BARLEY SILAGE OR CORN SILAGE FED IN COMBINATION WITH BARLEY GRAIN, CORN GRAIN, OR A BLEND OF BARLEY AND CORN GRAIN TO BACKGROUNDING BEEF CATTLE

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ABSTRACT

The objective of this study was to determine the effect of either barley (BS) or corn (CS) silage fed with dry-rolled barley (BG), dry-rolled corn (CG), or a blend of barley and corn grain (BCG) on predicted nutrient digestibility and growth performance of backgrounding cattle (Study 1) and dry matter intake, ruminal fermentation, total tract digestibility and nitrogen balance (Study 2). In study 1, Steers (n = 288) were stratified by BW into 24 pens and pens were randomly assigned to one of six treatments (n = 4) in a two × three factorial design. For Study 2 five ruminally cannulated heifers were used in an incomplete 6 × 6 Latin square design. Periods were 25-d including five days of dietary transition, 13 days of dietary adaptation, and seven days of sample collection. Treatments contained (DM basis) either BS or CS included at 55% in combination with 30% BG, CG, or BCG, 8% canola meal, varying amounts of urea to balance CP, and 5% of a mineral and vitamin supplement. There were no interactions among silage or grain source and no differences in ADG (1.01 kg/d) or G:F (0.10 kg/kg) among diets. However, DMI was 0.8 kg/d greater for steers fed CS ($P = 0.018$) than BS. Final BW was 8.4 kg greater for steers fed CS ($P = 0.004$) compared to steers fed BS. Fecal starch was greatest for CG, intermediate for BCG, and least for BG ($P < 0.01$). Whole barley kernels appearing in feces were greatest in BG compared to BCG while partial corn kernels in feces were greater in CG compared BCG ($P < 0.01$). Fine fibre particles in feces were greatest in BG diets with CG and BCG being least ($P < 0.01$ In study 2 Acetate concentrations were greatest for the CG and BCG diets ($P < 0.01$) while propionate was greatest for BS-BG and the least for CS-BCG ($P < 0.05$). Rumen ammonia concentrations were greatest for CG treatments ($P < 0.01$). Barley grain had greater DM, OM, starch and GE digestibility comparted to CG with BCG being intermediate ($P < 0.05$). Fecal nitrogen excretion was greatest for cattle fed CS ($P < 0.05$) as wells as for CG ($P < 0.01$). Use of CS improved DMI, ending BW and nutrient digestibility; while dry-rolled BG improved nutrient digestibility and reduced fecal starch concentration as compared to CG or BCG in diets for backgrounding cattle.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fibre
ADG	Average daily gain
aNDFom	NDF assay performed using amylase and sodium sulfite and corrected for ash content
BCG	Blended grain treatment with equal barley grain and corn grain inclusion
BG	Barley grain
BMR	Brown midrib corn
BS	Barley silage
BS-BCG	Barley silage with blended grain treatment
BS-BG	Barley silage with barley grain treatment
BS-CG	Barley silage with corn grain treatment
BW	Body weight
CG	Corn grain
CHU	Corn heat units
CP	Crude protein
CS	Corn silage
CS-BCG	Corn silage with blended grain treatment
CS-BG	Corn silage with barley grain treatment
CS-CG	Corn silage with corn grain treatment
DDGS	Dried distillers' grains with solubles
DE	Digestible energy
DM	Dry matter
DMI	Dry matter intake
EE	Ether extract
GDD	Growing degree days
GE	Gross energy
G:F	Gain to feed ratio
N	Nitrogen
NASEM	National Academy of Sciences, Engineering, and Medicine
NDF	Neutral detergent fibre
NEG	Net energy of gain
NEM	Net energy of maintenance
NIR	Near infrared spectroscopy
NP	Not present
OM	Organic matter
PD	Purine derivatives
peNDF	Physically effective fibre
PI	Processing index

RDP	Rumen degradable protein
RUP	Rumen undegradable protein
S×G	silage by grain interaction
SCFA	Short-chain fatty acid
SEM	Standard error of the means
TDN	total digestible nutrients
TMR	Total mixed ration

1.0 GENERAL INTRODUCTION

Barley is a common feedstuff in western Canada and is used as both a forage source and a grain source for livestock. However, with the development of new short-season corn varieties for areas such as western Canada there is increasing use of corn as a source of forage and grain for beef cattle production. While there are agronomic risks associated with growing corn such as high input costs, drought and early frost, the substantial yield increase for corn relative to barley serves as a attractant for corn production (Lardner et al. 2017).

For backgrounding cattle forage is the major dietary component and as such, quality is an important factor affecting the performance of growing beef cattle (National Acadamies of Science, Engineering and Medicine (NASEM) 2016). Research on short-season corn varieties for silage, especially comparing them with barley silage, is limited to a few very recent studies (Miorin et al. 2018; Chibisa and Beauchemin 2018; Johnson et al. 2020a). Additional studies have evaluated short-season corn for winter grazing in western Canada (Lardner et al. 2017; McMillan et al. 2018). In general, this research has highlighted that short-season corn is generally greater in starch and lower in crude protein than barley. However, when comparing performance of cattle fed corn or barley silage, some studies have reported improved responses for those fed corn silage (Johnson et al. 2020a) while others have reported the opposite (Chibisa and Beauchemin 2018). Thus, in addition to the lack of research, there is a clear discrepancy in the results obtained.

Barley grain is the most common feed grain in western Canada. Due to high barley and moderate corn prices, some of the barley is being substituted by corn grain. In addition, corn has greater starch concentration, increasing availability in western Canada. and at times. When dry-rolled, barley grain is degraded to a much greater extent compared to dry rolled corn. Rapid degradation comes with challenges such as ruminal acidosis due to rapid rates of fermentation (Penner et al. 2007). Dry rolled corn has a lower starch availability due to the nature of the starch and protein matrix and as such some of the starch will bypass the rumen and be digested in the small intestine or excreted in feces. When feeding corn grain, another factor to consider is its protein content. The protein in corn is lower than barley and without additional protein sources, corn grain-based diets are not likely to meet the requirements of growing cattle. Inclusion of a protein supplement may add cost to the ration especially if the price of corn (CG) and barley grain (BG) are similar. Another consideration is the cost and method of grain processing and its impact

the on nutrient utilization and growth performance of cattle. Corn grain requires a more extensive processing (e.g. fermentation or steam-flaking) compared to barley grain and the adequate processing of corn grain may require additional infrastructure or management that is not readily available in western Canada.

Combinations of cereal grain and cereal silage sources with differing rates of fermentation and chemical composition have the potential to improve ruminal fermentation and performance in growing beef cattle. The use of multiple grain sources has been studied over the years aiming to improve the efficiency of cereal grains use through positive associative effects (Kreikemeier et al. 1987; Stock et al. 1987; Bock et al. 1991; Huck et al. 1998; May et al. 2010). In Canada, the majority of this work has focused on the inclusion of wheat and by-product feeds as replacements for barley grain (Gibb et al. 2008; Joy et al. 2016; Johnson et al. 2018). However, there is limited research comparing combinations of CG and BG for beef cattle (Campling 1991; Johnson et al. 2020a, 2020b) and none for backgrounding cattle. Data is even more limiting on these cereal grain combinations and their interaction if these cereals are used to produce silage for backgrounding cattle (Johnson et al. 2020a, 2020b).

2.0 LITERATURE REVIEW

2.1 Cereal Grains as a Feed for Cattle

2.1.1 Cereal Grain Production in Western Canada

Canada is one of the top 10 barley producers in the world and reportedly produced 8.4 million tonnes of barley in 2018 (Statistics Canada 2019). Barley grain production in western Canada represents 95% of the total Canadian production (Statistics Canada 2019) further emphasizing its importance in this region. Although barley grain is typically grown for malting purposes, approximately 70 to 80% of barley grain does not meet malt and is used as livestock feed (SaskBarley Development Commission 2018). Assuming that 80% of the barley does not achieve malt, approximately 6.7 million tonnes of barley may be diverted for use as livestock feed (Statistics Canada 2019). While Canadian export of barley equated to 1.18 million tonnes in 2018, most of exports were malt barley.

The most common types of barley produced are two row as opposed to the six row varieties (O'Donovan et al. 2011). Two row varieties have fewer kernels per plant allowing for larger kernels with more starch. Six row varieties tend to have lower starch content due to a smaller kernel size (O'Donovan et al. 2011). Given their higher starch concentration, the two row barley varieties are best suited for malt, but also make good feed barley (O'Donovan et al. 2011). Hull-less barley is a variety that has a hull that is easily separated from the pericarp which reduces its fiber content and increase the starch and protein concentrations. While the feeding of hull-less barley has been primarily fed to monogastrics, it has also been assessed as a feed for ruminants (Beauchemin et al. 2001; Damiran and Yu 2012). Hull-less barley requires a narrower roller gap than hulled barley to be adequately processed so as to have similar feed value (Firkins et al. 2001).

With approximately 76.3% of the Canadian feedlot cattle fed in Alberta and Saskatchewan in 2018 (CanFax 2019), feed barley is used exclusively in western Canada due to its lower shipping costs than corn. Barley prices are considerably volatile depending on supply, world feed grain markets, as well as trade. In recent years, high barley prices have been a challenge for the cattle feeding sector, and at times, corn from the United States has been priced similarly (Klassen 2019). High barley pricing has encouraged producers to find alternate feed grains to feed cattle such as corn, wheat, or oats.

Corn grain production in western Canada is a growing but is a relatively new industry. Corn grain is a relatively new crop in Saskatchewan, as 2019 was only the second year for it to be reported in crop input costs (Statistics Canada 2019). In 2018, approximately 190,040 ha in the prairies were seeded to produce 1.35 million tonnes of corn grain, with 1.2 million tonnes of that produced in Manitoba (Statistics Canada 2019). It is clear that corn grain production is small, but growing and will likely continue to increase as an energy source for livestock.

The development of short-season corn varieties has allowed producers to grow corn in areas, such as western Canada even though this area does not receive enough heat units to allow conventional corn crops to mature. Short-season varieties mature earlier than conventional varieties used in the USA or eastern Canada. These short-season varieties also increase the opportunity for producers in regions with longer growing seasons as they may be able to incorporate double cropping strategies or plant corn in years in which seeding has been delayed. However, in areas where corn heat units (CHU) are limiting, corn maturation to grain may still not occur. In such cases, immature corn has greater neutral detergent fibre (NDF) and lower starch concentrations than fully matured varieties due to the incomplete filling of corn kernels (Darby and Lauer 2002). As such, research evaluating short-season corn varieties grown in western Canada is needed to ensure accurate characterization of energy content.

Other cereal grains used for beef cattle in western Canada include wheat and oat. In 2018, 9.43 million ha of wheat were seeded in the prairie provinces (SK, AB, MB) yielding approximately 0.55 tonne/ha or 29.1 million tonnes (Statistics Canada 2019). A large portion of the wheat grown is used for human food or for ethanol production. However, as with barley, wheat not meeting quality standards for human consumption can be used as a livestock feed. As there are many differing types of wheat, there are clear challenges with wheat processing and wheat characterizing wheat as a feed. In 2018, 1.29 million ha of oats were grown, yielding 0.59 tonne/ha resulting in a total production of 3.1 million tonnes (Statistics Canada 2019).

Wheat and its by-products have been long used as sources of feed for beef cattle particularly in the backgrounding and finishing phases of production. Wheat is commonly grown in the prairies making it a readily available feed ingredient for cattle. In 2018, 23.3 million acres of wheat were seeded in the prairie provinces, yielding approximately 0.55 tonnes/ha and producing 29.1 million tonnes (Statistics Canada 2019). For cattle, wheat is a rapidly fermentable starch source that has been fed with slower fermenting grains such as corn (Bock et al. 1991) so

as to modulate the availability of starch in the rumen. In a study by Gibb et al. (2008) evaluating wheat dried distillers grains with solubles (DDGS), a by-product of ethanol production, it was observed that wheat DDGS had a similar feeding value to that of barley grain indicating that it could be used as a replacement if feed barley prices were high. The processing of the wheat for human food or ethanol generates by-products that can still be used to feed cattle with minimal secondary processing (Gibb et al. 2008).

