the finishing trial had a higher CP than other treatments. Despite the variability in CP, all diets met metabolizable protein requirements (BCNRM 2016). Despite the increased CP in WDDGS treatment, all diets had similar EE (backgrounding- 2.5 ± 0.1%; finishing- 1.9 ± 0.1%), NE_m (backgrounding- 1.5 ± 0.01 Mcal kg^{-1}; finishing-1.9 ± 0.01 Mcal kg^{-1}) and NE_g (backgrounding-0.9 ± 0.01 Mcal kg^{-1}; finishing- 1.3 ± 0.01 Mcal kg^{-1}) values.

Table 3.4. Chemical Composition of canola meal (CM), soybean meal (SBM), and wheat dried distillers' grains with solubles (WDDGS).

	Protein Supplement		
	CM	SBM	WDDGS
% DM basis			
Crude Protein	40.05 ± 0.51	50.00 ± 0.50	40.37 ± 0.22
Acid Detergent Fiber	21.68 ± 0.19	5.88 ± 0.26	13.90 ± 0.8
Neutral Detergent Fiber	29.83 ± 0.87	9.35 ± 0.49	32.57 ± 1.33
Calcium	0.91 ± 0.02	0.4 ± 0.04	0.14 ± 0.02
Phosphorus	1.20 ± 0.02	0.68 ± 0.11	1.05 ± 0.02
Total Digestible Nutrients	60.5 ± 0.47	78.78 ± 0.33	81.1 ± 0.65
Net Energy of Maintenance (Mcal $kg^{-1)}$	1.33 ± 0.01	1.90 ± 0.01	1.97 ± 0.03
Net Energy of Gain (Mcal $kg^{-1)}$	0.75 ± 0.01	1.27 ± 0.01	1.33 ± 0.01

Note: Values displayed as mean ± standard error. Net Energy of Maintenance and Net Energy of Gain based on chemical analysis of feed

3.3.2 *In Situ* Degradability

In situ protein and dry matter degradability results are presented in Table 3.5. The non-linear model used to estimate degradation characteristics appropriately fit all data used. With regard to DM disappearance, CM had a lower S fraction (18.5 ± 0.5%; $P < 0.05$) than SBM (29.9 ± 0.4%) and WDDGS (39.3 ± 0.2%) and a higher D fraction than WDDGS (64.1 ± 1.3% vs. 48.3 ± 0.6%). Soybean meal had a lower U fraction (1.5 ± 1.5%; $P < 0.05$) than CM (17.4 ± 1.3%) or WDDGS (12.4 ± 0.7%). This resulted in SBM having a higher (78.1 ± 3.9%; $P < 0.05$) effective DM degradability than CM and WDDGS (61.6 ± 1.0% and 65.6 ± 0.5%) and a lower rumen undegradable dry matter (21.9 ± 3.9 %; $P < 0.05$) compared to CM and WDDGS (38.4 ± 1% and 34.5 ± 0.6%).

As with dry matter, WDDGS had a higher S crude protein fraction (25.7 ± 0.1%; $P < 0.05$) an a lower D fraction (69.1 ± 0.6%; $P < 0.05$) than CM (S-6.8 ± 1.0%; D- 84.6 ± 1.0%) and SBM (S-9.3 ± 1.2%; D-89.1 ± 2.8%). Soybean meal had a lower U fraction (1.6 ± 1.6%; $P < 0.05$) than CM (8.6 ± 1.0%), resulting in it having the highest effective degradability of protein (61.4 ± 7.4%) CM and WDDGS (56.0 ± 1.9% and 53.1 ± 0.2%), although it was not significant ($P > 0.05$). Numerically ($P > 0.05$), WDDGS had the highest content of RUP (46.9 ± 0.2%), closely followed by CM (44.0 ± 1.9%) with SBM having the least RUP (38.6 ± 7.4%).

All three RUP values fall within the range of recently reported values (Li et al. 2012; Maxin et al. 2013b; Paz et al. 2014). However, the similarity in RUP value between CM and WDDGS was somewhat unexpected. Over the past several years, the RUP value of CM has been steadily increasing (Beauchemin et al. 1995b; Stanford et al. 1995; Patterson et al. 1999; Maxin et al. 2013b), possibly due to the fact that gums, phospholipids, and screenings are increasingly being added back into the canola meal during processing. The increase in RUP in CM is bringing its rumen degradability value closer to that of WDDGS (Li et al. 2013; Maxin et al. 2013b).

Table 3.5. Ruminal degradation characteristics of dry matter and crude protein in canola meal (CM), soybean meal(SBM), and wheat dried distillers' grains with solubles (WDDGS).

	Protein Supplements				
	CM	SBM	WDDGS	PSEM	*P* value
Dry Matter					
Kd (% h^{-1})	8.4	10.4	4.8	1.66	0.13
Lag Time (h)	0.4	0.6	0.0	0.23	0.29
S (%)	18.5c	29.9b	39.3a	0.38	<0.0001
D (%)	64.1a	68.6a	48.3b	1.24	<0.0001
U (%)	17.4a	1.5b	12.4a	1.23	0.0003
Effective Degradability (%)	61.6b	78.1a	65.5b	1.348	0.0003
Rumen Undegradable Dry Matter (%)	37.4a	21.9b	34.5a	1.348	0.0003
Crude Protein					
Kd (% h^{-1})	8.4	9.2	4.0	1.37	0.07
Lag Time (h)	0.0	0.3	0.2	0.15	0.46
S (%)	6.8b	9.3b	25.7a	0.88	<0.0001
D (%)	84.5a	89.1a	69.1b	1.92	0.001
U (%)	8.6a	1.6b	5.3ab	1.40	0.03
Effective Degradability (%)	56.0	61.4	52.1	2.54	0.14
Rumen Undegradable Protein (%)	44.0	38.6	46.9	2.54	0.14

Note: Least squares means within a row not sharing lowercase letters are different ($P < 0.05$) according to the Tukey-Kramer method PSEM = pooled standard error of the mean. Kd = rate of degradation; S = soluble fraction; D = potentially degradable fraction; U = undegradable fraction.

The CM and SBM used in this trial had S fractions lower than expected, while the S fraction in WDDGS was similar to previous estimates (Beauchemin et al. 1995b; Stanford et al. 1995; Azarfar et al. 2013; Maxin et al. 2013b; Paz et al. 2014). The low S fraction in CM and SBM could be attributed to the fact they were not ground prior to in situ incubation. Maxin et al. (2013) ground samples through a 2-mm screen prior to incubation and subsequently had a higher soluble fraction in CM (12.9%) and SBM (11.85). Other trials used bags with 50 μm porosity (Boila and Ingalls 1992; Stanford et al. 1996; Li et al. 2012) and found higher soluble fractions for CM (28.2%) and SBM (19.3%).The bags used in this trial had a smaller pore size (41μm) which could also contribute to the lower observed soluble fractions in CM and SBM.

Not only was the similar in situ degradability of CM and WDDGS seen in the in situ study unexpected, but the RUP value of SBM was also higher than the reference value used for diet formulation. Target RUP values for each of the diets were calculated according to the RUP values from Canola Council of Canada (2015) and Canadian International Grains Institute (2013) with the RUP estimated at 48.1%of CP, 33.3%, and 54.5% for CM, SBM, and WDDGS, respectively. The RUP values determined from the in situ incubation for each of the protein supplements was different from predicted, thereby altering the actual RUP supply from the predicted. The RUP content of the protein sources had a much smaller range than predicted. In Trial 1, it was predicted that the range of RUP content of the TMR would be 29.9% to 35.1% of the total dietary CP. However, using the in situ RUP values for and the literature RUP values for barley silage (20.8%), brome hay (39.1%), and barley grain (32.8%), the estimated RUP supply from each of the diets was: CM-32.6%, SBM- 31.3%, CM+WDDGS-33.5%, SBM+WDDGS-32.7%, making the range of RUP content much smaller. In Trial 2, the predicted range of RUP content of the finishing TMR was 32.0% to 36.6% of total dietary CP. When using the RUP values determined by the in situ trial for the protein supplements and literature values for barley silage (20.8%) and barley grain (50.8%), the RUP content of each diet would have been: CM-34.1%, SBM- 32.9%, WDDGS- 35.0%, CM+WDDGS- 34.4%, SBM+WDDGS-33.7%, once again making the range of RUP values smaller. The smaller range in RUP in both trials would have made the likelihood of seeing any differences because of RUP/RDP supply more unlikely.

3.3.3 Trial 1 Performance

There were no treatment differences noted ($P > 0.05$) in DMI (8.2 ± 0.1 kg d^{-1}) or G:F (0.17 ± 0.01; Table 3.6). Both these values are similar to those previously reported in trials using various protein supplements including CM, WDDGS, and SBM (Yang et al. 2012; Nair et al. 2015). This supports the theory that a variety of protein supplements can be effectively used to maintain optimum performance in growing cattle.

Average daily gain was the only parameter that showed a response to the different protein supplements during the Trial 1. Cattle fed SBM+WDDGS had a lower ($P = 0.03$) ADG (1.32 ± 0.03 kg d^{-1}) than those fed SBM (1.45 ± 0.04 kg d^{-1}) with cattle fed diets containing CM and CM+WDDGS being intermediate. In a study comparing five protein supplements, backgrounding cattle fed diets supplemented with CM or SBM had similar ADG (0.84 and 0.87 kg d^{-1}), whereas cattle supplemented with fish meal exhibited a higher ADG (0.97 kg d^{-1}) and those supplemented with meat meal a lower (0.76 kg d^{-1}) ADG (Veira et al. 1995). The fish meal supplement had the highest 18 h undegradable N value of the protein supplements examined (Veira et al. 1995). Based on their results, it would've been expected that the addition of WDDGS would improve ADG due to its higher undegradable protein concentration.

In the current study, it was hypothesized that cattle fed meals supplemented with WDDGS would have superior performance due to higher RUP levels. One possible reason for cattle fed diets containing CM, CM+WDDGS, and SBM+WDDGS having similar ADG could be that the WDDGS and CM used in this trial had similar levels of RUP (44.0 ± 1.9% vs. 46.9 ± 0.2%) while the SBM was lower in RUP (38.6 ± 0.2). Baumann et al. (2004) suggested that DM intake and DM digestibility in cattle fed medium quality forage respond differently to RDP levels because of differences in the type of energy supplementation. These authors found that supplementing RDP to diets with corn or soyhulls as the energy source had different effects on diet digestibility. While the addition of RDP to diets containing soyhulls improved duodenal flow of OM and total tract digestibility of OM and CP, the addition of RDP to corn supplemented diets improved duodenal flow of OM to a greater magnitude as well as the total tract digestibility of OM, ADF, NDF, and CP, suggesting that the corn diet was deficient in RDP (Baumann et al. 2004).

Table 3.6. Effect of canola meal (CM) versus soybean meal (SBM) with or without wheat dried distillers' grains with soluble (WDDGS) on the growth performance of backgrounding steers.

	Treatment					
	CM	SBM	CM+ WDDGS	SBM+ WDDGS	PSEM	*P* value
Start of trial weight (kg)	288.9	288.2	288.4	288.6	0.75	0.93
End of trial weight (kg)	419.5	418.5	426.4	418.7	3.31	0.33
Average daily gain (kg d^{-1})	1.37ab	1.45a	1.42ab	1.32b	0.02	0.03
Dry matter intake (kg d^{-1})	8.4	8.1	8.3	8.2	0.20	0.72
Gain:Feed	0.16	0.17	0.18	0.17	0.005	0.60
Feed cost of gain ($ kg^{-1})	0.83	0.86	0.78	0.83	0.030	0.29
Net Energy of Maintenance (Mcal kg^{-1})	1.7	1.7	1.7	1.7	0.06	0.72
Net Energy of Gain (Mcal kg^{-1})	1.1	1.1	1.1	1.1	0.05	0.72

Note: Least squares means within a row not sharing lowercase letters are different ($P < 0.05$) according to the Tukey-Kramer method. PSEM= pooled standard error of the mean. Feed cost of gain calculated based on December 2016 feed benchmark prices (Alberta Pulse Growers 2016). Net Energy of Maintenance and Net Energy of Gain calculated based on growth performance using equation according to Zinn et al. 2002.

In a trial comparing barley grain- to corn- based finishing diets with or without protein supplementation, it was found that cattle fed corn based diets with no protein supplementation had lower live weight gains and DMI (Koenig and Beauchemin 2005). It was suggested that this was due to limitations in microbial growth in the rumen due to the low availability of nitrogen in corn (Koenig and Beauchemin 2005). Microbial synthesis was sufficient in the barley based finishing diet (Koenig and Beauchemin 2005), suggesting that barley based diets may not require RUP to optimize the growth of finishing cattle. Other research has suggested that oversupplying RUP in finishing diets may adversely affect ADG due to increased energy expenditure from greater nitrogen recycling and ammonia detoxification (Wagner et al. 2010). The improvement in ADG seen in cattle fed diets with SBM in this trial could be attributed to the higher level of RDP improving diet digestibility and energy balance.

There was no treatment effects on final BW (420.7 ± 1.8 kg; $P = 0.30$) or G:F (0.16 ± 0.003; $P = 0.60$). Similar results were seen in the comparison of five protein supplements by Veira et al. (1995) with steers fed silage-based diets supplemented with fish meal, SBM, CM, corn gluten meal and blood meal, or meat meal all having similar G:F. However, this is in contrast with the results of Yang et al. (2012) who found that backgrounding cattle fed a barley based diet supplemented CM had improved feed efficiency over cattle fed diets including WDDGS. The lack of difference in G:F can likely be attributed to the similar DMI among treatments (8.2 ± 0.1 kg d^{-1}). The performance of cattle fed WDDGS can be variable due to fluctuations in CP and EE in the protein source (Yang et al. 2012). The lots of WDDGS used in this trial had similar EE levels to SBM and CM so growth performance was not limited by reduced energy levels as a result of lower EE content in the diet.

While there were no significant effects of protein supplement on feed cost of gain ($0.83 ± 0.02; $P = 0.29$), there was $0.03 per kilogram of gain saving when feeding CM ($0.83 kg^{-1}) vs. SBM ($0.86 kg^{-1}) and an additional $0.05 per kilogram when WDDGS was included in the CM diet ($0.78 kg^{-1}) and $0.03 per kilogram saved when WDDGS was included with SBM ($0.83 kg^{-1}). Feed costs were calculated based on actual cost of the brome hay and the vitamin/mineral supplement and feed benchmark prices of barley, CM, SBM, and WDDGS from December 2016 (Alberta Pulse Growers 2016). The value per tonne of barley silage was calculated as twelve times the value of barley grain per bushel according to Alberta Agriculture and Forestry (2004). The cost of the brome hay was $126.46/tonne (DM; $102.00/ tonne as fed) and the cost of the

supplement was $423.78/tonne ($389.88/tonne as fed). Barley grain was valued at $218.24 /tonne including processing, barley silage at $113.24/tonne, CM at $335.23/tonne, SBM at $535.16/tonne, and WDDGS at $225.81/tonne. While very little difference was seen in the growth performance of backgrounding steers fed CM versus SBM with or without WDDGS, the $0.08/kg difference in cost of gain between cattle fed SBM compared to cattle fed CM+WDDGS would represent a significant benefit to producers, and therefore makes CM and WDDGS the preferred protein sources for backgrounding cattle in western Canada.

3.3.4 Trial 2 Performance

Unlike Trial 1, there was no treatment effect ($P > 0.05$) on ADG (1.3 ± 0.02 kg d^{-1}) in the relatively short backgrounding period (Table 3.7). However, DMI was higher ($P = 0.04$) in cattle fed CM+WDDGS (8.4 ± 0.1 kg d^{-1}) compared to cattle fed SBM (7.9 ± 0.1 kg d^{-1}). There were no treatment effects however on G:F (0.17 ± 0.002). Although the improvement in DMI when fed CM+WDDGS was not seen in Trial 1, studies using dairy cows have noted an improvement in DMI for CM compared to SBM or WDDGS compared to CM (Huhtanen et al. 2011; Chibisa et al. 2012). The average backgrounding DMI, ADG, and G:F values seen in this trial were similar to those seen in Trial 1, as well as in other backgrounding trials using various protein supplements including CM, SBM, and WDDGS (Lardy and Kerley 1994; Yang et al. 2012; Nair et al. 2015).

There was no effect of diet ($P > 0.05$) on the DMI (10.8 ± 0.1 kg d^{-1}), ADG (1.8 ± 0.02 kg d^{-1}), or G:F (0.17 ± 0.002) of finishing steers. The ADG and G:F in this trial were higher than values reported by Hinman et al. (1999) and Nair et al. (2015) when the performance of cattle fed CM to urea or different levels and types of CM were examined. The rations in this trial had lower NDF and ADF values than those used by both Hinman et al. (1999) and Nair et al. (2015), which likely explains the improved performance of steers in the present trial. In diets varying in RDP, Wagner et al. (2010) found similar ADG to this trial and a slightly improved G:F with similar levels of fiber in the diet to this trial.

Table 3.7. Effect of canola meal (CM) or soybean meal (SBM) with or without wheat dried distillers' grains with solubles or WDDGS on the growth performance of backgrounding to finishing steers.

	Treatment						
	CM	SBM	WDDGS	CM+ WDDGS	SBM+ WDDGS	PSEM	*P* value
Start of trial weight (kg)	304.3	304.8	308.4	305.1	30.4	2.18	0.69
End of backgrounding weight (kg)	379.3	380.9	380.7	381.1	378.9	2.46	0.95
End of trial weight (kg)	642.0	658.0	647.8	654.3	645.3	5.20	0.22
Dry Matter Intake (kg d^{-1})							
Backgrounding	8.3ab	7.9b	8.2ab	8.4a	8.1ab	0.11	0.04
Finishing	11.1	10.9	10.7	10.7	10.7	0.20	0.51
Overall	10.3	10.1	10.0	10.1	10.0	0.15	0.50
Average Daily Gain (kg d^{-1})							
Backgrounding	1.34	1.36	1.34	1.36	1.36	0.040	0.97
Finishing	1.79	1.89	1.83	1.79	1.80	0.032	0.22
Overall	1.62	1.70	1.63	1.68	1.63	0.029	0.28
Gain : Feed							
Backgrounding	0.16	0.17	0.16	0.16	0.16	0.006	0.63
Finishing	0.16	0.17	0.17	0.17	0.17	0.004	0.16
Overall	0.16	0.17	0.16	0.17	0.16	0.004	0.31
Overall Feed Cost of Gain ($ kg^{-1})	1.57	1.62	1.51	1.56	1.59	0.027	0.17
Finished Live Weight Value ($ hd^{-1})	2618	2684	2642	2668	2632	21.2	0.22
NE_m of diet (MCal kg^{-1})	1.7	1.8	1.8	1.8	1.8	0.03	0.17
NE_g of diet (MCal kg^{-1})	1.1	1.2	1.1	1.1	1.1	0.02	0.15

Note: Least squares means within a row not sharing lowercase letters are different ($P < 0.05$) according to the Tukey-Kramer method. PSEM= pooled standard error of the mean. Feed cost of gain calculated based on December 2016 feed benchmark prices (Alberta Pulse Growers 2016). Net Energy of Maintenance and Net Energy of Gain calculated based on growth performance using equation according to Zinn et al. 2002.

From background to finishing, there were no diet effects ($P > 0.05$) on ADG (1.7 ± 0.01 kg d^{-1}), DMI (10.1 ± 0.1 kg), G:F (0.16 ± 0.002), or final body weight (649.5 ± 6.6 kg) in this trial. In two finishing trials comparing SBM, CM, extruded SBM, extruded CM, and ground whole seed canola, Rule et al. (1994) also did not find any significant differences in DMI, ADG, or G:F between finishing cattle fed CM or SBM. In a meta-analysis by Huuskonen et al. (2014), it was noted that the greatest effect of protein on growth was seen in younger cattle with no effect or only small effects seen in the growth of finishing cattle. This is consistent with the growth data from this trial as there were no differences between treatments regarding overall growth. The similarity in protein degradability between WDDGS and CM as found in the in situ trial likely explains the lack of effect of WDDGS on growth performance. It was predicted that additional RUP provided by the WDDGS would improve growth, however because of the similarity in degradability between CM and WDDGS, no advantages was measured.

While not significant, ($1.57 ± 0.01; $P = 0.17$) feed cost of gain was numerically higher for cattle fed diets containing SBM ($1.62 kg^{-1}) than for those supplemented with CM ($1.57 kg^{-1}) or WDDGS ($1.51 kg^{-1}). The addition of WDDGS to SBM resulted in a saving of 3 cents per kilogram ($1.59 kg^{-1}) while the addition of WDDGS to CM saved 1 cent per kilogram ($1.56 kg^{-1}). Values for feed cost of gain were the same as used in the Trial 1. As these cattle were not priced on a grid, there were no price bonuses for cattle grading Canada AAA or Prime. However, an average finished live weight value per head was determined through the price offered for live cattle and the final body weight of the steers. There were no treatment differences seen in final value based on live weight ($2649 ± 9.94; $P > 0.05$).

3.3.5 Carcass Characteristics

There were no diet effects ($P > 0.05$) on hot carcass weight (858.9 ± 3.1 kg), LM area (14.5 ± 0.1 cm^2), or dressing percentage (60.0 ± 0.1; Table 3.8). Similarly, Wagner et al. (2010) found that when the amount of RDP and total CP in the diet were increased, there was no effect on hot carcass weight, LM, or dressing percentage. Studies using lambs have also reported similar carcass yields and dressing percentages between lambs fed CM, lupin seeds, and urea (Wiese et al. 2000, 2003) and for lambs fed lignosulfonate or untreated SBM and CM (Stanford et al. 1995). Combined, these results support the theory that the type of protein supplement fed to

finishing cattle has little effect on carcass yield, provided that the protein requirements of the animal are being met (Huuskonen et al. 2014).

Carcass subcutaneous fat depth was lower ($P = 0.02$) in cattle fed SBM+WDDGS (1.17 ± 0.06 cm) as compared to cattle fed CM+WDDGS (1.46 ± 0.05 cm) with the other three treatments being intermediate. Cattle fed SBM+WDDGS also had a lower marbling score (398.75 ± 15.19) than cattle fed WDDGS (440.10 ± 8.20; $P = 0.05$). There was a tendency ($P = 0.09$) for a greater proportion of AAA carcasses with the WDDGS treatment (66.1 ± 6.2%) while SBM+WDDGS fewer AAA carcasses. Similarly, Stanford et al. (1995) found that that lambs fed diets containing CM had the higher levels of subcutaneous fat than lambs fed SBM. However, other trials using lambs found that carcass fat deposition was largely unaffected by protein source (Wiese et al. 2000, 2003; McKeown et al. 2010). An increase in dietary crude protein has been noted to improve carcass fat in beef cattle due to an increase in gluconeogenic amino acids, which can contribute to extra energy resulting in more carcass fat (Huuskonen et al. 2014). However, the SBM+WDDGS diet in this trial had a crude protein level of 12.7 ± 0.11%, which met the requirements for metabolizable protein and consequently crude protein availability did not limit partitioning of energy to fat deposition.

Lysine and methionine have been known to be critical amino acids for maintaining lean muscle deposition and growth performance in beef cattle and lambs, but most trials have found little to no effect of these amino acids on carcass fat deposition (Oke et al. 1986; Wright and Loerch 1988; Nolte et al. 2008; Hosford et al. 2015). In finishing cattle fed corn based diets, including zilpaterol with either no amino acid supplementation, ruminally protected lysine, ruminally protected methionine, or both ruminally protected lysine and methionine supplementation had no effect on marbling score. However, the steers supplemented with rumen protected lysine had a higher fat depth than cattle fed zilpaterol with no amino acids (Hosford et al. 2015).

Table 3.8. Effect of canola meal (CM) or soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS) or WDDGS on carcass composition of finishing steers.

	Treatment						
	CM	SBM	WDDGS	CM+ WDDGS	SBM+ WDDGS	PSEM	*P* value treatment
Hot carcass weight (kg)	393.2	388.8	388.8	391.1	385.3	3.21	0.50
Subcutaneous fat (cm)	1.3ab	1.3ab	1.4ab	1.5a	1.2b	0.06	0.02
Longissimus dorsi area (cm^2)	90.1	91.6	92.1	91.2	89.4	21.17	0.90
Dressing percentage	59.6	59.7	60.1	60.5	59.9	0.24	0.11
Marbling Score	417.1ab	412.3ab	440.1a	436.0ab	398.8b	9.99	0.05
Yield grade (% of cattle)							
Canada 3	17.2	23.7	33.9	30.0	19.3	5.61	0.23
Canada 2	31.0	27.1	27.1	40.0	38.6	6.09	0.42
Canada 1	51.7	49.2	39.0	30.0	42.1	6.38	0.17
Quality grade (% of cattle)							
Prime	0.0	0.0	0.0	1.7	0.0	0.74	1.00
AAA	63.8	63.3	66.1	60.0	41.4	6.30	0.09
AA	36.2	33.3	33.9	36.7	56.9	6.26	0.09
A	0.0	1.7	0.0	1.7	0.0	1.05	1.00
B4	0.0	1.7	0.0	0.0	1.7	1.06	1.00

Note: Least squares means within a row not sharing lowercase letters are different ($P < 0.05$) according to the Tukey-Kramer method. PSEM= pooled standard error of the mean. Marbling score; 300 – 399 = slight, 400 – 499 = small.

While RDP is important for microbial protein synthesis and maintaining volatile fatty acid production, and therefore providing sufficient metabolizable energy and protein to the animal, high RUP diets have previously been found to have positive impacts on carcass fat deposition (Cecava and Parker 1993; Bach et al. 2005). Supplementing RUP has been known to improve the flow of amino acids and nitrogen to the small intestine and increase total metabolizable protein, if RDP is not limiting (Cecava and Parker 1993). When altering RUP levels fed to finishing steers by incremental replacement of CM with urea, Hinman et al. (1999) found that marbling was higher for cattle fed no CM andit was lower when the protein supplement in the diet consisted of 100%, 50%, 75% CM . The diets fed in this trial used corn silage as the forage source (Hinman et al. 1999). It has been suggested that barley silage is a better promoter of microbial protein synthesis than corn silage (Koenig and Beauchemin 2005). Therefore, it is likely that the base diet used by Hinman et al. (1999) was not meeting RDP requirements. The addition of urea to the diet likely improved the RDP supply so that requirements were met, which improved carcass fat deposition. This could be the reason that the high RDP diet (0% CM) improved marbling as compared to the RUP diet (100% CM), a result that would confirm our findings.

In the current study, the SBM+WDDGS diet would have provided the poorest profile of rumen escape amino acids as well as having a lower RUP content than diets including CM, CM+WDDGS, and WDDGS. These two factors combined could have led to the poorer fat deposition by the cattle fed this diet. Although differences were small, cattle fed CM+WDDGS and WDDGS would have been eating the highest RUP diets and both had an adequate supply of rumen escape lysine and methionine to maximize carcass fat deposition.

It is worth noting that if these cattle had been priced on a grid, there may have been more of a value difference between the treatments, as SBM and SBM+WDDGS had a percentage of carcasses that graded B4 while the other treatments did not. Cattle fed SBM+WDDGS also tended to have the lowest percentage of AAA carcasses which would have impacted the value of carcasses priced on a grid system.

3.3.6 Carcass fatty acid composition

Changes in carcass fatty acid composition are shown in Table 3.9. The pre-trial fatty acid composition was not used in statistical analysis due to the difference in fat depots sampled. Different areas of the carcass have been found to have different fatty acid profiles due to changes in fat deposition (Turk and Smith 2009). These authors found that the brisket had the lowest concentrations of palmitic, stearic, vaccenic, and saturated fatty acids, and the highest concentration of MUFA compared to other carcass locations including LM, flank, and round (Turk and Smith 2009), thus making the statistical analysis of differences between fat sampled from the tail head at the beginning of the trial and fat sampled from the brisket at the end of the trial inappropriate.

A tendency was noted ($P = 0.09$) for cattle fed CM+WDDGS (0.27 ± 0.01% FAME) and SBM+WDDGS (0.30 ± 0.02% FAME) to have higher concentrations of n-3 fatty acids than cattle fed CM (0.22 ± 0.02% FAME) and SBM (0.27 ± 0.01% FAME), mostly due to the increased ($P = 0.05$) concentration of C18:3 n-3 in cattle fed SBM+WDDGS (0.26 ± 0.02% FAME) compared to those fed CM (0.19 ± 0.02% FAME). The increase in C18:3 n-3 levels in steers fed SBM+WDDGS could be due to the fact that WDDGS contain a relatively high amount of the fatty acid compared to barley grain (Mapiye et al. 2014). This would also suggest that SBM contained more C18:3 n-3 than the CM. The n-3 PUFA have been known to have several health benefits for humans, including reduction in the risk for cardiovascular disease and cancer, and improving maternal health (Mapiye et al. 2014) so increasing the content of these fatty acids in beef is important to human health. However, the relatively small change in concentration seen in this trial may be of little biological significance.

Interestingly, no differences ($P > 0.05$) in CLnA concentration (0.02 ± 0.001% FAME) in the adipose tissue of steers fed the different diets was observed. Previous work with finishing steers found that increased concentrations of C18:3 n-3 in the muscle corresponded with increased CLnA concentration (Mapiye et al. 2014) due to the isomerisation of C18:3 n-3 to CLnA being the first step in biohydrogenation of C18:3 n-3. Following the isomerisation of C18:3 n-3, CLnA is hydrogenated to *t*11, *c*15-18:2 which also was not affected by dietary treatment.

Table 3.9. Effect of canola meal (CM) or soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS) on carcass fatty acid concentration.