Oat is a cereal grain typically fed to younger ruminants with minimal to no processing. The majority of the oats are used for equine and cattle feeds with 1/3rd grown for human consumption (Webster and Wood 2011). Oats are a low energy grain due to the fibrous hull but are also relatively high in protein. Starch in oats is degraded very quickly compared to other cereal grains but access to the starch allows slower degradation (Herrera-Saldana et al. 1990b).

2.1.2 Chemical Composition of Barley Grain and Corn Grain

Barley grain kernels have five layers including the: hull; pericarp; testa; aleurone; and endosperm (Figure 2.1). The pericarp, testa, and hull are fused tightly together making it very difficult to remove them. These outer layers protect the endosperm from microbial degradation (MacGregor, 2003). The pericarp, testa, and hull are the fibrous components of the kernels accounting for approximately 25% (acid detergent fibre (ADF) + NDF) of the fiber contained within barley grain (Cumberland Valley Analytical 2019). The endosperm is composed of starch and protein which accounts for approximately 63% and 12.5% respectively of the kernel composition (Herrera-Saldana et al. 1990b). Barley grain has a lower starch content than wheat and corn grain, whereas the protein in wheat is higher than barley, with corn grain having the lowest protein content (Herrera-Saldana et al. 1990b). Protein and starch content depend on the growing conditions and variety of the barley grown. In particular, malting barley varieties tend to have lower protein and greater starch content than feed barley (O'Donovan et al. 2011). As the plant matures, the starch content increases and the fibrous portion proportion decreases (Hunt 1996).

Starch granules in barley grain consist of amylose and amylopectin. Both amylose and amylopectin consist of glucose molecules, but they differ in the linkages that hold the glucose together. Amylose is a linear chain of glucose monomers connected by α-1,4 linkages. Amylopectin also contains α-1,4 linkages but also has α 1,6 branched linkages every 24 to 30 glucose molecules. Starch granules contain approximately 60 to 75% amylopectin and 25 to 30%
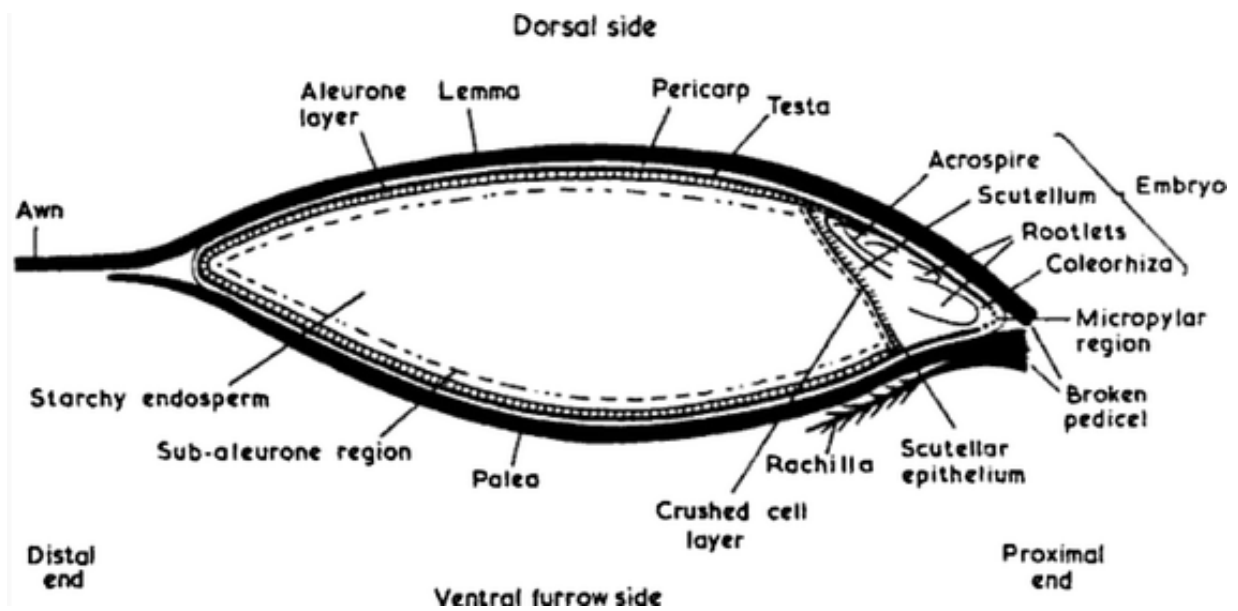
Figure 2.1. Barley kernel structure (Steiner et al. 2011).

amylose (Takeda et al. 1999). Amylopectin and amylose are degraded by α amylases though hydrolysis in the rumen where a water molecule is added to the glucose to hydrolyze the α-1,4 linkage. The α-1,6 linkages require α glucoamylase to release the glucose molecules (Beauchemin et al. 2004). Branched chains have slower rates of degradation compared to the linear chains (Foley et al. 2006). These enzymes are used by the microbes to release the glucose molecules to be used for microbial fermentation.

Corn grain also has a pericarp but unlike the barley kernel there is no testa or hull (Figure 2.2). There are many different types of corn, which are classified based on the nature of the starch in the endosperm. Dent corn is a variety high in starch typically used as feed corn, and flint corn which has a very hard pericarp that resists breakage. The vitreousness of the corn starch is directly related to the concentration of prolamin proteins (Lopes et al. 2009). These proteins surround the starch granules creating the protein matrix that surround the starch granules. Vitreousness and starch digestibility are negatively related (Lopes et al. 2009) and as a result, floury varieties have greater ruminal and total-tract starch digestibility (Lopes et al. 2009).

Short-season corn hybrids have been developed using two compatible inbred lines to create a superior hybrid line. In Canada, corn grain contains approximately 9.2% crude protein (CP), 14.7% fiber (ADF + NDF), and 71.8% starch (Cumberland Valley Analytical 2019). The concentration of these chemical constituents are slightly different from the corn grain in the USA due to differences in varieties. Corn in the USA is lower in protein, higher in fiber, and similar in starch content (Cumberland Valley Analytical 2019). The endosperm type of Canadian hybrids is typically dent as that is the type most commonly used for feed corn.

2.1.3 Digestibility of Barley Grain and Corn Grain

Grain processing is very important for most cereal grains as the outer pericarp or hull is resistant to degradation by ruminal microorganisms. There are numerous differing methods for cereal grain processing including: dry grinding; dry-rolling; temper-rolling; steam-flaking; and ensiling high-moisture grain. Grinding, using a hammer mill is commonly used for feeds that will be pelleted or presented in a meal form but can also be used to process grain to feed to cattle. Ground barley grain has a high fermentation rate and therefore is at risk of causing ruminal acidosis due to the large proportion of fines that this method produces. Dry-rolling is a processing method which cracks or crushes the kernel between two rollers. Temper rolling involves the addition of water to the grain, 12 – 24 h prior to processing so as to increase its moisture content to 20% to

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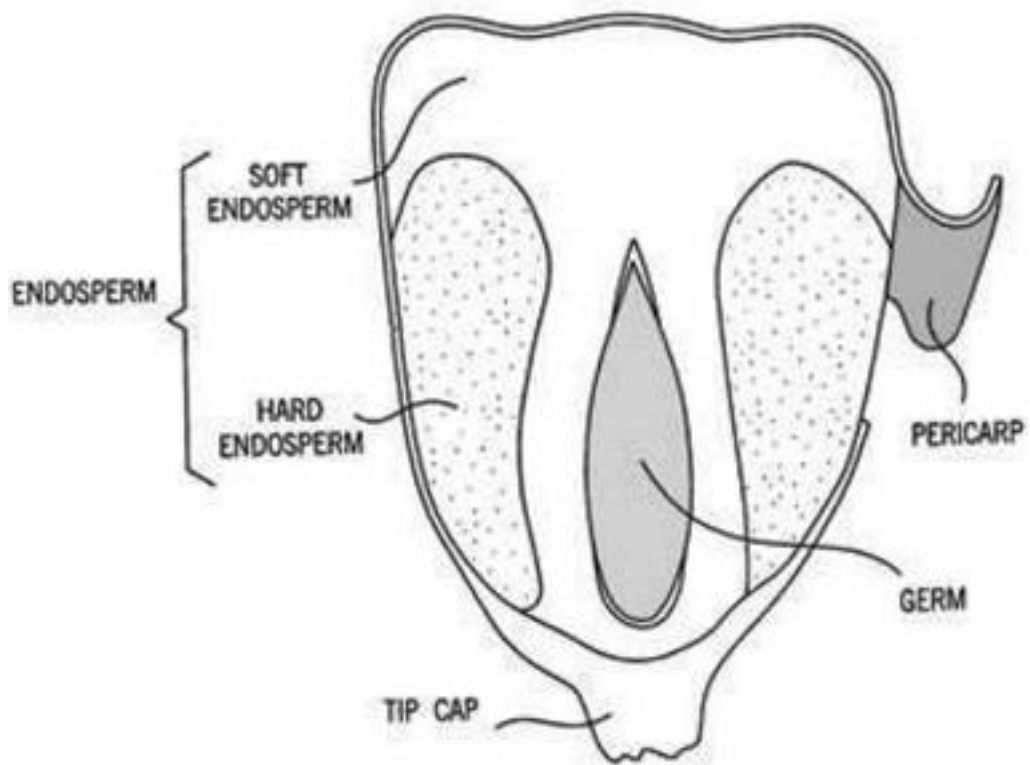
Figure 2.2. Corn kernel structure from Burger and Rheeder (2017).

25%. Tempering the grain prior to rolling reduces shattering of the kernels allowing for a more uniform product as compared to dry rolling (Dehghan-banadaky et al. 2007). High moisture grain is harvested at a greater moisture content (25%) than regular feed grains and is preserved through ensiling (Campling 1991). The high moisture content leaves the pericarp and testa of BG and the pericarp or CG more pliable and can either be rolled or ground (Wardynski et al. 1993; Owens et al. 1997) or fed whole (Huck et al. 1998). Steam-flaking grains requires heat and moisture to disrupt the starch-protein matrix inside the kernel and partially gelatinizes starch, making it more accessible (Zinn and Barajas 1997). The value of steam flaking varies among grain sources and the added processing costs need to be considered to determine if steam flaking is a cost-effective option.

Processing index (PI) is a volume weight to weight measurement of grain before and after processing as an approach to estimate the degree of processing (Beauchemin et al. 2001). As the grain is processed to an increasing severity, the density decreases. A higher processing index indicates low processing whereas a lower processing index indicates extensive processing. The optimal processing index for dry rolling barley is around 75% (Beauchemin et al. 2001). Optimal processing index can differ based on grain type as well as processing method used on the grain.

Grinding grain through a hammer mill allows maximal starch exposure in the rumen (Dehghan-banadaky et al. 2007). This is not always desirable for high barley grain diets where the risk of ruminal acidosis (McAllister and Cheng 1996) and bloat is inherently elevated (Ørskov and Mcdonald 1979) as a result of this type of processing. In theory, grinding allows the greatest digestibility due to increased surface area for microbial attachment and greater starch exposure, but may also cause a reduction in dry matter intake (DMI; Mathison (1996). Grinding corn grain increases starch digestibility by 14% over whole corn (Corona et al. 2005). Therefore, ground corn grain does not have the same risk of causing acidosis as ground barley grain as it did not reduce DMI or growth performance.

In western Canada, dry rolling grains is a common practice. Dry rolling is a relatively simple method with low infrastructure investment. Cereal grains such as barley, wheat, and oats do not require extensive processing using heat and steam and as a result dry rolling is a cost-effective method. In contrast, corn can be dry-rolled but requires a more extensive processing method such as steam flaking to maximize the ruminal digestion of starch, particularly within the

grain is increased by approximately 16% (Mathison 1996) as compared to the whole grain. The starch in barley grain is rapidly digested to a high extent in the rumen, providing the endosperm is exposed (Hunt 1996). Digestion of barley grain can be as high as 90% in the rumen whereas corn grain must be steam-flaked in order for ruminal starch fermentation to occur at a rate that is similar to barley grain (Ørskov 1986). If the corn grain is not adequately processed, some of the starch can escape degradation in the rumen and be degraded in the small intestine.