	Treatment							
	Pre-trial	CM	SBM	WDDGS	CM+ WDDGS	SBM+ WDDGS	PSEM	*P* value
Fatty acid concentration (%of total fatty acid methyl esters)								
∑PUFA	1.61 ± 0.09	1.25	1.52	1.60	1.56	1.67	0.105	0.09
∑n-6	1.06 ± 0.06	1.02	1.24	1.35	1.29	1.37	0.090	0.09
C18:2n-6	1.05 ± 0.06	0.98	1.20	1.30	1.24	1.31	0.089	0.09
C20:4n-6	0.02 ± 0.003	0.04	0.05	0.04	0.05	0.05	0.003	0.21
∑n-3	0.55 ± 0.04	0.22	0.27	0.25	0.27	0.30	0.018	0.07
C18:3n-3	0.53 ± 0.04	0.19a	0.24ab	0.22ab	0.23ab	0.26b	0.016	0.05
C22:5n-3	0.03 ± 0.01	0.03	0.03	0.03	0.03	0.04	0.003	0.58
∑CLnA	0.09 ± 0.01	0.02	0.02	0.02	0.03	0.02	0.002	0.16
c9, t11, t15-18:3	0.05 ± 0.003	0.02	0.02	0.02	0.03	0.02	0.002	0.16
∑CLA	1.43 ± 0.10	0.60	0.67	0.68	0.72	0.75	0.047	0.28
*t*7, *c*9-/*c*9, *t*11-18:2	1.28 ± 0.10	0.50	0.56	0.59	0.62	0.66	0.043	0.14
*t*9, *c*11-18:2	0.02 ± 0.003	0.05	0.05	0.06	0.04	0.04	0.008	0.21
*t*11, *c*15-18:2	0.07 ± 0.01	0.03	0.03	0.02	0.03	0.02	0.002	0.13
∑AD	0.96 ± 0.06	0.58	0.58	0.61	0.62	0.62	0.029	0.75
*c*9, *t*14-/*c*9, *t*13-18:2	0.24 ± 0.01	0.15a	0.15a	0.16ab	0.20b	0.20b	0.015	0.03
*t*11, *c*15-18:2	0.44 ± 0.04	0.15	0.12	0.15	0.11	0.12	0.018	0.31

Table 3.9. con't. Effect of canola meal (CM) or soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS) on carcass fatty acid concentration

	Treatment							
	Pre-trial	CM	SBM	WDDGS	CM+ WDDGS	SBM+ WDDGS	PSEM	*P* value
∑MUFA	44.82 ± 1.16	61.1	62.0	60.5	60.9	60.0	0.765	0.49
∑*t*-MUFA	4.29 ± 0.38	2.41	2.04	2.56	2.21	2.13	0.261	0.61
*t*6-18:1	0.20 ± 0.02	0.15	0.15	0.15	0.15	0.15	0.024	0.99
*t*9-18:1	0.27 ± 0.01	0.21	0.23	0.20	0.23	0.22	0.016	0.67
*t*10-18:1	0.20 ± 0.02	1.53	1.13	1.64	1.08	0.98	0.224	0.20
*t*11-18:1	2.85 ± 0.29	0.29a	0.30a	0.33ab	0.44b	0.47b	0.031	0.01
*t*12-18:1	0.19 ± 0.02	0.08	0.08	0.08	0.11	0.11	0.010	0.05
t13-/t14-18:1	0.43 ± 0.04	0.14	0.14	0.15	0.18	0.19	0.014	0.05
*t*11-18:1 : *t*10-18:1	14.42 ± 1.57	0.21a	0.26a	0.31ab	0.54b	0.70b	0.100	0.02
∑*c*-MUFA	40.24 ± 1.42	58.6	59.8	57.8	58.6	57.8	0.857	0.45
*c*9-14:1	1.40 ± 0.20	1.52	1.48	1.51	1.44	1.79	0.132	0.44
*c*7-16:1	0.38 ± 0.03	0.13a	0.15ab	0.14ab	0.18b	0.17ab	0.009	0.01
*c*9-16:1	4.27 ± 0.45	6.20	6.81	6.55	6.17	7.17	0.336	0.24
*c*9-17:1	0.76 ± 0.04	1.70	1.79	1.83	1.58	1.57	0.071	0.05
*c*9-18:1	31.92 ± 0.91	44.2	44.6	43.1	44.7	42.5	0.888	0.36
*c*11-18:1	0.98 ± 0.05	3.16	3.30	3.02	2.98	3.03	0.131	0.39
*c*12-18:1	0.08 ± 0.01	0.08	0.07	0.09	0.10	0.09	0.010	0.27
*c*13-18:1	0.25 ± 0.05	1.16	1.17	1.17	1.09	1.12	0.067	0.88
*c*9-20:1	0.14 ± 0.01	0.09	0.10	0.09	0.11	0.11	0.005	0.07
*c*11-20:1	0.08 ± 0.01	0.37	0.31	0.29	0.31	0.27	0.029	0.26

Table 3.9. con't. Effect of canola meal (CM) or soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS) on carcass fatty acid concentration

	Treatment						PSEM	*P* value
	Pre-trial	CM	SBM	WDDGS	CM+ WDDGS	SBM+ WDDGS		
∑BCFA	2.75 ± 0.15	1.01	1.13	1.01	1.25	1.31	0.086	0.09
C17:0iso	0.56 ± 0.03	0.26	0.28	0.26	0.32	0.33	0.021	0.13
C17:0ai	0.76 ± 0.02	0.42	0.49	0.42	0.52	0.53	0.034	0.08
C18:0iso	0.12 ± 0.01	0.09	0.10	0.09	0.10	0.10	0.008	0.55
∑SFA	48.00 ± 1.05	35.1	33.8	35.3	34.6	35.3	0.723	0.55
C12:0	0.24 ± 0.02	0.09	0.10	0.09	0.09	0.10	0.008	0.64
C14:0	6.39 ± 0.27	2.91	2.86	2.91	2.74	3.10	0.156	0.64
C15:0	0.93 ± 0.08	0.48	0.47	0.53	0.48	0.50	0.031	0.41
C16:0	26.71 ± 0.68	22.4	21.9	23.1	22.2	22.8	0.572	0.56
C17:0	1.21 ± 0.07	1.15ab	1.12ab	1.23b	1.04a	0.98a	0.042	0.01
C18:0	12.43 ± 0.89	8.05	7.36	7.41	7.36	7.78	0.401	0.59

Note: Pre-trial fatty acid concentrations are displayed as mean ± standard error. Least squares means within a row not sharing lowercase letters are different ($P < 0.05$) according to the Tukey-Kramer method. PSEM= pooled standard error of the mean

However, other AD isomers, *c*9, *t*14-18:2 and *c*9, *t*13-18:2, followed a similar pattern ($P = 0.03$) to the C18:3 n-3 with steers fed CM+WDDGS (0.20 ± 0.01% FAME) and SBM+WDDGS (0.20 ± 0.01% FAME) having higher concentrations of the AD than those fed CM (0.15 ± 0.02% FAME) or SBM (0.15 ±0.002% FAME) with those fed WDDGS being intermediate (0.16 ± 0.02% FAME). These isomers are thought to be biohydrogenation products of C18:2 n-6 (Mapiye et al. 2014), which tended ($P < 0.10$) to be higher in cattle fed CM+WDDGS (1.24 ± 0.05% FAME), SBM+WDDGS (1.31 ± 0.09% FAME), and WDDGS (1.30 ± 0.14% FAME) than those fed CM (0.98 ± 0.08% FAME) and SBM (1.20 ± 0.05% FAME).

While the total concentration of MUFA, *t*-MUFA, and *c*-MUFA was not affected by diet ($P > 0.05$), the concentration of *t*11-18:1was higher in steers fed CM+WDDGS (0.44 ± 0.03% FAME) and SBM+WDDGS (0.47 ± 0.05% FAME) than those fed CM (0.29 ± 0.03% FAME) and SBM (0.30 ± 0.03% FAME). The ratio of *t*11-18:1 : *t*10-18:1 was also higher for cattle fed CM+WDDGS (0.54 ± 0.07) or SBM+WDDGS (0.70 ± 0.04) compared to those fed CM (0.21 ± 0.08) or SBM (0.26 ± 0.09; P=0.02). A higher ratio of *t*11-18:1 : *t*10-18:1 is more desirable due to the benefits of *t*11-18:1 and the negative effects of *t*10-18:1 (Mapiye et al. 2014). While high grain diets are known to shift the biohydrogenation pathways towards the production of *t*10-18:1, the addition of WDDGS in the diet seemed to reverse this to some degree. Previous work using lambs and steers have found similar responses with the addition of DDGS improving *t*11-18:1 deposition compared to a control diet (Dugan et al. 2010; McKeown et al. 2010). Interestingly, in this trial the combination of WDDGS with CM and SBM improved upon this further. Previous work replacing up to 30% of a finishing diet with yellow or brown seeded CM found similar results, with cattle eating 30% CM having lower concentrations of *t*10-18:1 and higher concentrations of *t*11-18:1, although *t*10-18:1 was still the predominate fatty acid (He et al. 2013). These authors suggested that much of the fatty acid effects seen were due to residual oil in the CM (He et al. 2013). The combination of residual oil in CM and SBM with the improvements in pH with the addition of WDDGS could have caused the slight improvement in the *t*11-18:1 : *t*10-18:1 ratio.

The concentration of *c*7-16:1 was highest ($P = 0.01$) in cattle fed CM+WDDGS (0.18 ± 0.01% FAME) compared to those fed CM (0.13 ± 0.01% FAME). The values of this fatty acid are similar to those found by Mapiye et al. (2014) when WDDGS were added into a finishing

diet at up to 30% with sunflower seeds, however steers fed the control diet had a higher concentration of *c*7-16:1 as compared to those fed WDDGS (Mapiye et al. 2014).

No differences in BCFA (1.14 ± 0.04% FAME) or SFA (34.89 ± 0.32% FAME), profiles were observed in steers fed the different diets, although steers fed CM+WDDGS (1.04 ± 0.05% FAME) and SBM+WDDGS (0.98 ± 0.06% FAME) had lower (P = 0.01) concentrations C17:0 compared those fed WDDGS (1.23 ± 0.03% FAME). The decreased C17:0 concentration could be related to a reduction in decarboxylation of C16:0 or C18:0 or reduction in the use of propionate for lipogenesis (Jenkins et al. 2015). Saturated fatty acids are associated with high risk for multiple human diseases, including heart disease, fatty liver disease, and cancer (Jenkins et al. 2015), making the reduction of SFA in ruminant products important. While a reduction in C17:0 was seen when CM+WDDGS or SBM+WDDGS were fed, no reduction in other SFA or total SFA were seen, making the change of little biological significance.

3.4 Conclusion

Fluctuations of protein level in the diets fed during these trials may have led to some slight variation in the performance of the steers fed both the backgrounding and finishing diets. However, the results of this study indicate that CM is no different than SBM as a protein supplement for backgrounding and finishing cattle. The addition of WDDGS as a source of RUP did not improve growth performance due to the similarity in degradability in CM and WDDGS. The addition of WDDGS to SBM negatively influenced carcass fat deposition likely due to the intermediate level of RUP compared to the other diets and the poorer profile of rumen escape amino acids. While few differences in performance were seen relative to CM versus SBM with or without WDDGS, the economic savings of feeding CM or WDDGS relative to SBM makes SBM less desirable as a protein source in a feedlot setting. The increased profit seen in finishing cattle fed WDDGS suggests that WDDGS was the ideal protein source in this trial.

4.0 THE EFFECT OF CANOLA MEAL VERSUS SOYBEAN MEAL ON RUMEN FERMENTATION, OMASAL NUTRIENT FLOW, MICROBIAL PROTEIN PRODUCTION, AND TOTAL TRACT NUTRIENT DIGESTION.

Abstract

Our objective was to compare canola meal (**CM)** versus soybean meal (**SBM)** fed with or without wheat dried distiller's grains with solubles (**WDDGS**) as crude protein (**CP**) supplements for beef cattle. The trial evaluated rumen fermentation as well as ruminal and total tract nutrient digestibility characteristics in 4 cannulated heifers in a Latin square design with 28 d periods. Backgrounding diets were formulated with one of four protein supplements included: 1) CM (8.8% DM), 2) SBM (6.6% DM), 3) CM+WDDGS (6.4 and 3.3% DM), 4) SBM+WDDGS (5.0 and 2.8% DM). Omasal, rumen, and fecal samples were collected every 8 h for 3 d following 10 d of infusion with YbCl, Cr-EDTA, and ^{15}N to determine omasal flow of solid and fluid nutrients and microbial synthesis, respectively. Heifers fed diets including WDDGS had lower ($P < 0.05$) DM (11.8 ± 0.3 kg d^{-1} vs. 13.3 ± 0.4 kg d^{-1}), OM (11.0 ± 0.3 kg d^{-1} vs. 12.1 ± 0.4 kg d^{-1}), and N intake (246.9 ± 6.6 g d^{-1} vs. 278.9 ± 12.2 g d^{-1}) than those fed diets without WDDGS. Canola meal tended (1283.8 ± 67.7 g d^{-1}; $P = 0.08$) to increase RDP supply compared to SBM (1042.2 ± 85.7 g d^{-1}). There was a tendency ($P < 0.10$) for heifers fed CM to have lower omasal outflow of DM (9.2 ± 0.6 kg d^{-1} vs. 10.4 ± 0.8 kg d^{-1}) and OM (7.7 ± 0.5 kg d^{-1} vs. 8.8 ± 0.6 kg d^{-1}) than those fed SBM. Diets containing CM had greater DM (4.2 ± 0.4 kg d^{-1} vs. 2.8 ± 0.3 kg d^{-1}; $P < 0.05$) and OM (36.9 ± 3.6% vs. 27.1 ± 1.9%) apparently digestibility in the rumen compared to diets containing SBM. There was a tendency for WDDGS to decrease apparent ruminal DM digestibility (2.8 ± 0.3 kg d^{-1} vs. 3.5 ± 0.4 kg d^{-1}; $P < 0.10$). A protein source by WDDGS interaction ($P < 0.05$) for apparently digested ruminal N was noted with WDDGS decreasing apparent N digestibility of CM diets(-58.7 ± 12.1 g d^{-1} vs. -81.9 ± 22.5 g d^{-1}), and increasing it in SBM diets (-132.2 ± 13.6 vs. -117.5 ± 19.1 g d^{-1}). Diets containing CM had a higher apparent digestibility of N in the rumen (-58.7 ± 12.1 g d^{-1}; -21.3 ± 5.5% vs. -132.2 ± 13.6 g d^{-1}; -44.3 ± 3.0%; $P = 0.01$) increased ($P = 0.03$) N truly digested in the rumen (181.1± 11.5 g d^{-1}vs. 138.6 ± 13.6 g d^{-1}) than diets containing SBM. There were no t differences ($P > 0.05$) noted in DM (61.13 ± 0.57%), OM (62.7 ± 0.8%), crude protein (70.1 ± 0.8%), ADF (33.3 ± 2.3%), or NDF digestibility (36.1 ± 1.1%) among diets. These results indicate CM is not

different than SBM as a protein supplement and that there is no benefit to adding WDDGS with respect to rumen fermentation or total tract nutrient digestion.

4.1 Introduction

With the rise in production of canola meal, it is becoming an increasingly popular protein source in ruminant diets and its value as such has been well studied for lactating dairy cows (Huhtanen et al. 2011) and less so for beef cattle. In a meta-analysis, it was found that CM improved total DMI and forage DMI in dairy cows when compared to SBM and a soybean/fish meal combination (Huhtanen et al. 2011). In this analysis, OM, CP, NDF, and ADF total tract digestibility were a superior profile of essential amino acids (Huhtanen et al. 2011). When compared to three levels (10, 15, 20%) of WDDGS, lactating cows fed CM as a protein supplement had a lower DM and CP intake as well as milk production (Chibisa et al. 2012). Omasal flows of nutrients and amino acids remained similar among treatments. However, there was a tendency for OM truly digested in the rumen to decrease with an increasing levels of WDDGS (Chibisa et al. 2012). In a comparison of CM, SBM, WDDGS, and high protein DDGS in dairy cows, Maxin et al. (2013a) noted that CM resulted in the highest concentration of essential amino acids in the plasma. Plasma essential amino acid concentrations were lowest in cows fed SBM or WDDGS (Maxin et al. 2013a). It has also been shown that dairy cattle fed isonitrogenous diets supplemented with CM, SBM, or WDDGS did not differ in their in ruminal pH, ammonia concentration, or VFA concentration (Sánchez and Claypool 1983; Huhtanen et al. 2011; Chibisa et al. 2012).

Research on the effects of CM compared to other protein supplements on rumen fermentation and diet digestibility of backgrounding diets fed to beef cattle is more limited. In a study comparing omasal flow and digestibility of nutrients from backgrounding diets supplemented with CM, WDDGS, fractionated DDGS, or corn DDGS, Li et al. (2013) reported there was no difference in omasal flow of OM, starch, or NDF in heifers although the flow of microbial OM was greater for CM and WDDGS. They also reported that ruminal OM, NDF, and starch digestibility did not differ between protein supplements (Li et al. 2013). Microbial protein flow to the duodenum was higher for CM and WDDGS a compared to corn DDGS and fractionated DDGS but the microbial efficiency was similar among protein sources (Li et al. 2013). Contrary to the results of Maxin et al. (2013b) and Chibisa et al. (2012) with dairy cattle,

Li et al. (2013) found that the supply of total essential amino acids, histidine and leucine was higher with WDDGS than CM in beef cattle. When compared to SBM and lupin seeds as a protein supplement for growing lambs, CM supplemented diets had similar digestibility's of DM, OM, energy, and NDF. However, SBM supplemented diets had improved ADF digestibility (Stanford et al. 1996). Diets containing SBM had the highest digestible energy content, followed by CM, then lupin seeds (Stanford et al. 1996). There has been little research carried out on omasal flow of nutrients, rumen fermentation, and ruminal digestibility of nutrients in backgrounding beef cattle fed CM compared to other protein supplements

The objective of this research was to determine the omasal flow of nutrients, ruminal and total tract nutrient digestibility, and rumen fermentation of diets containing CM and SBM as a protein supplement with or without WDDGS in beef cattle.

4.2 Materials & Methods

4.2.1 Animal Housing and Experimental Design

Four ruminally cannulated Hereford cross heifers (540.3 ± 28.6 kg BW) were housed in 9m^2 pens equipped with rubber floor mats and individual feeders and waterers. Heifers were randomly assigned to one of four treatments using a 4 × 4 Latin square design balanced for carry-over effects. Each period consisted of 28 days with 7 days of dietary adaptation and 6 days of sample collection. Voluntary intake was measured from day 7 to 12, markers were infused from day 13 until day 22 and rumen and omasal samples were collected between day 20 and 22. Feed was restricted to 90% of ad libitum intake beginning on day 23, with fecal collection on days 26-28.

4.2.2 Treatments and Feeding

Heifers were fed backgrounding diets which included barley silage, barley green-feed, barley grain, oat hulls, a vitamin/mineral supplement, and one of four protein treatments (Table 4.1) including: (1) CM supplementation at 8.8% of the diet, (2) SBM supplementation at 6.6% of the diet, (3) CM and WDDGS supplementation at 6.4 and 3.3% of the diet, respectively, and (4) SBM and WDDGS supplementation at 5.0 and 2.8% of the diet, respectively (DM basis). Diets were formulated to 13.5% CP and to meet the NRC requirements for net energy of maintenance (1.52 Mcal kg^{-1}) and net energy of gain (0.93 Mcal kg^{-1}) for heifers growing at 1.2 kg per day.

Treatments 3 and 4 were designed to vary the amount of RUP being delivered to the heifers using an approximate 3:1 ratio of CM or SBM to WDDGS. Target RUP values were formulated based on RUP estimates of 48.1%, 33.3%, and 54.5% for CM, SBM, and WDDGS, respectively. (Canola Council of Canada 2015; Canadian International Grains Institute 2014). A barley grain RUP content (32.8%) was taken from Prusty et al. (2014), values for barley silage (20.8%), barley hay (32.8%), and oat hulls (46.4%) were adapted from the BCNRM (2016) , and the value for the supplement was assigned based on its ingredient composition (33%). The formulated RUP content for the treatment diets, as a % CP, were: CM- 34.2%, SBM- 33.8%, CM+WDDGS- 37.8%, SBM+WDDGS- 35.2%, while still maintaining an overall CP level of 13.5%.

Heifers were fed in 2 equal portions of the diet at 0800 and 1500h each day. Orts were removed, weighed, and recorded daily before the morning feeding.

4.2.3 Feed Sampling and Analysis

Samples of barley silage and barley green-feed were taken weekly and analyzed for moisture to maintain constant forage to concentrate ratio in the diet. Samples of barley grain, oat hulls, CM, SBM, and WDDGS were taken from each lot delivered. Samples of TMR were collected weekly and samples of orts were collected on the first and last day of measurement of voluntary intake and daily during fecal collection. All samples were dried and ground through a 1 mm screen (Christy and Norris 8” Lab mill, Christy Turner Ltd. Chelmsford, UK; Retsch, Haan, Germany).

Ground TMR, orts, fecal, and protein samples were sent to Cumberland Valley Analytical Services (Hagerstown, MD) and were analyzed according to the Association of Official Analytical Chemists (2000) for DM (AOAC method 930.15), ash (AOAC method 942.05), CP using the nitrogen combustion method (AOAC method 990.02), NDF (Van Soest et al. 1991), ADF (AOAC method 973.18), EE (AOAC method 920.39), and minerals (AOAC 985.01). Feed and fecal samples were analyzed for gross energy using a Parr 1281 bomb calorimeter (Parr Instrument Company, Moline, Il).

Table 4.1. Ingredient and chemical composition of diets used to evaluate the effects of canola meal (CM) versus soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS) on nutrient digestibility and ruminal fermentation.

	Treatment			
	CM	SBM	CM+WDDGS	SBM+WDDGS
Diet Composition (% DM basis)				
Barley Silage	32.2	33.6	31.7	32.9
Barley Green-feed	7.2	7.4	7.2	7.3
Oat Hulls	15.3	15.6	15.3	15.5
Barley Grain	29.6	30.1	29.4	29.8
Supplement	6.8	6.9	6.7	6.8
Canola Meal	8.8	-	6.4	-
Soybean Meal	-	6.6	-	5.0
WDDGS	-	-	3.3	2.8
Ration Analysis (% DM basis)				
Crude Protein	13.7 ± 0.4	12.6 ± 0.2	13.0 ± 0.3	13.1 ± 0.3
Acid Detergent Fiber	23.3 ± 0.9	23.2 ± 1.0	23.5 ± 1.3	23.5 ± 0.9
Neutral Detergent Fiber	37.3 ± 1.1	38.2 ± 1.1	39.4 ± 2.1	38.7 ± 1.2
Calcium	0.8 ± 0.2	0.9 ± 0.1	0.9 ± 0.03	0.8 ± 0.1
Phosphorus	0.4 ± 0.02	0.3 ± 0.01	0.4 ± 0.01	0.4 ± 0.02
Net Energy of Maintenance (MCal kg^{-1})	1.6 ± 0.1	1.6 ± 0.02	1.6 ± 0.04	1.6 ± 0.03
Net Energy of Gain	0.9 ± 0.1	1.0 ± 0.02	1.0 ± 0.04	1.0 ± 0.02

Note: Ration analysis values displayed as mean ± standard error. Net Energy of Maintenance and Net Energy of Gain determined through chemical analysis of feed and calculated according to the equations by Weis et al. (1992). Supplement nutrient composition: 8.1% CP, 10.2% Ca, 0.5% P,1.5% Na, 2.0% Mg, 0.6% K, 0.1% S, 5.0 mg Co, 190.4 mg Cu, 8.7 mg I, 488.5 mg Fe, 569.7 mg Mn, 2.46 mg Se,434.2 mg Zn, 0.7 mg MGA, 43,525.5 IU Vitamin A, 5,440.7 IU Vitamin D3, 652.9 IU Vitamin E,

Fecal output was estimated using indigestible NDF (**iNDF**). Approximately 3.0 g of fecal material was weighed into nylon bags (6 μm pore size; Pete x 07-6/5; Ankom Technology, Macedon, NY) and subsequently incubated in the rumen of 3 cannulated heifers for 12 days. During incubations heifers were fed a diet consisting of 81.1% barley silage, 12.1% barley grain, 3.7% CM, and 3.1% vitamin/mineral supplement. Upon removal from the rumen, bags were rinsed in cold water to remove excess rumen contents and then washed 6 times in cold water. The bags were then dried for 48 hours and the residual used for NDF analysis with the addition of sodium sulfite and α-amylase (Van Soest et al. 1991).

4.2.4 Marker and Omasal Sampling

Omasal sampling (Huhtanen et al. 1997) was used to determine apparent and true ruminal digestibility of nutrients and amino acid flow to the omasum. Indigestible NDF was used as a marker for the large particle phase (**LPP**), YbCl for the small particle phase (**SPP**), and Cr-EDTA for the fluid phase (**FP**). Ruminal microbial protein production was determined using ammonium sulfate labelled with ^{15}N as a marker. Two solutions, one containing 2.27 g/L of Cr and another containing 3.35 g/L of Yb and 0.22 g/L of ^{15}N, were infused into the rumen of each heifer. On day 13, samples of omasal digesta were taken prior to infusion of markers and used to determine the natural abundance of ^{15}N. Priming doses (0.5 L) of each infusion solution were then administered through the ruminal cannula. Marker solutions were continuously infused using a peristaltic pump at a constant rate of 1 L per day from days 13 – 22.

Sampling of omasal digesta began at 0800 h on day 20 and was conducted every 8 hours until 2300 h on day 22 so as to be representative of a 24-h period. A 525-mL sample of omasal digesta was collected and divided into 100, 125, and 300 mL samples. The 100 and 300 mL samples were pooled by heifer over the sampling period to yield an 800 mL and a 2.4L composite sample and frozen until analyzed.

The 125 mL sub-samples were placed on ice and pooled over 2 sampling times to create composite samples which were used to isolate particle associated bacteria (**PAB**) and fluid associated bacteria (**FAB**) (Brito et al. 2007). Immediately after collection of the second 125 mL sub-sample, the composite samples were filtered through 2 layers of cheesecloth and the solids washed with 250 mL of 0.85% saline solution. Solids were then transferred into a container and thoroughly mixed with 175 mL of a 0.85% saline containing 0.1% Tween-80 solution and stored

on ice. The mixture was centrifuged at 1000 x g for 5 min at 5°C and the fluid was collected. The fluid was centrifuged once again at 11,300 x g for 30 minutes at 5°C and then stored at 5°C for 24 hours prior to PAB isolation. The fluid obtained was discarded while the pellet was re-suspended in 50 mL of McDougall's buffer (McDougall 1948). The suspension was centrifuged once again at 11,300 x g for 30 minutes at 5°C and the resulting FAB pellet was frozen, composited over sampling period, and stored for later analysis. After storage for 24 hours at 5°C, the PAB solution was filtered through 2 layers of cheesecloth and then centrifuged at 1000 x g for 5 min at 5°C. The pellet was discarded and the supernatant processed as described for the FAB solution.

4.2.5 Rumen Fluid Sampling

Sampling of ruminal contents occurred at the same time as omasal sampling to quantify rumen pH, VFA and ammonia concentration. Ruminal contents were strained through 4 layers of cheesecloth and ruminal pH was measured using a Model 265A portable pH meter (Orion Research Inc., Beverly, MA). Three 10 mL subsamples of rumen fluid were collected and frozen for later analysis. One sample was mixed with chilled 25% meta-phosphoric acid for future determination of VFA, one was mixed with 1% sulfuric acid for future determination of ammonia and the third used as a spare sample.

4.2.6 Fecal Collection

Fecal grab samples (~250 g) were taken directly from the rectum to avoid contamination. Sampling occurred every 8 h starting at 0800 h on day 26 and ending at 2300 h on day 28. Samples were frozen after collection, and then thawed and pooled over each sampling period. The pooled samples were dried at 55°C for 96 h and then ground through a 1 mm screen (Retsch ZM100, Retsch, Haan, Germany).

4.2.7 Sample Analysis

Frozen rumen fluid samples acidified with metaphosphoric acid were thawed and centrifuged at 12,000 x g for 10 min at 5°C to obtain a clear supernatant. After centrifugation,

1.5 mL of supernatant was pipetted into micro-centrifuge tubes then centrifuged at 16,000 g at 4°C for 10 min. One milliliter of the supernatant was transferred into a 2 mL screw top glass vial and mixed with 0.2 mL of the internal standard (isocaproic acid). Samples were then analyzed for VFA by gas chromatography (Agilent 6890 series, Agilent Technologies, Santa Clara, Ca). To generate a calibration curve, a mixed standard consisting of known amounts of acetic, propionic, butyric, isobutyric, valeric, isovaleric, and caproic acids was used as a standard (Sigma Aldrich, St. Louis, Mo.).

Rumen samples that were stored with sulfuric acid were used to determine rumen ammonia concentration using the phenol hypochlorite method (Broderick and Kang 1980). Samples were first centrifuged at 12,000 x g for 10 min at 5°C to obtain a supernatant. After centrifugation, 25 μL of supernatant were pipetted into a test tube along with 1.25 mL of phenol reagent and 1.0 mL of hypochlorite reagent. Tubes were covered with a marble and placed in a water bath at 95°C for 5 min, then cooled in cold water for 3 min. Samples had 2.5 mL of distilled water added, were vortexed and then read on a spectrophotometer at 630 nm. Ammonia standards at 0 mg dL^{-1}, 5, 10, 15, 20, and 25 mg dL^{-1} were used to develop a calibration curve.

Composite omasal digesta samples were thawed and separated into LPP, SPP, and FP phases (Brito et al. 2007). The thawed sample was filtered through 1 layer of cheesecloth, with retained solids obtained constituting the LPP fraction. The fluid was then centrifuged at 1000 x g for 5 min at 5°C to separate the SPP from FP. All three phases and the cheesecloth used to filter the sample were then freeze-dried. The LPP and SPP were ground through a 1 mm screen (Retsch ZM100, Retsch, Haan, Germany) and the FP ground with a coffee grinder. The freeze-dried weights were used to determine DM of all three phases and the freeze-dried weight of the cheesecloth and residual LPP left on the cheesecloth were used to adjust the DM of LPP.

All three phases were digested in 15 mL of nitric acid and the concentrations of Cr and Yb determined using an atomic absorption spectrophotometer (Perkin Elmer 2300, Perkin-Elmer Corp., Norwalk, CT). To determine the concentration of iNDF in the LPP, SPP, feed, and orts, ruminal in situ incubations were performed as described above for fecal samples using 1.5 g of sample for LPP, 3.5 g for SPP, and 3.0 g for feed and orts. The concentrations of Cr, Yb, and iNDF in the LPP, SPP, and FP were used to reconstitute omasal true digesta (**OTD**) using the

triple marker method (France and Siddons 1986). The particulate phase (**PP**) was reconstituted from LPP and SPP.