Kernel uniformity, or lack thereof, presents a challenge when using dry rolling as a processing method. The size of the kernels, distribution of kernel size, and the roller gap influence the degree of grain processing. If the kernels are too small they may pass through the roller without damaging the pericarp. If the kernels are large relative to the roller gap, the grain will be over processed leading to production of fines and increased risk for ruminal acidosis (Ahmad et al. 2010). With a grain source that has variable kernel size, the roller gap will be set to attain the optimal PI, but some kernels maybe over processed, while others will be under processed. A potential solution to this problem is to sort the kernels based on size. Once segregated, the roller gap can be adjusted optimally to strategically processes each of the kernel sizes. Ahmad et al. (2010) compared a single roller gap size to multiple roller gap sizes targeted for kernels that had been separated based on size and reported an increase in starch digestibility, digestion rate, and effective degradability when rollers were specifically set based on size of the kernels. However, kernel sorting is an extra step in processing and requires specialized equipment and the ability to store size-separated kernels.

Temper rolling involves the addition of moisture (up to 25% moisture content for the whole kernel) and allowing the grain to temper for 24 h before rolling (Dehghan-banadaky et al. 2007). The moisture added to the grain reduces shattering when the kernel is rolled, reducing the amount of fines produced. The optimal PI for temper-rolled grain is reportedly 75% (Beauchemin et al. 2001). A review by Dehghan-banadaky et al. (2007) noted some studies found digestibility was increased over dry rolled barley grain while others reported reductions in digestibility. In a review by (Wang et al. 2003), temper rolling decreased starch digestibility in finishing cattle. In a study by Zinn et al. (1998) comparing temper rolled corn to dry rolled corn, they reported similar digestibility between the two methods. With backgrounding diets there is greater rumen retention time due to the presence of more forage in the diet and therefore starch digestion may be higher due to the longer duration that grain may be retained in the rumen.

Steam flaking is a common method of corn processing in the United States. Steam flaking is an intensive and time-consuming process that includes 20 to 30 min of conditioning in the steam chest where moisture and heat are applied to the grain. In most cases, the steaming occurs at atmospheric pressure. After the grain is adequately steamed, it is passed through a roller to flake the grain (Chen et al., 1994). The thinner the kernel is flaked, the smaller the resulting kernel and the lower the density of the flake. The optimum flaking density has been reported to range from 0.32 to 0.39 kg/L for corn grain while barley grain requires a higher flaking density (0.39 kg/L) as lower density can result in decreased DMI with a less dense flake (Safaei et al. 2017). Steam rolling is a term often used synonymously with steam flaking, but according to Dehghan-banadaky et al. (2007) the only difference between this procedure and steam-flaking is that the time the grain is held in the steam chest is reduced to 3 to 5 min. Steam flaking corn increases the total tract digestibility of starch by approximately 10% over coarsely ground corn grain (Yu et al. 1998). Cooper et al. (2002) compared dry rolled corn and steam flaked corn and found that ruminal and post ruminal starch digestibility was greater for the steam flaked corn. The rate of starch digestion in the study by Cooper et al. (2002) was 58% higher for the steam flaked corn compared to the dry rolled corn grain. While Yu et al. (1998) found no difference in the digestibility of steam-flaked vs finely ground corn grain in dairy cattle. The endosperm type of corn influences the cattle response to processing where corn with a floury endosperm responds less to steam flaking than does flint or dent varieties (Lopes et al. 2009). A less dense flake has also been shown to increase the digestibility of corn grain over more coarsely processed corn (Yu et al. 1998). The less dense flake increases surface area for microbial attachment to starch granules. Steam rolling barley grain has been less investigated relative to corn and results from available studies are mixed. One review suggested that there is little difference between steam rolling and dry rolling in terms of digestibility (Dehghan-banadaky et al. 2007). However, Owens et al. (1997) suggested that steam-flaking barley may cause a reduction in DMI without compromised ADG, depending on the flaking density. Some studies including Mathison et al., (1991) found increases in starch digestibility for steam rolled barley as compared to dry rolled barley. More recently, Burakowska et al. (2019) reported that 5 min of conditioning was sufficient to maximize the starch digestibility of steam-flaked barley grain. Thus, while benefits are clear with steam-flaking corn, additional research is required to determine the most appropriate flaking conditions for barley grain.

When compared to rolled barley grain, rolled corn grain has lower dry matter (DM) and starch digestibility in the rumen and the total tract (Hunt 1996). Starch and protein matrix are loosely associated within the floury endosperm whereas in the vitreous endosperm the starch and protein are very tightly bound, making starch less digestible (McAllister and Cheng 1996). With corn varieties that are high in vitreous endosperm it is critical to process the grains with a more extensive method such as steam flaking to ensure maximal starch digestibility.

Another less common method of processing is micronizing. This method uses dry heat generated by infrared electromagnetic short waves from propane burnt over a ceramic tile (McAllister and Sultana 2011). The goal of this processing method is to gelatinize the starch molecules increasing total tract digestibility of the grain. According to McAllister and Sultana (2011), micronizing decreases the rapidly degradable fraction and increases the slowly degradable fraction in wheat, barley, and corn grain. This processing approach may prevent digestive upsets arising from rapid starch fermentation in high grain diets. Micronizing is a processing method more commonly used for oilseeds that are high in fat such as flax or canola, promoting the escape of fat from the rumen and its digestion in the small intestine (Mustafa et al. 2002).

2.1.4 Cattle Performance When Fed Barley Grain or Corn Grain

Backgrounding cattle are fed a mixture of forage and grain diets that are balanced to meet the needs of growing cattle that are depositing muscle before being transitioned to a finishing diet that promotes fat deposition. Cattle for backgrounding are typically bought as weanlings and fed for 3 to 8 months when they gain between 0.35 kg/d and 1.15 kg/d (NASEM 2016). Depending on the time and weight at weaning, this phase may be omitted and calves may be placed directly onto a finishing diet. Backgrounding can also be used to vary the time that cattle enter the finishing phase so that the time of slaughter enables year-round marketing.

In western Canada, barley grain is commonly used in backgrounding and fishing diets for cattle. With dry-rolling being sufficient to promote adequate starch degradation. However, the nature of processing and severity of processing of barley grain can have an effect on the growth performance. Beauchemin et al. (2001) obtained greater final body weight (BW) for steers fed a medium rolled (PI = 75%) barley grain compared to the coarse rolled (PI = 82%) barley grain in a high grain diet. In a literature review, Owens et al. (1997), in a literature review, reported that there were no differences for DMI or average daily gain (ADG) for cattle fed barley that was dry-rolled, steam-rolled, or whole. Jancewicz et al. (2017) reported increased DMI with a lower processing severity,

with no effect on ADG. Reduced efficiency may be due to similar digestibility indicated by similar fecal starch contents across processing methods despite differing ruminal starch availability. In another study, the extent of barley grain processing did not affect DMI, but coarser processing (PI = 86%) allowed greater gain compared to a fine processing (PI = 61%; Koenig et al. 2003). A greater severity of processing leads to greater starch availability as well as increased starch digestion in the total tract. The downside to the finer particles produced by increased processing is that the potential for low ruminal pH and the risk of ruminal acidosis is greater (Sadri et al. 2007) leading to greater risk for ruminal acidosis. Repeated episodes of ruminal acidosis have been reported to decrease feed efficiency (Górka et al. 2015) as well as ADG (Castillo-Lopez et al. 2014) and DMI (Zinn et al. 2002). A PI of 75% in dry-rolled barley grain will still allow escape of starch in the feces (Jancewicz et al. 2017a), thus very low PI would be needed to achieve minimal fecal starch content at the possible risk of an increase in acidosis.

Processing also affects the growth performance of cattle fed corn grain. A review by Owens et al. (1997) found ADG was least for high moisture corn as compared to dry-rolled, steam-rolled, and whole corn grain, while the high moisture and dry rolled corn resulted in improved feed efficiency as compared to the steam rolled and whole corn treatments. Comparing DMI, dry rolled corn had a higher intake than whole, steam rolled, and high moisture corn. For dairy cattle, DMI was negatively affected by finely ground (0.58 kg/L) corn (Yu et al. 1998) at a 40% of the diets compared to coarsely ground corn (0.62 kg/L), steam flaked corn (0.36 kg/L, 0.31 kg/L), and steam rolled corn (0.49 kg/L). Milk yield in the same study was also affected by processing with steam flaked corn increasing yield by 1.6 kg/d relative to ground corn. In contrast, when comparing corn grain processing methods, Ferraretto et al. (2013) reviewed 260 treatment means for dry rolling and grinding and 35 means for steam flaking and found no difference in milk yield between those studies. DMI in those same studies was greatest for the dry processed corn with high moisture (25 means) being least and steamed processed being intermediate, but not different. Starch content of the diets varied varied from 5.2 to 43.7% with a mean of 27%. The lack of an effect reported in Ferraretto et al. (2013) is likely due to varying sources of corn as both dent and floury varieties were included in this study. Zinn et al. (1998) compared tempered and steam-flaked corn and observed greater DMI for cattle fed temper rolled corn, and these cattle also had greater rib eye area as compared to those fed steam-flaked corn. In a study comparing dry rolled, high moisture, and steam flaked corn, Huck et al. (1998) observed greater ADG for cattle fed steam flaked corn

compared to dry rolled and high moisture with no differences in DMI, but the feed efficiency of cattle fed the steam flaked corn was increased. Increasing processing severity for corn has the potential to have positive impacts on performance, but performance may also be negatively impacted if the corn is over processed.

It has been hypothesized that balancing diets for rates of starch and protein digestion can stabilize ruminal fermentation and promote microbial protein synthesis (Hall and Herejk 2001). Along this line, combining corn and barley grain could be beneficial as the rates of starch degradation are quite different. Johnson et al. (2020b) observed that feeding a mixture of corn and barley grain resulted in higher ruminal short-chain fatty acid (SCFA) concentration than in cattle fed either corn or barley grain alone. Despite evidence for positive associative effects with SCFA, total tract starch digestibility was not improved. Other than the studies of Johnson et al. (2020a, 2020b), studies that have assessed combinations of corn and barley for growing or finishing cattle are limited. A study using dairy cows by Khorasani et al. (2001) reported no differences in DMI, milk yield, or milk composition from coarse ground corn grain, barley grain, or a blend of barley and corn grain. A study using beef steers fed finishing diets designed to compare steam rolled corn and steam rolled barley, found that cattle fed barley had greater DMI, greater ADG, and improved feed conversion compared to those fed corn (Beauchemin et al. 1997). Johnson et al. (2020a) compared dry rolled corn and dry rolled barley and reported greater DMI for dry rolled corn grain with no difference in ADG, thus the gain:feed (G:F) was more favourable for steers fed barley.

In a meta-analysis by Ferraretto et al. (2013), 37 treatment means containing barley grain and 320 containing corn were used to compare production responses in lactating dairy cattle. Those authors determined that regardless of the processing method, corn grain regardless of processing promoted greater DMI, milk yield and improved feed conversion compared to barley. A review paper by Owens et al. (1997) deduced that severe processing of barley may reduced DMI to a greater extent than corn, owing to its more rapid rate of starch digestion. Processing can make the available energy in the grain more available for fermentation. For example, whole barley grain has an estimated ME of 2.85 Mcal/kg DM which, is improved by dry rolling to 3.40 Mcal/kg DM for finishing cattle (Owens et al. 1997). Whole corn has an estimated energy value of 3.56 Mcal/kg DM, that is not improved by dry rolling (3.26 Mcal/kg DM), but is improved by steam flaking (3.73 Mcal/kg DM; Owens et al. (997)). Taylor and Allen (2005) observed greater organic matter (OM) and starch digestibility in corn that contained more floury endosperm than vitreous

endosperm. The limited change in energy value for dry rolling compared to whole corn may differ among corn sources.