Reconstituted OTD samples were analyzed according to Association of Official Analytical Chemists (2000) for DM (AOAC method 930.15), OM (AOAC method 942.05), NDF (Ankom method 6, Ankom Technology, Macedon, NY), and ADF (Ankom method 5, Ankom Technology, Macedon, NY). Total nitrogen of OTD, PP, and FP was determined using the nitrogen combustion method (AOAC method 990.02). Ammonia nitrogen of OTD, FP, and PP was quantified by mixing 0.5 g of sample with 10 mL of 0.07 M sodium citrate and vortexed. The mixture was then placed in a forced air drying oven at 39°C for 30 minutes. The extracts were then centrifuged at 18,000 x g for 15 min and the supernatant analyzed for NH3-N as described above (Broderick and Kang 1980).

Background samples of omasal digesta, PAB, FAB, FP, PP, and OTD were ground using a ball mill and analyzed for ^{15}N as described by Brito et al. (2007). Approximately 100 μg of each sample was weighed into 5 × 9 mm tin capsules (Isomass Scientific, Calgary, AB). To volatilize NH_3-N, 50 μL of 72 mM K2CO3 was added and capsules were incubated at 60°C for 24 hours in a forced air oven. Enrichment of ^{15}N was determined through combustion to nitrogen gas in an elemental analyzer coupled to a continuous isotope ratio-mass spectrometer.

Samples of OTD and feed were analyzed for concentration of amino acids by the University of Manitoba (Winnipeg, MB). Samples were prepared by acid hydrolysis (AOAC, method 994.12) and then neutralized to liberate amino acids from proteins. The separation and analysis of individual amino acids was done using HPLC (Shimadzu, Columbia, MD). Cysteine and methionine were analyzed using performic acid oxidation.

4.2.8 Calculations and Statistical Analysis

Omasal flow of nutrients and apparent and true rumen digestibility were calculated as described by Brito et al. (2009). Apparent ruminal digestibility of DM, OM, N, and NDF were calculated as the difference between nutrient intake and omasal flow (kg/d).

The non-ammonia nitrogen (**NAN**) content of OTD, FP, and PP was calculated as the difference between total nitrogen content and ammonia content. Bacterial pellet ^{15}N enrichment (**APE**) was calculated as the difference between ^{15}N percent in the sample and ^{15}N in background samples.

FAB and PAB were assumed to be representative of the bacteria flowing out of the rumen with FP and PP, respectively. FAB NAN, PAB NAN, and total bacterial NAN omasal flows were calculated as:

$$\text{FAB or PAB NAN flow} = \text{FP or PP NAN flow} \times (\text{FP or PP } ^{15}\text{N APE} / \text{FAB or PAB } ^{15}\text{N APE})$$

$$\text{Total bacterial NAN flow} = \text{FAB NAN flow} + \text{PAB NAN flow.}$$

Omasal flow of non-ammonia non-bacterial nitrogen (**NANBN**), RDP supply, RUP supply, OM truly digested in the rumen (**OMTDR**) were calculated as follows:

$$\text{NANBN flow} = \text{total NAN flow} - \text{total bacterial NAN flow}$$

$$\text{RDP supply} = \text{total CP intake} - (\text{NANBN flow} \times 6.25)$$

$$\text{RUP supply} = \text{total CP intake} - \text{RDP supply}$$

$$\text{FAB or PAB DM flow} = \text{FAB or PAB NAN} / (\%\ \text{FAB or PAB NAN})$$

$$\text{FAB or PAB OM flow} = \text{FAB or PAB DM} \times (\%\ \text{FAB or PAB OM})$$

$$\text{Total bacterial OM flow} = \text{FAB OM flow} + \text{PAB OM flow}$$

$$\text{OMTDR} = \text{OM intake} - (\text{omasal OM flow} - \text{microbial OM flow})$$

where flows and intakes are in grams or kilograms per day.

Total tract nutrient digestibility using iNDF as a fecal marker was estimated by determining fecal output using the equation:

$$\text{Fecal output} = (\%\ \text{iNDF in feed} \times \text{DMI}) / \%\ \text{iNDF in feces.}$$

The calculated fecal output was then used to determine total tract digestibility of DM, OM, CP, ADF, NDF, and gross energy.

All data on rumen fermentation, digestibility, omasal flow, and excretion were analyzed using a 4 × 4 Latin square with a 2 × 2 factorial arrangement of treatments (CM vs SBM with or without WDDGS) using the mixed model procedure of SAS (version 9.4; SAS Institute Inc. Cary, NC). Treatment and period were fixed effects and heifer was random effect. The covariance structure with lowest AIC and BIC values was chosen for each data set. Significance was declared where $P \leq 0.05$ and trends declared where $P \leq 0.10$.

4.3 Results and Discussion

4.3.1 Diet Composition

The CM averaged 39.4 ± 0.8% CP, SBM 47.9 ± 1.1%, and WDDGS 33.7% CP (Table 4.2). A single lot of WDDGS was used for the entirety of the trial. Ingredient and chemical composition of the diets used are presented in Table 4.1. Diets were formulated to be isonitrogenous, however the SBM and the WDDGS both had lower CP throughout the trial than was originally formulated. This resulted in the CM diet being slightly higher in CP than the other three treatments. Regardless of the variation in CP, all four diets had similar NDF (38.4 ± 0.7%), ADF (23.4 ± 0.5%), NE_m (1.57 ± 0.02 Mcal kg^{-1}), and NE_g content (0.97 ± 0.02 Mcal kg^{-1}) and met the requirements for metabolizable protein for backgrounding heifers with a target gain of 1.2 kg per day (BCNRM 2016). The amino acid composition of the diets are presented in Table 4.3. The concentration of essential and nonessential amino acids were relatively similar between diets. For example lysine, methionine and leucine averaged 0.47 ± 0.02 %DM, 0.19 ± 0.004 %DM, and 0.74 ± 0.02 %DM, respectively. This was not expected as diets fed to dairy cattle in previous work comparing CM to SBM or CM to WDDGS found greater differences between diets in amino acid composition. Dairy calf diets containing CM have previously been found to have a higher methionine, threonine, glycine and tyrosine content than diets containing SBM (Khorasani et al. 1990). Lactating cow diets containing CM have also been found to have a higher content of most essential amino acids than a diet containing WDDGS at a similar inclusion level (Chibisa et al. 2009). The similarity in dietary amino acid content is likely related to the lower CP level of backgrounding diets compared to dairy diets. The inclusion of the supplemental protein sources in the current trial was lower than that seen with dairy diets, reducing the effect of the source of protein supplement on dietary amino acid concentration.

Table 4.2. Chemical composition of canola meal (CM), soybean meal (SBM), and wheat dried distillers' grains with solubles (WDDGS).

	Protein Supplement		
	CM	SBM	WDDGS
% DM basis			
Crude Protein	39.4 ± 0.8	47.9 ± 1.1	33.7
Soluble Protein	8.1 ± 0.1	10.4 ± 1.1	5.9
Acid Detergent Fiber	21.3 ± 0.2	5.8 ± 0.4	18.3
Neutral Detergent Fiber	27.6 ± 1.3	9.2 ± 0.7	33.7
Ash	7.6 ± 0.1	5.9 ± 0.2	5.1
Calcium	0.93 ± 0.02	0.40 ± 0.04	0.10
Phosphorus	1.20 ± 0.02	0.63 ± 0.17	0.95
Total Digestible Nutrients	60.2 ± 0.6	79.1 ± 0.1	83.2

Note: Values displayed as mean ± standard error.

Table 4.3. Amino Acid Composition (% of DM) of the treatment diets used to evaluate canola meal (CM) versus soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS) as a protein supplement for backgrounding cattle.

	Treatment			
	CM	SBM	CM+ WDDGS	SBM+ WDDGS
Essential AA				
Arginine	0.50 ± 0.01	0.49 ± 0.02	0.48 ± 0.02	0.53 ± 0.07
Histidine	0.36 ± 0.01	0.32 ± 0.02	0.32 ± 0.03	0.33 ± 0.01
Isoleucine	0.41 ± 0.02	0.38 ± 0.02	0.41 ± 0.02	0.41 ± 0.05
Leucine	0.74 ± 0.03	0.73 ± 0.03	0.74 ± 0.04	0.77 ± 0.07
Lysine	0.46 ± 0.02	0.45 ± 0.02	0.47 ± 0.03	0.51 ± 0.07
Methionine	0.19 ± 0.01	0.19 ± 0.01	0.19 ± 0.01	0.20 ± 0.01
Phenylalanine	0.48 ± 0.01	0.47 ± 0.02	0.46 ± 0.03	0.48 ± 0.05
Threonine	0.40 ± 0.02	0.39 ± 0.02	0.40 ± 0.02	0.43 ± 0.03
Valine	0.54 ± 0.03	0.53 ± 0.02	0.56 ± 0.02	0.57 ± 0.02
Nonessential AA				
Alanine	0.59 ± 0.02	0.61 ± 0.02	0.59 ± 0.02	0.62 ± 0.04
Asparagine	0.75 ± 0.02	0.72 ± 0.04	0.77 ± 0.05	0.83 ± 0.10
Cysteine	0.20 ± 0.01	0.20 ± 0.01	0.21 ± 0.02	0.20 ± 0.01
Glutamate	2.12 ± 0.10	2.10 ± 0.09	2.03 ± 0.10	2.17 ± 0.14
Glycine	0.47 ± 0.02	0.47 ± 0.01	0.47 ± 0.02	0.50 ± 0.04
Proline	0.91 ± 0.04	0.87 ± 0.04	0.81 ± 0.03	0.91 ± 0.05
Serine	0.49 ± 0.02	0.48 ± 0.02	0.49 ± 0.03	0.52 ± 0.05
Tyrosine	0.25 ± 0.01	0.25 ± 0.01	0.25 ± 0.02	0.26 ± 0.04

Note: Values displayed as mean ± standard error.

4.3.2 Rumen Fermentation

No treatment differences ($P > 0.05$) were noted in total VFA (88.74 ± 1.73 mMol), acetate (55.31 ± 0.96 mMol), propionate (18.19 ± 0.41 mMol), or ammonia concentrations (10.49 ± 1.20 mg dL^{-1}), or ruminal pH (6.19 ± 0.07; Table 4.4). There was a tendency ($P = 0.07$) for diets containing WDDGS (12.2 ± 0.9 mMol) to produce more butyrate than diets that did not contain WDDGS (11.1 ± 0.6 mMol). Similarly, Mulrooney et al. (2009) found that cattle fed a diet supplemented with CM and corn DDGS in 66:34 ratio had a higher butyrate concentration than a diet supplemented with CM alone. However, they noted that the differences between treatments were relatively small and of little biological significance. Previously reported values for the sugar content of SBM (11.6%) are lower than that reported for WDDGS (22.4%) (Reveco and Drew 2012; BCNRM 2016). This may have led to the diets containing WDDGS to have a slightly higher water soluble carbohydrate fraction than diets not containing WDDGS, shifting VFA production to produce slightly more butyrate (BCNRM 2016). There was a tendency ($P = 0.10$) for diets containing CM to have a lower ruminal pH (6.1 ± 0.1) than diets containing SBM (6.2 ± 0.1). Other trials have not previously found any differences in rumen pH when comparing diets containing CM to SBM (Broderick et al. 2015; Paula et al. 2017). When comparing CM versus SBM at two different protein levels, Broderick et al. (2015) found no treatment differences in rumen fermentation between CM and SBM at both low and high protein levels. Similarly, Paula et al. (2017) found no treatment differences when analyzing in vitro fermentation characteristics in SBM versus low- and high-RUP CM. The average ruminal pH for all four treatments was above 5.5, which indicates protein degradation was likely not affected by ruminal pH (Bach et al. 2005), and the differences in pH between CM and SBM were small and of little biological significance.

Table 4.4. Rumen fermentation characteristics from backgrounding heifers fed diets containing canola meal (CM) or soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS).

	Treatment					*P* value		
	CM	SBM	CM+ WDDGS	SBM+ WDDGS	PSEM	CM vs SBM	WDDGS	Protein × WDDGS
Volatile Fatty Acid concentration (mMol)								
Acetate	55.55	54.67	54.45	56.55	1.805	0.74	0.83	0.43
Propionate	18.75	18.23	17.97	17.82	1.055	0.75	0.57	0.87
Butyrate	10.57	11.79	11.56	12.67	0.985	0.13	0.07	0.93
Valerate	1.18	1.22	1.24	1.23	0.089	0.99	0.53	0.76
Isobutyrate	0.81	0.82	0.87	0.91	0.057	0.6	0.15	0.75
Isovalerate	1.44	1.48	1.63	1.55	0.195	0.94	0.55	0.79
Total VFA	88.63	87.59	87.52	91.23	3.479	0.69	0.70	0.48
Acetate: Propionate ratio	2.92	3.12	3.14	3.11	0.165	0.51	0.45	0.41
Mean Rumen Ammonia (mg dL^{-1})	11.84	10.28	9.08	10.66	0.933	0.86	0.19	0.12
Mean Rumen pH	6.10	6.21	6.19	6.25	0.072	0.10	0.17	0.65

Note: PSEM = pooled standard error of the mean. P values: CM vs SBM – effect of canola meal versus soybean meal; WDDGS – effect of inclusion of WDDGS in the diet; PS × WDDGS – Protein source by WDDGS interaction.

Protein source did not affect rumen fermentation to any great extent. Total VFA concentrations were lower than previously reported for cattle fed similar levels of protein and the ammonia concentration is higher (Li et al. 2013; Nair et al. 2016). The lower than normal total VFA concentrations are likely due to the lower ruminal degradability of the oat hulls in the diet (Thompson et al. 2002). Although total VFA concentrations are lower, the concentrations of isobutyrate and isovalerate are similar or higher than previously reported (Li et al. 2013; Nair et al. 2016). The higher than normal concentration of ammonia and the branched chain VFAs are not unexpected due to the release of branched chain VFA and ammonia from fermented proteins (Miura et al. 1980). McAllister et al. (1990) suggested that barley, as opposed to other cereal grains is rapidly colonized by ruminal bacteria which leads to rapid breakdown and the subsequent release of ammonia and VFA. The current trial used barley silage and barley grain as did Li et al. (2013) and Nair et al. (2016), however the barley silage (13.6 ± 0.3%) and barley grain (12.6 ± 0.6%) used in this trial were higher in crude protein than the barley silage and barley grain used by these other researchers which could have led to the slightly higher than expected ammonia and branched chain VFA levels.

4.3.3 Nutrient Intakes, Ruminal Digestibilities, and Omasal Outflows

There was no difference ($P > 0.05$) in DM or OM intake in heifers fed CM or SBM (Table 4.5). However, heifers fed diets containing WDDGS had lower ($P = 0.01$) DM (11.8 ± 0.3 kg d^{-1}) and OM intake (11.0 ± 0.3 kg d^{-1}) than heifers fed either CM or SBM (13.3 ± 0.4 kg d^{-1} and 12.1 ± 0.4 kg d^{-1}). There were no treatment differences ($P > 0.05$) in NDF (4.8 ± 0.1 kg d^{-1}) or ADF intake (2.9 ± 0.1 kg d^{-1}). The improvement in DMI for diets not containing WDDGS was somewhat unexpected.

Table 4.5. Nutrient flow from and digestion in the rumen of beef cattle fed canola meal (CM) versus soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS).

	Treatment					P value		
	CM	SBM	CM+ WDDGS	SBM+ WDDGS	PSEM	CM vs SBM	WDDGS	PS× WDDGS
DM								
Intake, kg/d	13.4a	13.2a	11.8b	11.8b	0.51	0.72	0.01	0.82
Omasal flow, kg/d	9.2	10.4	9.0	9.6	0.45	0.07	0.26	0.42
Apparent digestion, kg/d	4.2	2.8	2.8	2.5	0.31	0.04	0.06	0.08
Apparent digestion, % of DM Intake	31.7	21.2	23.6	18.9	2.35	0.07	0.24	0.1
OM								
Intake, kg/d	12.2a	12.1a	10.9b	11.0b	0.50	0.9	0.01	0.83
Omasal flow, kg/d	7.7	8.8	7.6	8.0	0.37	0.07	0.16	0.26
Apparent digestion, kg/d	4.5	3.3	3.4	3.4	0.31	0.13	0.69	0.09
Apparent digestion, % of OM Intake	36.9	27.1	30.6	28.5	2.58	0.04	0.06	0.08
True Digestion, kg/d	7.2	6.6	6.3	6.7	0.41	0.68	0.14	0.05
True Digestion, % of OM Intake	59.3	54.4	57.3	58.5	1.75	0.41	0.39	0.07
NDF								
Intake, kg/d	5.0	5.0	4.7	4.6	0.25	0.85	0.23	0.91
Omasal flow, kg/d	3.5	3.5	3.3	3.7	0.15	0.23	0.90	0.32
Apparent digestion, kg/d	1.5	1.4	1.3	1.0	3.06	0.51	0.33	0.62
Apparent digestion, % of NDF Intake	29.1	28.9	27.7	20.9	0.19	0.54	0.28	0.64

Note: Least squares means within a row not sharing lowercase letters are different ($P < 0.05$) according to the Tukey-Kramer method. PSEM = pooled standard error of the mean. P values: CM vs SBM – effect of canola meal versus soybean meal; WDDGS – effect of inclusion of WDDGS in the diet; PS × WDDGS – Protein source by WDDGS interaction.

In Trial 2 in the previous chapter, DMI was increased during backgrounding when steers were fed CM+WDDGS and was lowest in steers fed SBM. Work using dairy cattle has found that cows fed increasing levels of WDDGS have an increased or similar DMI compared to cows fed CM (Mulrooney et al. 2009; Chibisa et al. 2012), or cows fed CM and SBM (Maxin et al. 2013a). In previous digestibility trials using beef cattle and lambs, no differences were seen in DM or OM intake between beef cattle or lambs fed CM, WDDGS, SBM, or high RUP CM (Stanford et al. 1995; Gozho et al. 2009; Li et al. 2013). In finishing beef cattle, WDDGS has been found to improve DMI when used to replace barley grain in the diet, possibly due to an increaset in rumen pH (Beliveau and McKinnon 2008; Walter et al. 2010). However, in a backgrounding trial in which 10% of the barley grain was replaced with CM, WDDGS, corn DDGS, or fractionated corn DDGS, steers fed CM had a higher DMI as compared to those fed control or DDGS diets (Yang et al. 2012). Similarly, Avila-Stagno et al. (2013) found that DMI linearly decreased as WDDGS was increased in finishing diets for lambs, where it replaced SBM, soybean hulls, and alfalfa hay. However, intake data from backgrounding trials using WDDGS was fed have been quite variable, likely due to the variability in the nutrient profile of the supplement (Yang et al. 2012).

No interactions were detected ($P > 0.05$) for omasal outflow of DM (9.5 ± 0.3 kg d^{-1}), OM (8.0 ± 0.3 kg d^{-1}) or NDF (3.5 ± 0.1 kg d^{-1}). There was a tendency ($P = 0.07$) for cattle fed CM to have a decreased omasal outflow of DM (9.2 ± 0.6 kg d^{-1} vs. 10.4 ± 0.8 kg d^{-1}) and OM (7.7 ± 0.5 kg d^{-1} vs. 8.8 ± 0.6 kg d^{-1}) compared to cattle fed SBM. Diets containing CM (4.2 ± 0.4 kg d^{-1}; $P = 0.04$) had the highest DM apparently digested in the rumen compared to diets containing SBM (2.8 ± 0.3 kg d^{-1}), and there was a tendency ($P = 0.06$) for inclusion of WDDGS in the diet to decrease apparent ruminal DM digestibility (2.7± 0.3 kg d^{-1} vs. 3.5 ± 0.4 kg d^{-1}). When expressed as a percent of intake, there was a tendency ($P = 0.07$) for cattle fed CM based diets to have a higher apparent ruminal DM digestibility (31.7 ± 2.9%) than those fed SBM (21.2 ± 2.6%).

No significant interactions were seen for apparent OM digestibility, however, there was an interaction between protein source and WDDGS inclusion was significant (P=0.05) for ruminal true OM digestibility. In this case, true ruminal OM digestion was reduced as a result of WDDGS inclusion in CM diets, but it was not when WDDGS was included in SBM diets. Diets

including CM had a higher (P = 0.04) apparent digestibility of OM (36.9 ± 3.6%) than diets containing SBM (27.1 ± 1.9%). The difference between CM and SBM was somewhat surprising as previous work in dairy cattle found similar apparent ruminal OM digestibility between diets containing CM or SBM (Brito et al. 2007) and similar total tract OM digestibility in cattle or lambs fed CM vs. SBM (Stanford et al. 1995; Huhtanen et al. 2011).The CM and the SBM used in the present trial differed more in organic matter content than that reported by Stanford et al. (1995) which may have contributed to the differences in true ruminal OM digestibility. Canola meal based diets also had a higher (P = 0.04) apparent DM ruminal digestibility, which also contributed to the improved OM digestibility.

The apparent and true ruminal OM digestibility of all diets were within the range stated in the published literature (apparent- 30 to 60%; true- 40 to 70%) as reported by Titgemeyer (1997), however apparent ruminal OM digestibility was lower than most other studies using beef cattle (Owens et al. 2014; Rotta et al. 2014; Gorka et al. 2015; Rosser et al. 2016). The previously reported results for OMTDR are more variable; the OMTDR seen in the current trial was similar to those reported by Li et al. (2013) and Gorka et al. (2015). Once again, the increased DMI in the current trial compared to those reported by Owens et al. (2014), Rotta et al. (2014), and Rosser et al. (2016) could have accounted for the lower OM ruminal digestibility due to a faster passage rate.

There were no treatment differences (P > 0.05) in NDF intake (4.8 ± 0.1 kg d^{-1}), omasal flow (3.5 ± 0.1 kg d^{-1}), or the amount of NDF apparently digested in the rumen (1.3 ± 0.1 kg d^{-1}), or apparent digestibility as a percent of NDF intake (26.7 ± 1.9%). The NDF apparently digested in the rumen is lower than what has been noted in other trials (Li et al. 2013; Owens et al. 2014; Rotta et al. 2014; Rosser et al. 2016) using beef cattle. This could partially be due to the increased DMI in the current trial but also due to the inclusion of oat hulls in the diets. Oat hulls are known to be high in fiber, especially lignin, and free phenolic acids such as ferulic acid, which can inhibit degradability of the fiber in the hull vary from 11.8 to 22.5% (Thompson et al. 2000). Oat hulls were included in the diets at approximately 15% of dietary DM, which could have been sufficient to limit the NDF digestion of each of the diets.

The calculated apparent ruminal digestibility of ADF (41.0 ± 2.2%; 1.3 ± 0.1 kg d^{-1}) from this trial was higher than expected based on NDF digestibility and ADF total tract digestibility. As it is not mathematically possible for ruminal ADF digestibility to be higher than total tract

ADF digestibility or ruminal NDF digestibility, the apparent ADF omasal flow and ruminal digestibility was removed from Table 4.5. It is unclear as to why the ADF apparent ruminal digestibility was so high; errors in marker recovery and therefore in reconstitution of the OTD may have led to overestimation of ADF in the omasal digesta (Titgemeyer 1997; Rotta et al. 2014).

Protein supplementation of forage based diets has been shown to improve total diet digestibility, regardless of protein source, due to the stimulation of cellulolytic bacteria from amino acids and peptides (Hoover 1986; Huhtanen et al. 2011). The CM diet in this trial had higher CP than the other three diets which may have contributed to the ruminal DM and OM digestibility being higher with this diet than the other diets. While the diets in the current trial were not analyzed for ADIN or NDIN, the backgrounding diets in Trial 1 in the previous chapter were. In the backgrounding trial, the CM and SBM diets had similar ADIN (1.2 ± 0.1% vs. 1.1 ± 0.1%) however, the CM diet had a lower NDIN than the SBM diet (1.4 ± 0.2% vs. 1.7 ± 0.1%). The diets in the current trial were similar in nature to the diets used in Trial 1, so it could be assumed that the ADIN and NDIN values of the diets would follow the same trends. The CM diet in the current trial tended to supply more RDP (Table 4.6) than the SBM diet, and had a numerically higher ammonia concentration in the rumen, supporting the theory that the CM diet had a higher nitrogen availability. The improved availability of nitrogen in the CM diet along with the slight increase in crude protein and the increased ammonia production likely increased the growth of cellulolytic and fibrolytic bacteria, thereby improving apparent ruminal DM and OM digestion.

While DMI and passage rate can have an effect on ruminal apparent digestibility, the lower than expected ruminal digestibility could also be caused by the relatively low content of effective fiber in the diet compared to the high forage diets fed in trials using dairy cattle. It has been noted that the omasal sampling technique is not always accurate at estimating nutrient flow out of the rumen with high grain diets (Titgemeyer 1997; Gorka et al. 2015). Gorka et al. (2015) noted a negative effect on ruminal mat consistency when heifers were fed a high lipid by-product pellet which may have led to the omasal sample not being representative of what is flowing out of the omasal canal causing digestibility of nutrients to be low. While marker dysfunction and rumen mat inconsistency are often problems associated with high grain diets, this may have been a source of some error in the current trial. The diets in the current trial were approximately 55%

forage which should be sufficient forage for marker recovery, however 15% of the diet was oat hulls. The physical characteristics of oat hulls are not the same as other forages used in most dairy trials using omasal sampling techniques as their particle size is much smaller. The characteristics of a feed are important in maintaining optimal ruminal fermentation and diet digestibility (Mertens 1997). In a trial comparing long or short grind corn silage in finishing rations, it was found that diets containing 10% long grind silage had the same digestibility as diets containing 5% short grind silage, suggesting that smaller particles increase passage rate through the rumen and limit digestibility (Weiss et al. 2017). In the case of this trial, the small particle size of the oat hulls compared to other forages may have lead to an increased passage rate out of the rumen and had a negative effect on marker recovery, leading to underestimated diet digestibility.

Another factor which may have led to inaccuracies in the estimation of nutrient flow was that rumen samples were taken prior to omasal sampling. This may have contributed to mixing of ruminal contents leading to an error in estimation of nutrient outflow. This would have caused the sample taken to not be representative of the digesta flowing out of the omasal canal, leading to an overestimation of nutrients flowing out of the rumen (Titgemeyer 1997).

4.3.4 Omasal Flow of Nitrogen and Microbial Protein

Omasal flow of nitrogen and nitrogen constituents can be seen in Table 4.6. Heifers fed diets containing WDDGS (246.9 ± 6.6 g d^{-1}) had lower nitrogen intakes than diets not containing WDDGS (278.9 ± 12.2 g d^{-1}; $P = 0.03$), due to the difference in DMI between treatments.

A protein source by WDDGS interaction ($P < 0.05$) was observed for N apparently digested in the rumen whether expressed as g d^{-1} or as a % of N intake (Table 4.6.). The nature of these interactions was such that when WDDGS was added to CM diets, apparent N digestibility decreased (-58.7 ± 12.1 g d^{-1} vs. -81.9 ± 22.5 g d^{-1}; -21.3 ± 5.5% vs. -33.6 ± 9.3%) while it improved or was unchanged when fed with SBM (-132.2 ± 13.6 vs. -117.5 ± 19.1 g d^{-1}; -44.3 ± 3.0% vs. -49.8 ± 5.8%). In terms of main effects, diets containing CM had a higher apparent digestibility of N in the rumen whether expressed as g d^{-1} or as a percent of N intake (-58.7 ± 12.1 g d^{-1}; -21.3 ± 5.5% vs. -132.2 ± 13.6 g d^{-1}; -44.3 ± 3.0%; $P = 0.01$) compared to diets containing SBM. Canola meal-based diets also increased ($P = 0.03$) N truly digested in the rumen relative to diets containing SBM (180.9 ± 11.5 g d^{-1}vs. 138.6 ± 13.6 g d^{-1}). The improved

N digestibility was to be expected due to the improved DM and OM digestibility seen in CM diets compared to SBM diets (Table 4.5). The inclusion of WDDGS in the diet tended ($P = 0.08$) to decrease the N truly digested in the rumen (139.1 ± 8.8 g d^{-1}) compared to diets without WDDGS (159.8 ± 11.5 g d^{-1}), likely due to the tendency for diets including WDDGS to supply less RDP.

As a result of improved apparent and true N digestibility in the rumen, diets containing CM tended (1283.8 ± 67.7 g d^{-1}; $P = 0.08$) to increase RDP supply compared to diets containing SBM (1042.2 ± 85.7 g d^{-1}). These RDP values are unexpected in relation to the results from the in situ trial in the previous chapter and in relation to previously reported RDP and RUP values for CM and SBM. The calculated target RUP values for the diets based on feed ingredient RUP values from Canola Council of Canada (2015), Canadian International Grains Institute (2013), Prusty et al. (2014), and BCNRM (2016) were: 32.3, 30.8, 32.7 and 31.5% of dietary CP for CM, SBM, CM+WDDS and SBM+WDDGS, respectively. While the RDP and RUP levels were unexpected based on previously reported values, diets containing CM also increased apparent ruminal digestibility of DM, OM, and N compared to SBM, which led to the higher than expected RDP value of CM based diets. Inclusion of WDDGS with both CM and SBM based diets tended to decrease RDP supply (1019.2 ± 57.8 g d^{-1} vs. 1154.1 ± 70.1 g d^{-1}; $P = 0.10$), as was expected, however when expressed as a percentage of DMI or total dietary CP, no effect of WDDGS was noted. It should be noted that RUP values of protein supplements such as canola meal and WDDGS are subject to a great deal of variability, primarily as a result of processing, particularly heating. Historically canola meal has been considered to be a more degradable protein source (Ha and Kennelly 1984; Kirkpatrick and Kennelly 1987), however, recent processing practices where screenings, gums and oil are added back to the meal as well as excess heating during desolventization/toasting have led to higher and more variable RUP values for canola meal (Canola council of Canada, 2015). Similarly drying conditions during processing of WDDGS can greatly vary its RUP value (U.S. Grains Council 2012). This variability in RUP values of the protein supplements used likely led to treatment differences in dietary RUP values that were less than expected based on literature values.

Table 4.6. Intake, digestibility, and omasal flow of N constituents in beef cattle fed canola meal (CM) versus soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS).