2.2 Cereal Silage as a Feed for Cattle

2.2.1 Cereal Silage Production in Western Canada

Silage is a major forage source for feedlot and dairy cattle. Silage is chosen over dry forage due to increased DMI and improved digestibility (Murphy et al. 2000). While forage quality is often emphasized for dairy cattle, forage quality is also critical for backgrounding cattle. According to Nair et al. (2016), barley varieties with higher NDF digestibility have the potential to improve performance of beef cattle in backgrounding systems by allowing greater intake of both DM and DE. For corn silage, variety also affects the digestibility of the fiber such as for brown-midrib (BMR) corn which improves DMI and tended to improve ADG and G:F in backgrounding steers (Saunders et al. 2015).

Barley silage is commonly used in diets for growing cattle in the prairie provinces. Forage varieties are typically chosen to maximize forage yield (6.7 t/ha) as well as for their high nutritive value. In western Canada, barley silage has an average DM of 43.5%, 11.6% CP of 11.6%, 48.4% NDF, and 17.9% starch (Cumberland Valley Analytical 2019). Developments in barley varieties that have increased NDF digestibility can be an asset to producers. Improving NDF digestibility has potential to increase DMI (Nair et al. 2016). For harvest, it has been recommended that producers target the mid-dough stage of maturity to allow for greatest nutrient content and digestibility while optimizing yield (Nair et al. 2016). Among barley varieties there are large differences in CP, ADF, NDF, and starch content (Nair et al. 2016). Nutritional composition of the forage can have impacts on the performance of the animal due to changes in the fermentation of the forage source. Chop length of the forage at time of harvest can also have effects on DMI with a reduction in particle size potentially increasing DMI (Einarson et al. 2004). This is likely mediated through increased ruminal passage rate and thus decreased rumen fill. A smaller forage particle size (10 mm vs. 19 mm) may also increase the availability of plant call wall carbohydrates to the rumen microbiota (Einarson et al. 2004).

Kernel processing is mechanical processing of the silage though rollers prior to ensiling. In contrast with corn silage, barley silage is not harvested with a kernel processor. Part of this response may be due to the stage of maturity at harvest and that starch digestibility seems to be relatively high when whole-plant barley is fed (Rosser et al. 2013). Supporting the lack of a

requirement for a kernel processor, Eun et al. (2004) compared barley silage that had been harvested with a kernel processor (1 mm roller gap) relative to barley silage that had not been processed. Those authors found no difference in DMI, milk yield, or milk component yield in response to kernel processing. However, kernel processing of barley silage did increase ruminal degradation of DM, NDF, and ADF, suggesting there may be improvements in nutrient utilization. These differences may be more important if barley is harvested at a more advanced maturity.

Corn yields for varieties grown in the prairie provinces of Canada are approximately 1.2 t/ha for the grain and forage yields of 6.9 t/ha (Statistics Canada 2019). Should the growing season prevent complete maturation of the corn, yield will be reduced and chemical composition altered. Darby and Lauer (2002) evaluated the yield of conventional hybrids and observed the optimal yield and forage quality balance was at half milk line. For short-season hybrids, the milk line is not an accurate indicator of maturity for ensiling given marked differences in whole plant DM at a given maturity and that frost may stop plant growth. In a comparison study by Lardner et al. (2017), three short season corn varieties were grown over 3 consecutive years in 4 different locations: two in Saskatchewan and two in Alberta. The yield of the corn at half milk line was greater (11.2 t/ha, and 30.9% DM averaged over all sites for all years and corn varieties, n = 36) compared to that of the barley at the soft-dough stage (6.7 t/ha, and 31.5% DM averaged over all sites for all years, n = 12). The barley yields (6.7 t/ha) in Lardner et al. (2017) were similar to that reported by (McCartney et al. 2008) in which they reviewed cool season cereal crops for grazing purposes. The Government of Manitoba (2020) released a spreadsheet in 2020 to help producers compare the costs of silage production between corn and barley silage. Estimated farm gate revenue for barley silage was estimated at $373.50/ton DM and $598.50/ton DM for corn. The total costs including fixed, operating, and labour was $105.92/ton DM for barley silage and $110.91/ton DM for corn silage. Primary factors affecting the silage costs were the greater fertilizer expense, fuel for the moving and packing of silage, crop insurance, and labour costs for the corn compared to the barley. The increased yield of the corn over barley has made corn silage a favourable substitute for barley silage for some producers but, these data suggest that corn silage may still have a greater cost.

Short season varieties are typically harvested at ½ milk line although this may not achieve the appropriate plant maturity or an optimal DM content for ensiling (Guyader et al. 2018). Harvesting silage with less than 28% DM increases seepage losses from the silo, while DM

concentrations over 40% may not ensile properly due to difficulties in packing and reduced fermentation. Guyader et al. (2018) evaluated 6 hybrid corn varieties at 4 locations in western Canada over 3 years to select varieties with suitable CHU. All corn was harvested just before first frost, with the Lacombe location being the only one where whole-plant corn DM was at least above 30% DM. The low DM values obtained was due to the CHU accumulation not being adequate for the varieties chosen. They also found that starch fill, as indicated by the milk line, were correlated with whole plant DM, but this relationship was inconsistent among locations. This finding demonstrated that the milk line was not a reliable indicator of DM content for optimal ensiling of corn.

There are a few on farm methods to be able to measure silage DM, but both require the whole plant corn to be chopped (either with manually or a woodchipper; Mickan 2018) prior to measurement of DM. The first method uses a microwave heat the sample which is weighed after every 1 to 2 minutes until there is no further reduction in weight. Once the weight is constant, DM content can be calculated as ((final weight/initial weight) × 100%). The second faster methods is the hand method where a sample of the chopped forage is squeezed tightly for 20 to 30 seconds and the hand is quickly opened. If the ball of chopped forage holds its shape with lots of free juice, the DM is < 25%. If the ball of forage holds its shape and there is some moisture remaining on your hand, the DM is 25% to 30%. If the ball of forage slowly falls apart and there is little moisture on the hand surface, then the DM content is 30% to 40%, and if the forage ball quickly falls apart, the DM content is > 40%. Harvesting the corn too immature can lead to nutrient leaching due its high moisture content (Darby and Lauer 2002). Therefore, the timing of harvest at a point where the corn is mature enough to have adequate starch content in kernels proper moisture (32 to 38% DM) for ensiling it is critical to producing high quality corn silage (Guyader et al. 2018).

Kernel processing is a method used when harvesting corn silage to improve the digestibility of the starch. While harvesting corn silage, the silage is rolled through two rollers with a 2 mm gap to break the pericarp on the kernels to allow greater access for rumen microbes (Ferraretto et al. 2018). This is especially important for dryer corn silages as the kernels will be harder and even more resistant to degradation in the rumen (Ferraretto et al. 2018), a consideration that may also apply to barley silage. Kernel processing also reduces the silage particle size suggesting that the theoretical chop length may need to be adjusted. A review by Ferraretto et al. (2018) found several studies that reported no change in DMI with kernel processing. They believed this was due to the

fact that the unprocessed control treatments had a shorter chop length compared to the processed, resulting in a similar particle size overall. Kernel processing improves starch digestion due to the exposure of the corn kernel starch to rumen microbes (Ferraretto et al. 2018).

Chop length is an important factor to consider due to the impacts it has on silage packing, mixing in the feed wagon, and silage intake. Longer chop length may increasing chewing time for cattle and may stimulate the integrity of the rumen mat increasing particle retention time, NDF digestion, and ruminal pH as compared to a shorter particle size (Ferraretto et al. 2018). The downside of longer particle sizes is that it is easier for cattle to sort the feed for the concentrate as well as increasing the difficulty of packing the forage during ensiling. A study by Bal et al. (2000) comparing long (8.7 cm) to short (3.2 cm) chop length with or without kernel processing and reported greater DMI for kernel processed silage compared to unprocessed silage, but chop length had no effect on DMI. Cattle in that same study had greater milk production when fed the processed silage as compared to the control treatment.

Physically effective NDF (peNDF) considers those physical characteristics that are known to affect chewing behaviour as well as the nature of the ruminal contents (Mertens 1997). Chewing time tends to be longer when particle size of the fiber is longer (Soita et al. 2000), even within a given forage source. In another study comparing short and long silage particles in both barley and alfalfa silages, (Yang et al. 2001a) concluded that forage particle length did not affect DMI in dairy cattle. As with the previous study, there was no difference in milk yield as a result of differences in particle length. The particle size of the silage cut to the same theoretical chop length is highly variable across plant species (Yang and Beauchemin 2006). Many factors affect the particle size of a crop such as chop length, plant maturity, plant DM, and the type of harvester used. With all this variation in barley silage particle size, maintaining a uniform particle size across years, crop, and fields is challenging. The particle length though had no effect on passage rate of barley silage as the size of particles in the rumen after chewing were similar in size to those that initially came from silage with a shorter chop length. Therefore, providing a longer chop length simply results in cows reducing particle size to a greater extent. In contrast, Einarson et al. (2004) reported that reducing the chop length increased intake and increased passage rate of the barley silage. It is not clear why opposite results occurred between that of Yang et al. (2001b) and Einarson et al. (2004). Chop length, therefore, is another factor that differs between studies and farms. Mechanically processing barley silage using a kernel processor is not a common practice as there is no

digestibility or intake benefit to this extra step at harvest (Eun et al. 2004). Mechanical processing is common for corn silages to break apart the corn kernels but for barley it would only serve to crush the barley kernels that are already susceptible to bacteria when they are high in moisture.

Like barley silage, the particle size of the corn silage is affected by harvesting equipment, maturity and chop length, factors that can generate considerable variation (Kononoff et al. 2003). Cattle fed corn silage with a smaller particle size had greater DMI compared to those fed a larger particle size corn silage. Increased DMI when fed a smaller particle size silage also occurs for barley silage though not as consistently as it does for corn silage. The smaller particle size discourages sorting of total mixed rations (TMR), possibly providing cattle with a more balanced diet. Feedlot cattle fed short as compared to long particle size corn silage did not differ in DMI, ADG, or G:F (Gentry et al. 2016). In another study by (Kononoff and Heinrichs 2003), DMI of dairy cattle was not affected by the particle length of corn silage, but the TMR in this case had very similar particle sizes. A study by Beauchemin and Yang (2005) as well as Weiss et al. (2017) also found no differences in DMI with varying peNDF content. For barley silage there was no effect of particle length on DMI or total milk yield, but a shorter chop length did increase milk protein yield (Soita et al. 2000). Eating and rumination time was greater for the long chop length compared to the short. Overall, longer particle size increases chewing (min/d, min/kg forage intake, min kg forage NDF intake) and may not always effect on intake. However, with longer particle sizes the ability to pack the silage to an optimal density for ensiling may be impaired.

Packing density of the silage is important for proper fermentation and preservation of the feed. There are many factors that affect the packing density of the silage including moisture concentration, particle size, type of storage area, and forage type. The goal when packing silage is to exclude as much oxygen as possible so as to limit aerobic respiration (Bernardes et al. 2018). If too much aerobic respiration occurs, soluble carbohydrates are used for aerobic respiration decreasing their availability for fermentation acid production (Kung 2000; Schroeder 2013).

2.2.1.1 Cereal silage ensiling process

Silage ensiling is split into four phases with the first stage being aerobic respiration. Aerobic respiration occurs between the cutting of the forage and for a period of at least two hours after it has been sealed. If the aerobic phase lasts longer, the quality of the silage will be greatly reduced as soluble carbohydrates are used up by spoilage microorganisms before the lactic acid bacteria can ferment them (Schroeder 2013). As a result of aerobic respiration oxygen is depleted,

leading to anaerobic fermentation where it is important that the storage system continues to exclude oxygen.

In phase 2 (anaerobic fermentation), initially acetic acid production drops the pH and lactic acid bacteria proliferate fermenting soluble carbohydrates (Schroeder 2013). There are two types of lactic fermenters: those that are classified as homolactic (only produce lactic acid) and heterolactic which produce more than one final product (lactic acid, acetic acid, propionic acid, ethanol, or CO_2; Kung 2000). Homolactic bacteria are often used as silage inoculants as they only produce lactic acid as the sole end product. However, heterolactic acid bacteria may help improve the aerobic stability of the silage during feed out. Once fermentation is complete (approximately 21 – 40 days), the silage is defined as being in the storage phase (Phase 3). As the silage is stored, the starch digestibility improves, while NDF digestibility does not change over time (Der Bedrosian et al. 2012). Silage can be preserved in the storage phase almost indefinitely, as long as the silage is not exposed to oxygen.

The final phase (Stage 4) is the feed-out phase. In the feed-out phase, the silage is exposed to oxygen as it is removed from the storage structure. In bunker silos, it is important to have good face management so as to reduce spoilage and the onset of secondary aerobic respiration. It is recommended that silage is fed out at a rate over 2 m per week in warmer climates and at least 1.1 m per week in cooler climates (Bernardes et al. 2018). If the feed-out rate is too slow, the surface of the silage may promote growth of yeasts and moulds decreasing quality, increasing DM loss, and the portion of silage that must be discarded due to low quality (increased shrink).

Inoculants are used by producers to promote fermentation and increase aerobic stability at feed out (Elferink et al. 2000). One type of inoculant includes the use of homolactic acid bacteria which was mentioned previously. Adding these bacteria to the silage allow lactic acid bacteria to out compete other bacteria thereby promoting a rapid decline in pH and improving silage quality (Kung 2000). Heterolactic bacteria can also be used to promote aerobic stability at feed out due to their ability to produce acetic acid which inhibits yeast and moulds (Kung 2000). Increasing the number of desirable bacteria may also limit yeast growth and spoiled silage (Oude Elferink et al. 2000). Bernardes et al. (2018) concluded that adding the lactic acid bacteria to silage reduced the spoilage and improved stability at feed out. Another outcome of increasing lactic acid bacteria is that the increase in lactic acid may improve NDF digestibility (Muck et al. 2018).

When choosing an inoculant, it is important to consider the current condition of the crop to be ensiled. If the crop is harvested with low concentrations of and soluble carbohydrates, the addition of sugar in the form of molasses or the addition of enzymes that stimulate the release of sugars from plant cell walls may provide the lactic acid bacteria substrate for fermentation. If the levels of soluble carbohydrates are adequate, the addition of lactic acid bacteria alone should be sufficient for optimal fermentation (Oude Elferink et al. 2000). In terms of moisture content, if the forage is harvested too wet, proliferation of clostridial species may occur and the addition of fermentation inhibitors such as lactic acid, nitrites, and sodium chloride may inhibit these bacteria (Bernardes et al. 2018). Chemical additives include lactic acid, nitrite salts, sulfite salts, urea, ammonia, propionic acid, benzoic acid, and formic acid. Some of these chemicals are used to inhibit fermentation such as formic acid, lactic acid, nitrite and sulfite salts. Propionic and benzoic acid are used to prevent aerobic deterioration of the silage caused by yeasts. Others such as urea and ammonia are used to improve aerobic stability while acting as a N source for rumen bacteria. As alluded above, such chemical additives may also improve silage stability at feed out (Bernardes et al. 2018). Commercially available additives often combine more than one type of bacteria in an attempt to cover multiple silage quality and preservation strategies (Oude Elferink et al. 2000).

2.2.2 Chemical Composition of Barley Silage and Corn Silage

The chemical composition of silage varies greatly with forage type but also with harvest management, feeding management, and the efficacy of the inoculant chosen. Generally, corn silage has greater starch, less protein, and similar NDF concentrations to barley silage (National Acadamies of Science Engineering and Medicine (NASEM) 2016).

Silage composition differs from region to region according to data from Cumberland Valley Analytical (2019). For example, when comparing corn silage in the upper Midwest USA to corn silage in western Canada where short-season varieties are grown, it is apparent that corn silage from the USA has lesser CP, NDF, and ADF, but higher ether extract (EE) and starch. Short season Canadian varieties are more early maturing and therefore the potential for starch deposition is lower as compared to corn in the USA. Short season varieties may also not reach physiological maturity before frost. As a result of lower starch deposition with short season varieties, concentrations NDF and ADF are greater.

When comparing western Canadian corn silage to western Canadian barley silage, corn silage has less CP, NDF, and ADF, but higher starch (Table 2.1). Corn silage may be subject to

freezing before harvest and this can have effects on the chemical composition of the silage such as increasing whole plant DM content as moisture is lost from plant cells that have been ruptured due to frost (Aboagye et al. 2019). A light frost will still allow the plant to continue to accumulate starch until a killing frost ceases starch deposition.

2.2.3 Digestibility of Barley Silage and Corn Silage

There are limited data that have compared the digestibility of barley silage to short season corn silage. Finishing diets that contained either barley (BS) or corn silage (CS) did not differ in total tract digestibility, whereas in situ starch while DM digestibility was greater for the diets that contained corn silage (Johnson et al. 2020a). The lack of differences in total-tract digestibility differences in this case may be due to the low inclusion of silage (10% DM) in finishing diets. The maturity of barley silage at the time of harvest also has an effect on the digestibility with more immature plants having greater digestibility (Acosta et al. 1991). In fact, NDF and ADF digestibilities were 25.3% and 23.6% greater respectively, and CP digestibility was 26.5% greater for barley forage harvested at the boot stage (harvested at 30.8% DM) relative to the soft dough. However, harvesting at the boot stage also reduced DM yield by up to 58% (Acosta et al. 1991). With this large of a reduction in yield, the benefits of the greater digestibility associated with less mature barley are likely outweighed by the reduction in yield. In addition, harvesting at an earlier stage may require wilting in the field to ensure an appropriate forage DM content for ensiling (Miorin et al. 2018).

As mentioned previously, increasing the duration of storage improves the digestibility of the starch in silage, particularly for corn silage. As maturity of the corn plant increases, total tract DM digestibility of corn silage decreases largely as a result of decreased starch, NDF, and ADF digestibility (Andrae et al. 2001). Variety has an impact on digestibility of the forage especially in corn where both the type of fiber and the nature of the endosperm may vary. For example brown mid-rib (BMR) corn varieties contain less NDF and have greater NDF digestibility allowing better fermentability of the silage (Ebling and Kung 2004). Some corn varieties produce leaves and stem that result in a higher DM yield, but lower starch content. Corn varieties that are used for short-season grain production are selected for their early silking dates to maximize the time for cob production.

Table 2.1 Nutrient composition and nutrient digestibility of corn and barley silage.

	Corn silage	Barley silage
Nutrient composition[1]		
DM, %	36.1	43.5
CP, %DM	8.6	11.6
NDF, %DM	45.7	48.4
ADF, %DM	26.7	29.2
Starch, %DM	25.3	17.9
Ether extract, %DM	2.8	3.1
Nutrient digestibility (% DM)[2]		
DM, %	76.0	76.2
CP	69.9	70.0
NDF	45.0	42.9
ADF	40.9	37.8
Starch	93.2	93.8
Ether extract	76.2	78.8

[1]Based on values from Cumberland Valley Analytical (2019) corn silage n = 7,264; barley silage n = 8,030. All values are from between Jan 2014 to Jan 2019 and the selected region is Canada for both forages.
[2]Based on values from (Johnson et al. 2020b).

Corn varieties have been developed for increased digestibility such as the BMR varieties (Ebling and Kung 2004). In dairy cattle, compared to conventional corn varieties, BMR corn silage did not improve starch digestibility but did improve DM digestibility after 30 h of incubation in the rumen. Developments in barley varieties have also aimed to improve forage digestibility. The digestibility of the NDF of the forage is very important as it has the potential to increase DMI as well as potentially replace a portion of the BG, reducing cost especially for backgrounding cattle where this would be most useful (Nair et al. 2017). For Nair et al. (2017), NDF content of varieties as opposed to NDF digestibility had more of an effect on the backgrounding cattle. In fact, varieties with the greatest NDF digestibility (CDC Cowboy) had a lower DMI, ADG, and G:F compared to the CDC Copeland and Xena varieties that had lower NDF content. Voluntary feed intake can be limited by NDF content of the diet. High NDF content of the diet may inhibit DMI. The digestibility of the NDF is important as this influences the rate of disappearance of the forage from the rumen by impacting digestion and passage. A lower passage rate will also limit intake as rumen distension becomes a limiting factor for DMI (Ketelaars and Tolkamp 1992). Tension receptors in the rumen stretch and indicate fill of the rumen signalling cattle to stop eating (Allen 1996). To increase the passage rate of the same quality forage a reduction in particle size would be necessary. Reducing the particle size allows for more microbial exposure in the rumen allowing for a more rapid rate of degradation. For forages, particle size can be reduced by chopping or grinding of the forage. For silages, the reduction in particle size occurs at harvest before packing or through the use of a mixer with knives.

2.2.4 Cattle Performance When Fed Barley Silage or Corn Silage

Many cereal silages are grown in western Canada but BS is the most prevalent (Nair et al. 2017). In a study comparing pea silage, alfalfa silage, and barley silage, milk yield was not affected by the type of silage but in this study, barley silage was lower in CP than was expected so CP levels were not balanced among treatments (Mustafa et al. 2000). Studies comparing short-season corn to barley silage, especially in backgrounding cattle are limited. Chibisa and Beauchemin (2018) compared corn silage to barley silage for backgrounding steers and observed greater DMI and ADG for cattle fed barley silage but similar G:F. In terms of finishing studies comparing corn silage to barley silage, Johnson et al. (2020a, 2020b) observed no differences between these silages on DMI and ADG but some carcass characteristics such as hot carcass weight, dressing percentage, and carcass-adjusted ADG were improved with corn silage. The results from Chibisa and

Beauchemin (2018) and Johnson et al. (2020a, 2020b) highlight the lack of comparative information on the feeding of short-season corn silage and barley silage to backgrounding and finishing cattle.

Increasing numbers of short-season corn silage varieties have been developed recently and most of these varieties are being used for cattle production. Comparisons have been done between different corn varieties, the problem with this is there are always new varieties replacing old varieties with similar characteristics. Hybrid variety can have an effect on the results of processing or maturity on the silage quality or how the cattle respond to the feed (Andrae et al. 2001). In a previous study, Johnson et al. (2003) found no difference in BW, DMI, or milk yield for either maturity or processing of the silage with corn silage produced from either a floury endosperm (dent) or vitreous endosperm (flint) varieties. Vitreousness increases with advancing maturity of the plant but ensiling mitigates the negative impacts on starch digestibility in a manner similar to that observed with high moisture corn. Ensiling promotes the breakdown of the starch protein matrix making the flint and floury endosperms similar in terms of digestibility.

Recently, in western Canada there has been interest in replacing barley silage with corn silage given that varieties have been proven to grow well in this environment (Lardner et al. 2017; Guyader et al. 2018). With the increased yield advantage for corn silage and high prices of land, the use of corn silage for growing cattle has potential benefits to producers looking to replace barley silage in their rations.

2.3 Interactions Among Cereal Silage and Cereal Grain Sources

Combinations of cereal grains and cereal silages could provide improvements in digestibility and stabilize ruminal fermentation thus reducing the risk of acidosis and allowing for improved performance. Providing a rapidly fermentable starch source such as barley grain with the more slowly fermented starch source of corn grain may provide a more stable supply of starch in the rumen. Johnson et al. (2020b) observed improvements for nitrogen (N) retention for cattle fed corn silage paired with barley grain as well as increases in SCFA proportions, min/d below pH 5.5, and minimum pH for different combinations of grains and silages (Johnson et al. 2020a). However, these responses did not improve the growth performance of steers. Others such as Cooke et al. (2009) fed combinations of silage types (corn silage and rye grass silage) with different grain processing methods (ground, steam flaked and hominy feed) to determine which combination provides a steady source of starch and improves animal performance. Cooke et al. (2009) observed

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similar performance across all diets, while including more rye grass silage increased fiber digestibility indicating all grain treatments were adequately processed to allow optimal starch digestion.

Corn and barley silage for backgrounding cattle produce similar results with differences between the studies affected by the feeding system and type of cattle being fed. The takeaway of this review is corn and barley each have their benefits from a production standpoint. Depending on the goals of the operation and the production system either forage source or grain source could benefit the operation depending on the price point of both the grains and the forages.

2.4 Hypothesis

I hypothesized that feeding corn silage would increase DMI, increase SCFA concentration, microbial protein supply to the small intestine and decrease ruminal pH, as compared to barley silage and that this effect would be greater for barley grain as compared to corn grain or a blend of barley and corn grain.