	Treatment					P value		
	CM	SBM	CM+ WDDGS	SBM+ WDDGS	PSEM	CM vs SBM	WDDGS	PS × WDDGS
N								
Intake g/d	293.9	263.9	246.1	247.7	13.70	0.11	0.03	0.07
Apparently digested in the rumen, g/d	-58.7	-132.2	-81.9	-117.5	17.33	0.01	0.96	0.04
Apparently digested in the rumen, % of N intake	-21.3	-44.3	-33.6	-49.8	6.32	0.01	0.77	0.03
Truly digested in the rumen, g/d	181.1	138.6	146.9	130.1	13.27	0.03	0.08	0.80
Truly digested in the rumen, % of N intake	61.9	52.2	59.8	49.1	9.77	0.92	0.42	0.32
RDP supply								
g/d	1283.8	1025.5	1042.2	983.7	120.70	0.08	0.10	0.92
% of DM intake	9.6	7.8	8.9	8.0	104.66	0.35	0.34	0.34
% of CP intake	70.3	61.9	67.8	60	6.38	0.14	0.37	0.53
Flow at Omasal Canal								
N								
g/d	350.8	396.2	328	372.5	28.44	0.28	0.74	0.31
% of N intake	114.5	149.8	133.6	148.9	10.33	0.28	0.72	0.06
NH3-N, g/d	23.3	27.3	19.2	27.4	2.02	0.72	0.52	0.20
NAN								
g/d	311.7	370.7	308.2	351.5	31.22	0.48	0.17	0.20
% of N intake	106.1	140.1	125.6	137.9	24.95	0.15	0.30	0.64
NANBN								
g/d	88.7	99.9	79.3	104	9.94	0.18	0.96	0.54
% of N flow	28.1	27.3	25.3	29.3	7.18	0.32	0.42	0.28
% of N intake	29.7	38.1	32.2	40	3.71	0.17	0.96	0.50
% of DM intake	0.7	0.8	0.7	0.8	3.82	0.33	0.34	0.34

Table 4.6. con't. Intake, digestibility, and omasal flow of N constituents in beef cattle fed canola meal (CM) versus soybean meal (SBM) with or without wheat dried distillers' grains with solubles (WDDGS)

	Treatment					P value		
	CM	SBM	CM+ WDDGS	SBM+ WDDGS	PSEM	CM vs SBM	WDDGS	PS × WDDGS
RUP supply								
g/d	554.2	624.2	495.9	603.4	92.45	0.87	0.22	0.54
% of DM intake	4.1	4.8	4.2	5.0	62.42	0.34	0.34	0.34
% of CP intake	29.7	38.1	32.2	37.9	5.13	0.56	0.58	0.31
FAB NAN								
g/d	113.7	133.0	111.5	131.7	14.46	0.69	0.33	0.40
% of total bacterial NAN	50.5	49.0	49.0	75.8	10.01	0.30	0.30	0.25
PAB NAN								
g/d	109.3	137.9	117.4	116.5	10.79	0.63	0.15	0.04
% of total bacterial NAN	49.5	51.0	51.0	46.8	53.43	0.42	0.42	0.50
Total Bacterial NAN								
g/d	223.0	270.8	228.8	248.1	27.97	0.85	0.21	0.15
% of NAN flow	71.9	72.7	74.7	71.7	21.58	0.36	0.33	0.38
Microbial efficiency								
g of microbial N/kg OMTDR	31.3	41.1	37.3	36.5	4.50	0.19	0.44	0.91

Note: Least squares means within a row not sharing lowercase letters are different ($P < 0.05$) according to the Tukey-Kramer method. PSEM = pooled standard error of the mean. P values: CM vs SBM – effect of canola meal versus soybean meal; WDDGS – effect of inclusion of WDDGS in the diet; PS × WDDGS – Protein source by WDDGS interaction. Abbreviations: RDP – rumen degradable protein; NAN- non-ammonia nitrogen; NANBN- non-ammonia non-bacterial nitrogen; RUP- rumen undegradable protein; FAB NAN-fluid associated bacterial non-ammonia nitrogen; PAB NAN- particle associated bacterial non-ammonia nitrogen.

No protein source by WDDGS interactions were noted ($P > 0.05$) in the omasal outflow of N or N constituents, nor were there any effects ($P > 0.05$) of CM vs. SBM or the inclusion of WDDGS (Table 4.6). The flow of N and NAN as a percent of N intake in the current trial were similar to previously reported values for backgrounding diets (Li et al. 2013; Owens et al. 2014). The flows of N and NAN in this trial and in previous trials are all greater than 100% of N intake, due to microbial protein production being greater than the amount of feed N being degraded, suggesting that recycling of N into the rumen was occurring (Owens et al. 2014).

A protein source by WDDGS interaction (P = 0.04) was seen with respect to PAB NAN flow where flow increased (109.3 ± 4.0 g d^{-1} vs. 117.4 ± 9.4 g d^{-1}) when WDDGS was included with CM, while it decreased when included with SBM (137.9 ± 12.1 g d^{-1} vs. 116.5 ± 10.5 g d^{-1}). No effects ($P > 0.05$) of protein source or inclusion of WDDGS were seen regarding total bacterial protein flow. These results suggest that there was little difference between protein supplements regarding ruminal microbial protein production. It was expected that WDDGS would decrease PAB and FAB NAN flow when included with both CM and SBM (Li et al. 2013). Likewise, in a comparison of CM to SBM, cottonseed meal, and urea as protein supplements for dairy cattle, Brito et al. (2007) found no differences in FAB, PAB or total bacterial NAN flow between cattle fed CM, SBM, or cottonseed meal but that cattle fed urea had a depressed microbial protein flow. These authors noted that not only is RDP important for bacterial growth, but the presence of branched chain volatile fatty acids is also vital for cellulolytic bacteria (Brito et al. 2007). In the current trial, no significant differences were noted in concentration of isobutyrate or isovalerate, however numerically, cattle fed WDDGS had a higher concentration. The small increase in concentration of branched chain VFA when WDDGS was included with CM may have been more balanced with the RDP provided by CM to contribute to improved microbial protein production.

There were no treatment effects ($P > 0.05$) on microbial efficiency with an average of 36.5 ± 1.6 g microbial N/kg OMTDR. The total bacterial NAN flow and microbial efficiency are higher than previously reported with backgrounding heifers (Li et al. 2013; Owens et al. 2014). The intake of DM, OM, and N in both of these trials was lower than in the current trial, as was the amount of OM and N digested, resulting in less energy and protein being available for microbial growth than in the current trial (Li et al. 2013; Owens et al. 2014). It has also been noted that an increase in intake can lead to an increased microbial efficiency due to increased

passage rate and therefore lower maintenance energy requirements of the microbes (Chibisa et al. 2012). The higher DMI of the heifers in this trial relative to other trials using backgrounding beef heifers may have contributed to the higher than expected microbial efficiency.

4.3.5 Omasal Flow of Amino Acids

An interaction ($P = 0.04$) was noted in the flow of arginine and alanine out of the rumen, with the addition of WDDGS reducing the flow of arginine (53.9 ± 1.8 g d^{-1} vs. 68.6 ± 6.6 g d^{-1}) and alanine (80.4 ± 5.9 g d^{-1} vs. 94.5 ± 8.3 g d^{-1}) when combined with SBM, but increasing the flow of arginine (59.7 ± 3.5 g d^{-1} vs. 52.5 ± 5.8 g d^{-1}) and alanine (89.7 ± 7.0 g d^{-1} vs. 77.9 ± 7.3 g d^{-1}) when combined with CM. No differences ($P > 0.05$) were seen in flow of essential or nonessential amino acids out of the rumen between CM and SBM, nor were there any differences as a result of WDDGS inclusion. This finding is in contrast with most work that has reported either omasal outflow of amino acids or in situ ruminal degradability of amino acids in CM and SBM. In previous in situ work, CM has been found to have a higher concentration of rumen undegradable amino acids than SBM, including methionine, threonine, valine, cysteine, glycine, and proline than as well as more rumen undegradable histidine, isoleucine, lysine, threonine, valine, glycine, proline, and tyrosine than WDDGS (Maxin et al. 2013b; Paz et al. 2014). However, similarly to the current trial, when comparing omasal outflow of amino acids in dairy cows fed different levels of WDDGS as compared to CM, Chibisa et al. (2012) found that all amino acid concentrations were similar between the CM diet and the diet containing the lowest inclusion level of WDDGS. Flow of the individual amino acids and of total amino acids from the omasum in this study are higher than previously reported for the flow of amino acids in the duodenum of beef cattle (Li et al. 2013). The heifers in the current study also had higher nitrogen flow at the omasum than in the study by Li et al. (2013) as well as higher DMI and N intake, which lead to the increased flow of amino acids.

Table 4.7. Omasal outflow of amino acids (g/d) in beef heifers fed canola meal (CM)or soybean meal (SBM) with or without wheat dried distillers grains with solubles (WDDGS).

	Treatment					P value		
	CM	SBM	CM+ WDDGS	SBM+ WDDGS	PSEM	CM vs SBM	WDDGS	PS × WDDGS
Essential AA								
Arginine	52.5	68.6	59.7	53.9	8.88	0.27	0.41	0.04
Histidine	55.2	67.7	57.6	55.7	9.83	0.19	0.24	0.09
Isoleucine	66.0	81.8	76.9	71.4	7.72	0.50	0.98	0.18
Leucine	97.4	120.0	108.3	102.0	8.68	0.30	0.63	0.08
Lysine	80.0	102.9	88.3	82.0	7.19	0.23	0.36	0.05
Methionine	27.3	31.8	28.7	27.2	2.41	0.40	0.37	0.11
Phenylalanine	63.6	85.0	72.3	73.1	7.54	0.14	0.82	0.17
Threonine	66.2	80.2	73.7	68.9	5.34	0.37	0.70	0.09
Valine	74.3	85.2	82.1	74.9	8.10	0.82	0.88	0.29
Total Essential AA	582.5	723.4	647.6	608.4	9.86	0.33	0.63	0.10
Nonessential AA								
Alanine	80.3	89.7	94.5	77.9	7.2	0.84	0.53	0.04
Asparagine	163.6	203.0	177.2	167.8	10.5	0.33	0.48	0.13
Cysteine	20.9	24.1	22.1	21.2	8.0	0.45	0.58	0.19
Glutamate	199.0	245.2	225.6	207.6	19.3	0.43	0.76	0.10
Glycine	68.8	77.6	75.0	64.2	7.0	0.90	0.63	0.21
Proline	79.6	102.4	70.7	70.3	11.7	0.38	0.13	0.36
Serine	66.5	83.0	70.7	69.8	5.5	0.19	0.43	0.14
Tyrosine	50.7	59.6	56.1	55.2	6.6	0.57	0.95	0.50
Total Nonesssential AA	729.4	889.4	787.1	740.8	67.6	0.42	0.52	0.16
Total AA	1311.9	1612.7	1434.7	1346.2	121.2	0.38	0.55	0.13

Note: Least squares means within a row not sharing lowercased letters are different ($P < 0.05$) according to the Tukey-Kramer method. PSEM = pooled standard error of the mean. P values: CM vs SBM – effect of canola meal versus soybean meal; WDDGS – effect of inclusion of WDDGS in the diet; PS x WDDGS – Protein source × WDDGS interaction.

The discrepancy between rumen undegraded amino acid values in the current study compared to previous work is likely related to the estimated flow of DM out of the omasal canal. As seen in Table 4.3, the diets all had similar amino acid composition, however, heifers fed the SBM diet had a one kilogram more of DM flowing out of the omasum than heifers fed the CM diet. This kilogram of difference in omasal outflow would have led to more amino acids flowing out of the omasum in heifers fed the SBM diet.

4.3.6 Total Tract Nutrient Digestion

There were no treatment differences ($P > 0.05$) noted in DM (61.13 ± 0.57%; Table 4.8), OM (62.7 ± 0.8%), crude protein (70.1 ± 0.8%), ADF (33.3 ± 2.3%), or NDF digestibility (36.1 ± 1.1%), gross energy supply (4.3 ± 0.01 Mcal kg^{-1}), or digestible energy (2.6 ± 0.03 Mcal $kg^{-1;}$; 29.5 ± 0.5 Mcal d^{-1}). Other trials have found similar results with higher forage diets containing CM, SBM, or WDDGS fed to either cattle or lambs (Stanford et al. 1996; Van De Kerckhove et al. 2011; Li et al. 2013), with the exception of ADF digestibility and digestible energy in lambs being improved by CM supplementation relative to SBM. Total tract digestion of DM, OM, NDF, and ADF were lower in this trial than other trials using cattle fed similar diets (Gozho et al. 2009; Li et al. 2013; Nair et al. 2016). Crude protein digestibility however was similar to previously reported values (Li et al. 2013; Nair et al. 2016). As discussed earlier, the lower than expected total tract digestibility values could be attributed to the lower digestibility of oat hulls in the diet (Thompson et al. 2002).

Table 4.8. Total tract digestibility of diets fed to beef cattle containing canola meal (CM) or soybean meal (SBM) with or without wheat dried distillers' grains with solubles.

	Treatment					*P* value		
	CM	SBM	CM+ WDDGS	SBM+ WDDGS	PSEM	CM vs SBM	WDDGS	PS × WDDGS
Nutrient Digestibility (%)								
Dry Matter	60.5	61.2	61.9	61.0	2.70	0.44	0.57	0.34
Organic Matter	61.7	62.8	63.6	62.9	2.89	0.49	0.63	0.33
Crude Protein	70.9	70.6	69.1	69.8	1.82	0.70	0.29	0.80
Acid detergent fiber	30.3	33.1	34.7	35.3	4.10	0.25	0.14	0.32
Neutral detergent fiber	33.2	34.9	38.7	37.2	1.96	0.61	0.14	0.48
Gross Energy (Mcal/kg)	4.25	4.27	4.3	4.32	2.33	0.34	0.33	0.34
Digestible Energy (Mcal/kg)	2.54	2.57	2.64	2.63	6.50	0.38	0.36	0.38
Digestible Energy (Mcal/d)	29.74	29.45	29.36	29.23	3.12	0.41	0.38	0.51

Note: Least squares means within a row not sharing lowercase letters are different ($P < 0.05$) according to the Tukey-Kramer method. PSEM = pooled standard error of the mean. P values: CM vs SBM – effect of canola meal versus soybean meal; WDDGS – effect of inclusion of WDDGS in the diet; PS x WDDGS – Protein source × WDDGS – interaction.

4.4 Conclusions

As in the previous chapter, fluctuations in protein content of the diets may have led to some variations in rumen fermentation and apparent and true ruminal digestibility. However, inclusion of CM, SBM or mixtures of these with WDDGS resulted in no differences in rumen VFA or ammonia concentrations or in ruminal pH. This indicates that none of the protein supplements differed in their influence on rumen fermentation to a great degree. The inclusion of WDDGS with either CM or SBM reduced DM, OM, and N intake. There were differences in apparent and true ruminal digestibility of DM, OM, NDF, and N among protein sources, with CM improving digestibility of DM, OM, and N compared to SBM. The inclusion of WDDGS with either CM or SBM tended to decrease ruminal digestibility of DM, OM, and N. Diets containing CM tended to supply more RDP than diets containing SBM and the inclusion of WDDGS tended to reduce the RDP supply. An interaction effect was seen in PAB NAN flow with the WDDGS reducing PAB NAN flow when combined with SBM, but increasing it when combined with CM. No other treatment differences were seen in regard to microbial protein flow, suggesting that the protein supplements in this trial had little effect on ruminal microbial protein synthesis. Few differences were seen in omasal outflow of amino acids, with interactions noted for arginine and alanine. For both, WDDGS increased the omasal outflow when added to diets containing CM but decreased the outflow when combined with SBM. No treatment differences were seen in total tract nutrient digestion, suggesting that protein supplements did not have an effect on total tract digestion. The results of this trial indicate CM no different than SBM as a protein supplement and that there is no benefit nor detriment to adding WDDGS with respect to rumen fermentation or total tract nutrient digestion.