2.5 Objectives

The global objective of the research within this thesis was to compare DMI, growth performance, ruminal fermentation, and total tract digestibility for growing beef cattle fed diets containing barley or corn silage in combination with either dry-rolled barley grain, corn grain, or an equal blend of barley and corn grain.

The specific objective of Study 1 was to determine the effect of using barley or corn silage in combination with dry-rolled barley, dry-rolled corn, or a combination of barley and corn grain on DMI, ADG, and estimated total tract digestibility of backgrounding beef steers.

The objective of Study 2 was to determine the effect of using barley or corn silage when fed in combination with dry-rolled barley, dry-rolled corn, or a combination of barley and corn grain on DMI, ruminal fermentation, microbial protein synthesis, and total tract digestibility for growing cattle.

3.0 USE OF BARLEY SILAGE OR CORN SILAGE WITH DRY-ROLLED BARLEY, CORN OR A BLEND OF BARLEY AND CORN ON PREDICTED NUTRIENT TOTAL TRACT DIGESTIBILITY AND GROWTH PERFORMANCE OF BACKGROUNDING STEERS[1]

3.1 Abstract

The objective of this study was to determine the effects of either barley or corn silage fed with dry-rolled barley, dry-rolled corn, or a blend of barley and corn grain (BCG) on predicted nutrient digestibility predicted using near infrared spectroscopy and growth performance of backgrounding cattle. Steers (n = 288) were stratified by BW into 24 pens and pens were randomly assigned to 1 of 6 treatments (n = 4) in a 2×3 factorial design. Treatments contained (DM basis) either BS or CS included at 55% in combination with 30% BG, CG, or BCG, 8% canola meal, varying amounts of urea to balance CP, and 5% of a mineral and vitamin supplement. Steers were weighed on two consecutive days at the beginning and end of the 71-d study, and every 2 wk to determine BW and ADG. Digestibility was predicted using near-infrared spectroscopy of fecal samples collected on d 45. There were no interactions among silage or grain source and no differences in ADG (1.01 kg/d) or G:F (0.10 kg/kg) among diets. However, DMI was 0.8 kg/d greater for steers fed CS ($P = 0.018$) than BS. Ending BW was 8.4 kg greater for steers fed CS ($P = 0.004$) compared to steers fed BS. Steers fed CS also had greater DM, OM, CP, ADF, starch, and gross energy digestibility values ($P < 0.01$) than those fed BS. Feeding BG improved NDF, ADF, and CP digestibility values ($P \leq 0.01$) over CG and BCG. In addition, diets with BG had higher starch digestibility than CG, and cattle fed BCG had the lowest starch digestibility ($P < 0.01$). Fecal starch was greatest for CG, intermediate for BCG, and least for BG ($P < 0.01$). Whole barley kernels appearing in feces were greatest in BG compared to BCG while partial corn kernels in feces were greater in CG compared BCG ($P < 0.01$). Fine fibre particles in feces were greatest in the BG diets with CG and BCG being least ($P < 0.01$). Relative to BS, feeding CS resulted in greater DMI, ending BW and nutrient digestibility; while dry-rolled BG improved nutrient digestibility and reduced fecal starch concentration as compared to CG and BCG in backgrounding diets.

3.2 Introduction

In western Canada, barley silage and barley grain are commonly used in diets for backgrounding and finishing cattle. However, development of short-season corn varieties has

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increased the potential for corn production in western Canada, particularly for silage, due to greater yields than barley (Lardner et al. 2017). In addition to greater yields, corn grain and corn silage have greater starch but lower protein concentration (Ward and de Ondarza, 2008) and reduced rates and extents of starch and protein degradation in the rumen relative to barley grain and barley silage (Tothi et al. 2003). Given the marked differences in the concentrations of starch and CP and rates of fermentation, it may be possible to combine differing sources of cereal silage and cereal grains as a strategy to balance ruminal fermentation and intestinal starch supply for efficient digestion.

Despite well documented effects of feeding corn and corn silage in backgrounding diets for beef cattle in the United States (Hedrick et al. 1983; Pelletier et al. 2010), it is important to recognize that short-season varieties of corn grown in western Canada result in corn silage that has lower starch and higher protein concentrations than conventional USA cultivars (Chibisa and Beauchemin 2018). In addition, recent evidence suggests that there are marked differences in starch digestibility among short-season hybrids (Miorin et al. 2018). Thus, research is warranted to evaluate the effects of feeding corn silage from short-season corn varieties on growth performance of backgrounding cattle.

I hypothesized that cattle fed diets containing corn silage would have greater DMI and ADG when fed with a blend of barley and corn grain. The objective of this study was to determine the effects of barley or corn silage with dry-rolled barley, dry-rolled corn, or a combination of barley and corn grain on DMI, ADG, and estimated total tract digestibility of backgrounding cattle.

3.3 Materials and Methods

3.3.1 Silage production

Crop production for both barley and corn followed conventional practices used in western Canada. Barley silage (CDC Copeland, SeCan, Kanata, ON) was planted on May 19, 2016 after being treated with a fungicide (Rancona Pinnacle at 0.3 L/100 kg of seed, Arysta LifeScience Corporation, Cary, NC). Anhydrous ammonia was applied at 64.6 kg/ha along with Mesz granular fertilizer (Mosaic Company, Plymouth, MN) supplying 2.6 kg/ha N, 8.6 kg/ha P, 0.2 kg/ha Zn, and 2.2 kg/ha S at seeding. The crop was sprayed with Curtail M (0.3 L/ha Corteva Agriscience, Indianapolis, IN), Buctril M (0.2 L/ha Bayer Crop Science, Thane, India), and Bison (0.2 L/ha Adama Canada Ltd., Winnipeg, MB). The crop was swathed, chopped (theoretical chop of 9.5 mm), and ensiled July 28, 2016 (Table 3.1). Silage was inoculated with Biomax 5 (Chr. Hansen

Inc., Milwaukee, WI) at a rate of 1g/tonne. There was a total of 855 growing degree days for the barley crop prior to swathing. Growing degree days were calculated on a daily basis by taking the average of the minimum and maximum temperature and subtracting 5°C these values were added together over the growing season (Rosser et al., 2013).

Corn (Pioneer 7213R; Dupont Pioneer, Mississauga, ON) was planted May 27, 2016 (12,950 plants/ha). Anhydrous ammonia was applied at 72.1 kg/ha along with a granular fertilizer supplying 82.1 kg/ha N and 27.4 kg/ha P at seeding. The crop was sprayed with R/T 540 twice (0.3 L/ha and 0.3 L/ha Monsanto Canada Inc., Winnipeg, MB). Corn was chopped to a theoretical chop length of 9.5 mm on August 31, 2016 using a kernel processer adjusted to have a 2 mm gap and an inoculant was added (Biomax 5 (Chr. Hansen Inc., Milwaukee, WI), 1g/tonne; Table 3.1) at the time of ensiling. The corn received 1940 corn heat units from seeding to harvest which was slightly lower than the 25-yr normal ranging from 2200 to 2299 CHU (Government of Saskatchewan 2016).

3.3.2 Animal Management, Experimental Design, and Dietary Treatments

The use of steers in this study was conducted in accordance with the Canadian Council on Animal Care (Ottawa, ON, Canada) and animal use was approved by the University of Saskatchewan Animal Research Ethics Board (protocol 20100021). Two hundred and eighty-eight steers were sourced through a local auction market with mean BW of 306 kg ± 17 kg. Upon arrival, steers were given a management tag, vaccinated with Bovashield Gold One Shot (Zoetis, Parsippany-Troy Hills, NJ), Ultrabac 7/Somubac (Zoetis), and Bimectin (Bimeda Canada, Cambridge, Ontario) was topically applied. Steers were also implanted upon arrival with Ralgro (36 mg zeranol, Merck Animal Health, Madison, New Jersey). Subsequently, steers were stratified by BW (341.1 kg ± 0.4 kg) into 1 of 24 pens with 4 pens/treatment and 12 steers/pen using a 2 × 3 factorial treatment arrangement. Pens were 12 × 24 m and had a 3.3 m high windbreak fence at the back of the pen. Diets included (Table 3.1): barley silage with barley grain (BS-BG); barley silage with corn grain (BS-CG); barley silage with barley and corn grain (BS-BCG); corn silage with corn grain (CS-CG); corn silage with barley grain (CS-BG); and corn silage with barley and corn grain (CS-BCG). Corn silage and barley silage were included at 55% of the diet on a DM basis. Both corn and barley grain were dry rolled with corn ground to allow for 5% of the material to pass through a 1-mm sieve and barley processed to a processing index of 65%. When calculated on the basis of a PI, the corn grain had a processing index 83% (Table 3.2). Diets were formulated to contain 13.5% CP

Table 3.1. Ingredient inclusion rate and chemical composition of diets composed of barley silage (BS) or corn silage (CS) with dry-rolled barley (BG), corn (CG), or an equal blend of barley and corn grain (BCG) fed to beef steers.

	BS			CS		
	BG	CG	BCG	BG	CG	BCG
Ingredient, %DM						
Barley silage	55.00	55.00	55.00	-	-	-
Corn silage	-	-	-	55.00	55.00	55.00
Barley grain	31.44	-	15.61	31.18	-	15.48
Corn grain	-	30.89	15.61	-	30.72	15.48
Canola meal	8.00	8.00	8.00	8.00	8.00	8.00
Urea	-	0.47	0.23	0.27	0.72	0.50
Premix pellet[1]	5.56	5.56	5.56	5.56	5.56	5.56
DM, %	53.66 ± 1.94	53.68 ± 1.88	53.66 ± 1.89	49.26 ± 2.21	49.28 ± 2.17	49.26 ± 2.18
OM, %DM	93.88 ± 0.09	93.71 ± 0.22	93.87 ± 0.13	94.28 ± 0.07	94.16 ± 0.28	94.23 ± 0.18
CP, %DM	13.22 ± 0.23	13.56 ± 0.12	13.38 ± 0.16	13.44 ± 0.12	13.74 ± 0.06	13.6 ± 0.03
NDF, %DM	35.6 ± 0.32	33.0 ± 0.37	34.3 ± 0.34	32.85 ± 0.19	30.27 ± 0.14	31.55 ± 0.15
ADF, %DM	20.89 ± 0.33	19.77 ± 0.24	20.33 ± 0.28	18.87 ± 0.35	17.76 ± 0.2	18.31 ± 0.27
Starch, %DM	32.3 ± 0.53	36.17 ± 0.84	34.3 ± 0.66	36.5 ± 0.03	40.37 ± 0.53	38.46 ± 0.28
Ether extract, %DM	2.67 ± 0.11	3.19 ± 0.04	2.93 ± 0.07	2.7 ± 0.05	3.22 ± 0.04	2.96 ± 0.02
Ca, %DM	0.8 ± 0.03	0.79 ± 0.04	0.79 ± 0.03	0.76 ± 0.03	0.75 ± 0.03	0.75 ± 0.03
P, %DM	0.38 ± 0.01	0.35 ± 0.01	0.36 ± 0.01	0.38 ± 0.01	0.35 ± 0.01	0.36 ± 0.01

[1] Premix pellet contains: Calcium 9.20%, phosphorus 0.32%, sodium 1.64%, Magnesium 0.28%, potassium 0.60%, sulfur 0.12%, cobalt 4.9 mg/kg, copper 185 mg/kg, iodine 16.6 mg/kg, iron 84 mg/kg, manganese 500 mg/kg, zinc 558 mg/kg, fluorine 100 mg/kg, vitamin A 40000 IU/kg, vitamin D3 5000 IU/kg, vitamin E 600 IU/kg, selenium 2.00 mg/kg, and monensin 550 mg/kg.

Table 3.2. Chemical composition of cereal silage and cereal grain sources.