5.0 GENERAL DISCUSSION

The purpose of this research was to determine the usefulness of CM as a protein supplement for feedlot cattle compared to SBM. The objectives were to 1) compare the performance of growing beef cattle fed CM as a protein supplement to relative to SBM when fed with or without WDDGS, 2) determine the effect of CM relative to SBM or WDDGS on performance and carcass quality of finishing cattle, and 3) determine if CM supplementation either alone or in combination with WDDGS improves rumen fermentation, ruminal nutrient digestion, microbial protein synthesis, intestinal amino acid supply, and total tract nutrient digestion in growing beef cattle compared to SBM. Two feedlot trials and a metabolism trial using the omasal sampling technique were run to evaluate these objectives. The hypothesis was that CM would prove to be an effective protein supplement compared to SBM and CM's superior RDP to RUP ratio and supply of essential amino acids would improve performance of feedlot cattle and that extra RUP supplied by WDDGS would further improve performance.

Two feedlot trials and an in situ trial were run to determine the effect of CM versus SBM with or without WDDGS as a RUP source on backgrounding and finishing growth performance and carcass quality. The first trial consisted of a 95-d backgrounding program using 398 steer calves (288 ± 17.6 kg) randomly assigned to 12 pens and fed one of four barley based backgrounding diets supplemented with either CM, SBM, CM+WDDGS, or SBM+WDDGS. The second trial consisted of a 61-d backgrounding period followed by a 147-d finishing program using 300 head (305 ± 18.4kg) randomly assigned to 25 pens and fed one of five barley based finishing diets supplemented with either CM, SBM, WDDGS, CM+WDDGS, or SBM+WDDGS. The in situ trial evaluated each of the protein supplements in triplicate in 'gradual in, all out' 48-h ruminal incubations.

As predicted, the effective dry matter degradability of SBM (78.1 ± 3.9%; $P < 0.05$) was higher than that of CM or WDDGS (61.6 ± 1.0% and 65.6 ± 0.5%) and the effective degradability of protein followed the same pattern (SBM- 61.4 ± 7.4%; CM- 56.0 ± 1.9%, WDDGS- 53.1 ± 0.2%; $P > 0.05$), although it was not significant. This resulted in RUP values for the three protein supplements being closer in value to each other than was desired (SBM- 38.6 ± 7.4%; CM- 44.0 ± 1.9%, WDDGS- 46.9 ± 0.2%), although all three values were within the range of previously reported values (Li et al. 2013; Maxin et al. 2013b; Paz et al. 2014). It is

possible that CM having a higher RUP value than expected is due to the increasing addition of gums, phospholipids, and screenings back into the meal during processing. Canola meal and soybean meal had lower S fractions than expected, which also contributed to RUP being higher than expected in these meals. This is likely due to the fact that the supplements were left unground as opposed to being ground prior to incubation and the bags had a smaller pore size than other trials (Stanford et al. 1996; Li et al. 2012).

In Trial 1, the only parameter affected by treatment was ADG with cattle fed SBM+WDDGS having a lower ($P = 0.03$) ADG (1.32 ± 0.03 kg d^{-1}) compared to those fed SBM (1.45 ± 0.04 kg d^{-1}). There were no treatment differences noted in final body weight, DMI, G:F, or feed cost of gain. Although there were no significant differences ($P > 0.05$) seen in feed cost of gain, cattle fed CM (\$0.98 kg^{-1}) as opposed to SBM (\$1.03 kg^{-1}) had a \$0.05 kg^{-1} saving, and the addition of WDDGS to either CM (\$0.93 kg^{-1}) or SBM (\$0.98 kg^{-1}) saved an additional \$0.05 kg^{-1}. Feed costs are the greatest fixed cost to feedlot producers, so a savings of \$0.05 or \$0.10 per kilogram of gain without negative repercussions on growth is of significant importance.

In Trial 2, cattle fed CM+WDDGS had a higher (8.4 ± 0.1 kg d^{-1}; $P = 0.04$) DMI during backgrounding compared to cattle fed SBM (7.9 ± 0.1 kg d^{-1}), a response that was not observed during finishing. No diet effects were seen on overall ADG or G:F. Once again, no significant effect was seen in feed cost of gain ($P > 0.05$), but cattle fed SBM had the numerically highest cost of gain (\$1.31 kg^{-1}) than cattle fed CM (\$1.26 kg^{-1}), a saving of \$0.05 per kilogram of gain. Cattle fed WDDGS had an even lower feed cost of gain at \$1.22 kg^{-1}. The addition of WDDGS to SBM resulted in a saving of 3 cents per kilogram (\$1.28 kg^{-1}) while the addition of WDDGS to CM did not change the cost of gain (\$1.26 kg^{-1}). No treatment effects ($P > 0.05$) were seen in hot carcass weight, *Longissimus Dorsi* area, or dressing percentage. Cattle fed SBM+WDDGS had the least fat deposition of the treatments, with lower fat depth (1.17 ± 0.06 cm; $P > 0.05$) compared to CM+WDDGS (1.46 ± 0.05 cm), lower marbling score (398.75 ± 15.19) compared to WDDGS (440.10 ± 8.20), and a tendency to have fewer AAA carcasses ($41.4 \pm 6.5\%$; $P < 0.10$) than cattle fed WDDGS ($41.4 \pm 6.5\%$).

Some changes were seen in carcass fatty acid composition between treatments and from pre-feeding to finish. As expected, the production of MUFA decreased between pre-feeding and finish as did CLA, CLnA, and BCFA. While these data could not be statistically analyzed due to the difference in fat depot sampled, the changes in fatty acid concentration were expected as

similar differences have been noted in grass fed versus grain fed cattle. Cattle fed WDDGS in combination with CM and SBM had better fatty acid profiles, with higher concentrations of C18:3 n-3 (0.24 ± 0.01% FAME vs. 0.21 ± 0.01% FAME), *t*11-18:1 (0.45 ± 0.02% FAME vs. 0.29 ± 0.02% FAME), and *c*7-16:1 (0.17 ± 0.01% FAME vs. 0.14 ± 0.01% FAME) and lower concentrations of *t*10-18:1 (1.03 ± 0.14% FAME vs. 1.32 ± 0.19% FAME) and C17:0 (1.03 ± 0.04% FAME vs. 1.15 ± 0.02% FAME) compared to those fed just CM or SBM. Omega-3 fatty acids and several MUFA, including *t*11-18:1, and *c*7-16:1, have been found to be beneficial to human health while some MUFA, including *t*10-18:1, and SFA have been found to have negative effects on human health. The shift in the fatty acid concentration is consistent with differences between cattle fed high concentrate diets and cattle fed high forage diets, suggesting that inclusion of WDDGS can reverse some of the negative effects of high concentrate feeding to a small extent and that the combination of WDDGS with an oilseed meal may further benefit this shift. There were few changes between diets in subcutaneous fat and the differences in fatty acid concentrations noted were relatively small, meaning the changes noted may be of little significance to human health.

It was expected that CM would improve performance of cattle in the feedlot due to its previously reported ideal supply of essential amino acids and RDP/RUP ratio and its success in the dairy industry (Mutsvangwa 2017). One of the causes for the similarity between treatments could have been the narrow range of RUP values of the three protein supplements. According to values from the Canadian International Grain Institute (2013) and the Canola Council of Canada (2015), the predicted RUP range of the protein supplements used in this trial would've been 33.3% to 54.5%. Instead, the range of RUP of the protein supplements determined by the in situ trial was 38.6% to 46.9%, making the opportunity to see any effects of RUP on performance much smaller. Another reason the protein supplements had lower than expected effects in the feedlot trials, could have been the relatively low inclusion rate of protein supplements in the diets compared to lactating dairy cow diets. Lactating dairy cows have a higher requirement for protein than growing and finishing beef steers and therefore have a higher inclusion rate of protein in their diets. Previous work comparing CM to other protein supplements, including SBM and WDDGS, have inclusion rates of CM from 8.8% of dietary DM to 20.8% of the diet (Chibisa et al. 2012; Maxin et al. 2013a). In Trial 1, CM was included at 8.7% of the diet, and in Trial 2, the finishing diet included CM at 5.7%. The lower demand for CP in beef animals, the

lower inclusion level of protein supplements in feedlot diets, and the narrow range of RUP values in the protein supplements would have made it much more difficult to see any effects of protein supplements.

A metabolism trial was conducted to determine the effects of CM versus SBM with or without WDDGS on rumen fermentation, apparent rumen digestibility, microbial protein production, and total tract digestibility in backgrounding beef heifers. Heifers were fed barley based backgrounding diets supplemented with one of four protein treatments: 1) CM (8.8% DM), 2) SBM (6.6% DM), 3) CM+WDDGS (6.4 and 3.3% DM), 4) SBM+WDDGS (5.0 and 2.8% DM) in a latin square design balanced for carry over effects. Rumen samples, omasal samples, and fecal samples were taken to determine rumen fermentation characteristics and nutrient digestibility. The triple marker method (using Cr, Yb, and iNDF) was used with the omasal sampling technique to estimate omasal nutrient outflow.

Overall rumen fermentation was not affected by protein source, which was to be expected given the similarity in degradability of the protein sources seen in the in situ trial. Contrary to the feedlot trials, heifers fed diets including WDDGS had lower DMI (11.8 ± 0.3 kg d^{-1}; $P < 0.05$) and organic matter intake (11.0 ± 0.3 kg d^{-1}) than heifers fed diets not containing WDDGS (13.3 ± 0.4 kg d^{-1} and 12.1 ± 0.4 kg d^{-1}). There were multiple differences between the feedlot trials and the metabolism trial which could be the reason the same effects on DMI were not seen in the feedlot trial. It has been shown that cattle that are group fed as opposed to individually fed, intakes will be higher due to competition in the pen (Kidwell et al. 1954; Albright 1993). Restlessness and boredom can contribute to increased intake; although it has been shown that rumination may be able to act as self-stimulation in cattle (Kidwell et al. 1954; Albright 1993). In this case, DMI was lower in the group fed situations than in individual fed situation, however the heifers were tethered for 10 days during the infusion of the markers and omasal sampling. They were provided with a ball for stimulation, however they may have become restless during this period and used feeding and rumination as a source of stimulation. The heifers in the metabolism trial also had a much higher start of trial weight (540.3 ± 28.6 kg BW) than the steers in the feedlot trials (1- 288 ± 17.6 kg; 2- 305 ± 18.4kg) which further contributed to the difference in DMI between the feedlot trials and the metabolism trial.

Diets containing CM were, overall, more digestible in the rumen than diets containing SBM. The CM diet ($P < 0.05$) had a higher apparent ruminal digestibility of DM (31.7 ± 2.9%

vs. 21.2 ± 2.6%) and organic matter apparently digested in the rumen (36.9 ± 3.6% vs. 27.1 ± 1.9%). No treatment differences were seen in ruminal digestibility of NDF or ADF. The ADF digestibility however, was higher than expected based on the NDF digestibility and ADF total tract digestibility. This is mathematically impossible, so the ADF apparent ruminal digestibility value was removed from the results table.

Overall, the apparent ruminal digestibility of nutrients were lower than expected based on similar work with beef cattle limitations with marker recovery. It has been noted that using the triple marker method with the omasal sampling technique does not always work as expected for animals fed high concentrate diets (Titgemeyer 1997). The smaller particle size of oat hulls used in the current trial may have sped up the passage rate of the diet so that it became closer to the passage rate of a higher concentrate diet rather than the 55% forage diet, leading to errors in marker recovery and underestimation of apparent rumuinal digestibility.

Somewhat surprisingly, the CM diet supplied more RDP than the SBM diet (9.6 ± 0.3% DMI vs 7.8 ± 0.3% DMI; $P < 0.05$). Diets containing CM also had an increased ($P < 0.05$) apparent digestibility of nitrogen in the rumen (-24.9 ± 5.5% vs. -49.8 ± 3.0%) and decreased NAN flow out of the rumen as compared to SBM (106.1 ± 5.4% vs. 140.1 ± 3.6%). This was unexpected based on the results from the in situ trial and literature RUP values. It was expected that diets containing CM would have had a lower apparent N digestibility in the rumen and an increased NAN flow. No differences were seen in total flow of bacterial NAN, nor were there any differences seen in microbial efficiency. Diets that are higher in RUP should have a lower microbial NAN flow due to the reduced degradable protein available for microbial synthesis and the increased dependence on recycled nitrogen (Wagner et al. 2010). Based on this and the higher ruminal digestibility of OM, the CM diets which supplied more RDP and digestible OM than diets containing SBM would have been expected to have a higher bacterial NAN flow than the SBM diets.

No differences were seen in total tract nutrient digestibility between diets containing CM or SBM, suggesting that the type of protein supplement used had no effect on total tract digestibility.

Based on this research, it can be concluded that CM is equal to SBM as a protein supplement for feedlot cattle. No differences in performance were noted between growing and finishing steers fed CM versus SBM, and only minor differences were seen in apparent ruminal

and total tract nutrient digestibility. Slight improvements were seen in the feed cost of gain when CM was fed compared to SBM and when WDDGS was added to either supplement, suggesting SBM may be of the least economic benefit to livestock producers.

Further research may include:

1. Supplementing CM vs. SBM with or without WDDGS in corn based backgrounding and finishing rations to determine its effect compared to other protein supplements with lower protein forage and concentrate options.
2. In situ work determining rumen undegradable amino acids in CM, SBM, and WDDGS.
3. The effect of CM compared to other protein supplements, including SBM and WDDGS, on plasma amino acid concentration in growing and finishing beef cattle.
4. Further investigation into the effect of WDDGS in combination with oilseed meals on carcass fatty acid composition in finishing beef cattle.

6.0 GENERAL CONCLUSION AND IMPLICATIONS

The hypotheses of this research was that CM would prove to be a superior protein supplement to SBM based on its more desirable ratio of RDP to RUP and superior amino acid profile. Addition of WDDGS as a RUP source would further improve the growth performance of feedlot cattle. The results of this trial indicate that, at the inclusion levels investigated, there were few differences between treatments in growth performance or carcass quality of steers fed the different protein supplements. The combination of SBM+WDDGS seemed to reduce partitioning of energy to fat deposition, reducing the feed value of SBM+WDDGS for finishing cattle. However, the fatty acid profile of the carcasses was improved to a small extent by combining WDDGS with either CM or SBM. Both CM and WDDGS reduced the cost of gain for backgrounding and finishing cattle compared to SBM, making CM and WDDGS more attractive as a protein source. Few differences were seen in apparent and true ruminal nutrient digestibility, total tract nutrient digestibility, or ruminal microbial protein production.

The results from this research indicate that CM no different than SBM as a protein supplement for backgrounding and finishing cattle. With respect to cost of gain, CM and WDDGS were determined to both be a better choice for livestock producers relative to SBM due to equal performance and lower cost of gain.

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