Variable	Ingredient			
	Barley silage	Corn silage	Corn grain	Barley grain
DM, %	40.7 ± 2.05	36.2 ± 2.06	87.5 ± 1.51	87.6 ± 0.58
OM, % of DM	94.3 ± 0.21	95.4 ± 0.06	98.9 ± 0.72	97.8 ± 0.03
CP, % of DM	10.2 ± 0.17	9.3 ± 0.12	8.8 ± 0.17	11.8 ± 0.46
NDF, % of DM	48.4 ± 0.67	43.5 ± 0.17	9.9 ± 0.56	18.0 ± 0.84
ADF, % of DM	30.1 ± 0.42	26.5 ± 0.46	3.7 ± 0.25	7.2 ±0.32
Starch, % of DM	21.4 ± 0.6	29.2 ± 0.59	72.9 ± 1.7	59.4 ± 0.97
Ether extract, % of DM	2.74 ± 0.2	2.81 ± 0.09	4.00 ± 0.31	2.27 ± 0.1
Ca, % of DM	0.3 ± 0.01	0.23 ± 0.01	0.02 ± 0.01	0.06 ± 0.00
P, % of DM	0.25 ± 0.01	0.25 ± 0.01	0.30 ± 0.02	0.38 ± 0.01

with the inclusion of cereal silage being held consistent among treatments. Cereal grain inclusion rates were also similar for all diets allowing starch concentration to vary with treatment. Canola meal was included to increase the protein concentration of the diets and urea was used to achieve isonitrogenous diets. While this may alter RDP:RUP ratio of the diets, only CP was considered in dietary formulation. All diets included monensin (Elanco, Greenfield, IN) to target 33 mg/kg DM. Steers were fed once daily between 0830 and 1100 h to achieve voluntary intake. The amount of feed delivered was recorded daily. Steers were weighed on two consecutive days at the beginning and end of the study to determine initial and final BW. During the study, steers were weighed every 2 wk on a single day. ADG was determined by regressing unshrunk BW with days on feed. Net energy of maintenance (NE_M) and net energy of gain (NE_G) were calculated based on Zinn and Shen (1998) and Zinn et al. (2002).

Feed bunks were cleaned on the same day as BW measurement and residual feed was weighed and removed. A sample of the refused feed was collected to determine DM and used to calculate DMI. At the time of refusal collection, a sample of all feed ingredients were also collected and all samples were dried in a forced-air oven at 55°C for 72 h to determine DM. Dry samples were ground using a Retsch ZM 200 grinder (Haan, Germany) to pass through a 1-mm screen and sent to Cumberland Valley Analytical Services (Waynesboro, PA, USA) for analysis of OM, CP, NDF, ADF, starch, EE, calcium, and phosphorus using wet chemistry. Briefly, the ash content was determined using the method 942.05 from the AOAC (2000). Crude protein was determined using method 990.03 (AOAC 2000) with Leco FP-528 Nitrogen Combustion Analyzer (LECO, St. Joseph, MI). NDF concentration was determined based on the method described by Van Soest et al. (1991) utilizing heat-stable α-amylase and sodium sulfite; however, the procedure was modified to incorporate the use of Whatman 934-AH glass micro-fiber filters (GE Healthcare Life Sciences, Chicago, IL) with a 1.5 um particle retention for the filtration steps. To correct for OM, the glass fiber filter was used while ashing the residue for 2 h at 535°C. Acid detergent fiber was determined according to the AOAC (2000) using the same glass micro-fiber filters as described for NDF. Starch was determined using the procedure described by Hall (2009) with correction for free glucose, and ether extract was determined using agravimetric method (954.02; AOAC 2000).

3.3.3 Fecal Grain Kernel Assessment and Predicted Apparent Total Tract Digestibility

On d 55, fresh fecal samples (maximum of 250 mL/steer) from at least 4 different steers, confirmed by visual observation of defecation, in each pen were collected from the pen floor and placed in a pail to achieve a final volume of 1 L. To avoid contamination from the pen floor, only fresh fecal pats were used and the top layer was scraped off. Fecal samples were then frozen and stored at -20°C to later determine fecal nutrient composition using NIR as well as DM determination. For analysis, samples were thawed and a 250 mL sample was weighed, placed in a 1.18-mm sieve, and washed with tap water until the water ran clear. The particles and fiber were weighed and dried for 48 h in a forced-air oven at 55°C. Once dry, whole grain particles, partial grain particles, and fines were separated by cereal grain type and weighed. These fractions were expressed as a percent of fecal DM. The remaining fecal material was weighed and dried in a forced-air oven at 55°C for 72 h. Once dry, fecal material was weighed again and ground to pass through a 1-mm screen (Retsch ZM 200; Haan Germany). The ground fecal material was used to determine fecal starch, digestible energy (DE), and the digestibility of DM, OM, NDF, ADF, starch, CP, fecal starch, and gross energy (GE) using near infrared spectroscopy (NIR; 2400 RTW, Unity Scientific, Brookfield, CT) with wave lengths between 1,200 and 2,400 nm using equations previously developed and validated for both backgrounding and finishing beef cattle as described by Jancewicz et al. (2016, 2017b). The original calibrations of (Jancewicz et al. 2016) were developed using diets containing barley silage and a variety of cereal grains including barley, corn, and wheat and these calibrations have been used to predict digestibility of diets containing short-season corn previously (Johnson et al. 2020a).

3.3.4 Statistical Analysis

All data were analyzed using the mixed model of SAS (version 9.4, Cary, NC) as a completely randomized design with a 2 × 3 factorial arrangement. The model included the fixed effects of silage type, cereal grain type, and their interaction (S × G). Pen was included as a random effect. Evaluation of grain kernels in feces was conducted using the mixed model of SAS (version 9.4, Cary, NC). However, data from treatments where it was impossible to have a specific kernel type in the feces (i.e. BS-BG diets could not have corn grain in the feces and CS-CG diets could not have barley grain in the feces) were removed from the analysis and denoted as not present (NP) in the results indicating the outcome was not possible. All data were tested for normality, and

if the residuals were normally and independently distributed, data were analysed using the mixed model of SAS (version 9.4, Cary, NC). If assumptions for normality were not met, the data were analysed using the GlimMix procedure of SAS (version 9.4 Cary, NC) with bionomial error structure and logit transformation. Presented means and SEM were reverse transformed for data presentation. Differences were declared significant when $P < 0.05$ and means were separated using the Tukey's mean separation test.

3.4 Results

3.4.1 Growth Performance

Although statistical analysis could not be conducted, the CS in this study was numerically greater in starch (29.2 vs 21.4%) and numerically lower in CP (9.3 vs. 10.2%), NDF (43.5 vs. 48.4%), and ADF (26.5 vs. 30.1%) when compared to barley silage (Table 3.2). Likewise, CG has numerically greater starch (72.9 vs. 59.4%) and lower CP (8.8 vs. 11.8%), NDF (9.9 vs 18.0%), and ADF (3.7 vs. 7.2%) than BG. The diets present study were balanced for CP thought the use of canola meal and urea, but allowed to vary in starch, NDF, and ADF concentrations based on the cereal silage and cereal grain sources used. As a result, diets for cattle fed CS had numerically greater starch and numerically lesser NDF and ADF concentrations (Table 3.1).

There were no interactions between cereal silage source and cereal grain source for any of the variables evaluated ($P \geq 0.17$; Table 3.3, 3.4, and 3.5) except the weight of the particles in feces that were retained on a 1.18 mm screen. As such, the main effects of cereal silage source and cereal grain source will be presented independently.

Although cattle were stratified by BW into pens and pens were randomly assigned to treatments, steers fed CS had a 1-kg greater starting BW than those fed BS ($P = 0.032$; Table 3.3). Likewise, steers fed CG tended ($P = 0.062$) to be lighter at the start of the study than those fed BG or BCG. Body weight at the end of the study was 8.3 kg greater ($P = 0.004$) for steers fed CS than for those fed BS while final BW was not affected by cereal grain type. Despite the greater final BW of CS vs BS fed cattle, ADG was not affected by cereal silage type or the cereal grain treatments averaging 1.1 kg/d. Dry matter intake was 0.8 kg/d greater ($P = 0.018$) for steers fed CS compared to those fed BS, but no differences were observed for the main effect of grain source. Gain: feed was not different among grain and silage sources. The calculated NE_M and NE_G based on BW, DMI, and ADG were not different among silage or grain sources.

3.4.2 Predicted Total Tract Digestibility and Fecal Grain Kernel Assessment

Steers fed CS had greater predicted total tract DM, OM, CP, NDF, ADF, and starch digestibility as well as a greater gross energy digestibility values ($P < 0.01$; Table 3.4) than steers fed BS. Fecal starch concentration was not affected by silage source. When evaluating grain source effects, steers fed BG had greater OM, CP, NDF, ADF, and starch digestibility compared to CG or BCG, with steers fed BCG having greater starch digestibility relative to CG. Fecal starch content was greatest for steers fed CG diets, intermediate for BCG diets, and least for steers fed BG.

The weight of the feces within the 250-mL sub-sample did not differ among silage source or grain source (Table 3.5). However, the weight of the particles retained on the 1.18-mm sieve numerically higher for steers fed BS with BG and intermediate for BS with CG or BCG and least for all diets containing CS (S × G, $P = 0.036$). When reported as a proportion of the retained material, feeding barley silage increased the proportion of whole barley in feces and feeding corn silage increased the proportion of partial corn kernels in feces. There was very little to no whole corn present in the feces. Barley grain diets had greater amounts of whole barley kernels compared to BCG diets ($P < 0.01$); whereas, partial corn grain in feces was greatest for CG and least for BCG ($P < 0.01$).

3.5 Discussion

In the present study, my objective was to evaluate whether interactions occurred among the cereal silage sources and the cereal grain sources when using corn and barley as the principle cereal silage and cereal grain sources for backgrounding cattle. While barley silage and barley grain have less starch and greater CP than corn silage and corn grain (NASEM 2016), the rates and extents of digestion for barley starch and protein are more rapid than corn (Herrera-Saldana et al. 1990b). Moreover, there is limited research evaluating short-season corn as a forage source and when evaluating S × G and grain source interactions for growing cattle. That said, previous research in finishing cattle has demonstrated that blending rapidly fermentable starch with starch that has a slower rate of fermentation may optimize ruminal fermentation (Vander Pol et al. 2009) leading to associative effects on growth performance. For example, Stock et al. (1987) and Huck et al. (1998) reported the greatest positive associative effects were observed in finishing diets when high-moisture corn was included with dry-rolled corn at a ratio of 75:25. Additionally, when using combinations of high-moisture corn and dry-rolled wheat, positive responses for feed conversion were reported with a ratio of 25:75% (Bock et al. 1991). In the current study, both the corn grain

Table 3.3. Growth, DMI, and predicted energy density of diets composed of barley silage (BS) or corn silage (CS) with dry-rolled barley (BG), corn (CG), or an equal blend of barley and corn grain (BCG) fed to beef steers.

Variable	BS			CS			SEM[1]	P values		
	BG	CG	BCG	BG	CG	BCG		Silage	Grain	S × G
Starting BW, kg	341.0	340.3	340.8	342.0	340.8	341.5	0.40	0.032	0.062	0.82
Ending BW, kg	457.8	461.3	459.5	468.3	468.5	466.8	3.03	0.004	0.70	0.83
ADG, kg/d	1.0	1.0	1.0	1.0	1.1	1.0	0.04	0.42	0.31	0.43
DMI, kg/d	10.0	9.6	9.7	10.2	10.9	10.6	0.45	0.018	0.86	0.39
G:F, kg/kg	0.11	0.11	0.10	0.10	0.10	0.10	0.01	0.14	0.65	0.86
NE_M, Mcal/kg[2]	1.04	1.04	1.09	1.06	1.06	1.08	0.08	0.93	0.90	0.99
NE_G, Mcal/kg[2]	0.51	0.51	0.55	0.52	0.52	0.54	0.07	0.93	0.91	0.98

[1] The standard error for the interaction are reported.

[2] Net energy values calculated based on Zinn et al. (2002) and Zinn and Shen (1998).

Table 3.4. Apparent nutrient digestibility predicted using near-infrared spectroscopy of dry feces collected from steers fed diets composed of barley silage (BS) or corn silage (CS) with dry-rolled barley (BG), corn (CG), or an equal blend of barley and corn grain (BCG) fed to beef steers.

	BS			CS				*P* values		
	BG	CG	BCG	BG	CG	BCG	SEM[1]	Silage	Grain	S×G
Apparent nutrient digestibility (% DM)										
DM, %	72.9	72.2	71.7	77.6	75.9	75.7	0.64	< 0.001	0.070	0.60
OM, %DM	74.3a	73.0b	72.4b	78.9a	76.4b	76.2b	1.38	< 0.001	< 0.001	0.67
CP, %DM	64.9a	61.2b	62.5b	68.2a	62.6b	63.7b	0.58	0.001	< 0.001	0.17
NDF, %DM	51.4a	50.1b	49.3b	54.0a	51.0b	52.1b	0.69	0.002	0.012	0.33
ADF, %DM	22.7a	18.1b	18.8b	29.2a	26.0b	26.6b	1.17	< 0.001	0.008	0.79
Starch, % DM	93.6a	90.4c	91.9b	95.8a	91.3c	92.9b	0.42	0.001	< 0.001	0.25
Gross energy, %	75.7a	74.9ab	73.2b	80.1a	77.8ab	78.6b	0.77	< 0.001	0.039	0.27
Fecal starch, % DM	9.7c	16.8a	14.9b	7.5c	17.0a	13.1b	0.90	0.11	< 0.001	0.38

[1]The standard error for the interaction are reported.

Table 3.5. Relative proportions of whole kernels, partial kernels, and fibre in feces from steers fed diets composed of barley silage (BS) or corn silage (CS) with dry-rolled barley (BG), corn (CG), or an equal blend of barley and corn grain (BCG) fed to beef steers.

Component	BS			CS			SEM[1]	P values		
	BG	CG	BCG	BG	CG	BCG		Silage	Grain	S × G
Fecal weight, g/250 mL	230.9	237.5	237.7	234.0	242.4	239.3	10.97	0.50	0.39	0.96
Particles retained, g DM	100.3z	76.7zy	84.9zy	70.2y	75.3y	72.9y	5.82	0.003	0.31	0.036
Whole barley, % of retained	15.6a	7.7b	11.3b	7.9a	NP[2]	4.9b	1.76	< 0.001	< 0.001	0.55
Partial barley, % of retained	1.9	0.6	1.1	2.2	NP	0.9	0.94	0.91	0.06	0.60
Whole corn, % of retained	NP	0.0	0.2	0.9	0.6	0.2	0.38	0.43	0.51	0.43
Partial corn, % of retained	NP	22.5a	11.8b	5.0c	30.4a	25.8b	3.38	0.006	< 0.001	0.38
Total fines, % of retained	82.3a	68.9b	75.2b	83.8b	66.4b	67.8b	6.25	0.35	0.001	0.47

abcMeans within a row with uncommon superscripts differ for grain treatments ($P < 0.05$).

zyx Means within a row with uncommon superscripts differ silage x grain interaction ($P < 0.05$).

[1]The standard error for the interaction are reported.

[2]NP represents treatments where the dependent variable was not present based on analysis and the treatment structure.

and corn silage had numerically greater starch concentrations compared to the barley grain and barley silage and given that both corn and barley grain were dry-rolled, it could be expected that rates and extents of ruminal fermentation differed among the grain sources (Campling 1991). However, I did not detect any additive effects when feeding combinations of barley and corn grain suggesting that when dry-rolled and included at low levels, differences in the fermentation rates are not sufficient to detect associative effects for barley and corn. In addition, the detection of positive associative effects in finishing studies may be in part due to the greater dietary inclusion rates of cereal grain when compared to diets for backgrounding cattle or diets for dairy cattle. In support of this concept, including a highly digestible forage source with a highly fermentable carbohydrate source in diets for dairy cattle did not yield positive additive effects for DMI, milk yield, or milk composition (Cooke et al. 2009). Moreover, there were no detectible interactions among the cereal silage sources and cereal grain sources suggesting that the digestion of the starch source from the silage may not interact with the cereal grain source at the inclusion level in the present study.

3.5.1 Effects of Cereal Silage Source

There is little data available on the use of short-season corn and its effects on growth performance of backgrounding cattle (Chibisa and Beauchemin 2018). In the present study, I observed that cattle fed CS had greater DMI and greater BW at the end of the study. In contrast, Chibisa and Beauchemin (2018) reported that short-season CS reduced DMI for backgrounding steers when included at an equivalent dietary concentration as barley silage. Consequently, Chibisa and Beauchemin (2018) also reported lower ADG and G:F for steers fed CS than BS. However, the CS in Chibisa and Beauchemin (2018) contained greater concentrations of NDF than barley silage and the authors speculated that the reduction in DMI may be due constraints related to NDF intake. Corn silage in the current study had lower NDF and greater starch than BS supporting the concept that forages with lower NDF concentration may stimulate DMI for growing cattle (Fox et al. 1992; Allen 2000). The increased DMI for CS-fed cattle relative to BS-fed cattle may also be in response to greater digestibility, as estimated by near-infrared spectroscopy of dry feces and established calibrations (Jancewicz et al. 2016), thereby reducing the filling effect of NDF (Oba and Allen 2003).

Kernel processing of CS at harvest cracks the kernels allowing for greater starch utilization relative to unprocessed CS (Cooke and Bernard 2005). In the current study, the diets containing

CS had greater starch digestibility compared to those fed BS. In contrast, there are currently no recommendations promoting kernel processing of BS; although, one study demonstrated improved starch digestibility when BS was processed using a 1-mm roller gap at the time of ensiling (Eun et al. 2004). While there is little data available evaluating kernel processing of BS, a novel aspect of this study was that I evaluated the appearance of kernels in the feces. These data further support increased starch digestibility for CS relative to BS as the use of BS increased the weight of particles retained on a 1.18-mm sieve and the appearance of whole barley kernels in feces relative to cattle fed CS. Moreover, the use of CG reduced, but did not eliminate the appearance of barley kernels in the feces of cattle fed BS indicating that the hull and pericarp of the barley kernels in the silage were not damaged consistently. Though there was greater appearance of whole kernels in the feces, the fecal starch concentration was only numerically greater suggesting that some of the kernels may be at least partially digested as observed by Loerch et al. (2006). Thus, the data indicate that for backgrounding cattle, BS may contribute to the appearance of the barley kernels in feces and strategies to enhance kernel processing may improve starch digestibility. The use of a kernel processor for BS may depend on the balance between the increased digestibility and the fuel and time required at time of harvest to chop the silage.

While initial BW was greater for CS steers than BS, the differences were interpreted not to have biological significance as the mean body weights differed by 700 g. However, as a consequence of greater DMI and greater nutrient digestibility for CS-fed cattle, final BW of the CS-fed steers was 8.4 kg greater than for steers fed BS. Despite greater final BW, ADG, G:F and the predicted NE_M and NE_G did not differ among steers fed BS vs CS. These data are interpreted to suggest that despite greater digestibility, use of short-season corn is not likely to improve G:F due to increased DMI and no differences for ADG.

3.5.2 Effects of Cereal Grain Source

While dietary starch numerically increased with increasing corn grain, there was no stimulatory effect on DMI, ADG, or G:F. A study conducted by Koenig and Beauchemin (2005) comparing BG and CG in a finishing diet found greater DMI, ADG and G:F for the BG treatments compared to the CG treatments with no added protein. Another study by Beauchemin et al. (1997) found greater DMI and ADG for BG compared to CG, but G:F was greater for the CG diets compared to the BG diets. In addition, Johnson et al. (2020a) also reported greater DMI for corn-based finishing diets. In a review, (Owens et al. 1997) found no differences between CG and BG

on DMI, ADG and G:F. The lack of differences detected between CG and BG in the present study seems to be consistent with the previous studies although this may be due to the low inclusion rate of grain in the present study compared to the high inclusion rates of the previous studies.

The cereal grains in this study were both dry rolled to avoid a bias of processing method. Processing for corn grain the present study was targeted to achieve a processing index such that 5% of the particles passed through a 1-mm sieve as an approach to minimize production of the fine particles. Retrospectively, this resulted in dry-rolled corn grain with a processing index of 83%: a value greater than the 70% typical of dry rolled CG (Zinn et al. 1998). It is likely that the severity of processing was insufficient to optimize the surface area available for microbial attachment and digestion when considering the starch and protein matrix in the endosperm (McAllister and Cheng 1996). I was unable to determine the concentrations of floury and vitreous endosperm, but past research has shown for flint corn, dry-rolling is likely not sufficient to maximize starch digestibility (Plascencia and Zinn 1996; Joy et al. 1997). In contrast, the BG was dry-rolled to achieve a processing index of 66%, as Koenig et al. (2003) reported that more extensively processed grain (86% vs. 61%) increased total tract starch digestibility. Past research has suggested a processing index ranging from 65 to 75% for BG (Beauchemin et al. 2001), and despite being processed, fecal starch concentration were still greater than other research averaging 8.6% DM, 14.0% DM, and 16.9% DM for BG, BCG, and CG, respectively. Jancewicz et al. (2017a) reported fecal starch concentrations of 2.24% for backgrounding cattle in commercial feedlots with greater fecal starch concentrations having a negative impact on G:F. While high fecal starch concentrations can be related to the lower starch digestibility for CG and the less severe processing of CG than BG, even with a PI of 66% for BG, fecal starch averaged 8.6% and I detected whole barley in the feces from the cattle. The appearance of whole barley in feces, is likely explained by variable kernel size and that some kernels may have passed through the rollers without being processed. In contrast, there was nearly no whole-corn present in feces suggesting that while the processing severity was low, nearly all kernels were cracked.

4.0 EFFECTS OF BARLEY AND CORN AS SOURCES OF SILAGE AND GRAIN ON DRY MATTER INTAKE, RUMINAL FERMENTATION, AND TOTAL TRACT DIGESTIBILITY FOR GROWING BEEF HEIFERS

4.1 Abstract

The objective was to evaluate the use of barley or corn as a cereal silage source when fed with dry-rolled barley, corn, or a blend of barley and corn for backgrounding cattle. Ruminally cannulated heifers (n=5) were assigned to an incomplete 6 × 6 Latin Square. Treatments contained either BS or CS included at 55% (DM basis) in combination with BG, CG, or an equal blend of barley and corn grain included at 30% (DM basis). The remainder of the diet contained canola meal (8% DM basis) and a mineral, vitamin, and urea supplement comprising the remaining 6%. Periods were 25 d including 5 d for dietary transition, 13 d for adaptation, and 7 d for data and sample collection. Samples were collected to determine DMI, ruminal fermentation, total tract digestibility, and nitrogen balance. Data were analyzed using the mixed model with the fixed effects of silage, grain, and the S × G interaction, and the random effects of heifer and period. DMI did not differ among grain source but tended (silage, $P = 0.065$) to be 0.56 kg/d greater when fed CS than BS. While ruminal pH was not affected by silage, grain, or the S×G, the total concentration of short-chain fatty acids was greater for heifers fed BS than CS (silage, $P = 0.002$). Fecal pH was less for diets containing BG or BCG than CG (grain, $P = 0.029$) and less for diets containing CS than BS (silage, $P = 0.014$). Corn silage increased bacterial N production over BS (silage, $P = 0.022$) increased fecal N excretion (silage, $P = 0.042$), but did not affect N retention. Silage source did not affect apparent total tract digestibility (silage, $P \geq 0.14$) but diets containing BG had greater DM, OM, starch, and GE digestibility compared to CG with BCG being intermediate and not different (grain, $P \leq 0.043$). Whole barley kernels in feces were greater when heifers were fed BS than CS (silage, $P < 0.001$) and greater for diets containing BG than CG or BCG (grain, $P < 0.001$). Appearance of partial kernels of corn was greatest when fed CG, intermediate when fed BCG, and least when fed BG (grain, $P < 0.001$). Based on limited S×G interactions, use of CS in backgrounding diets may reduce SCFA concentrations, and increase bacterial N production relative to BS. Feeding dry-rolled CG may reduce fecal pH and apparent total tract nutrient digestibility relative to dry-rolled BG in diets for backgrounding cattle. Moreover, BS may be a source of cereal grain appearing in feces.

4.2 Introduction

The development of short-season corn varieties has increased flexibility with corn production and has expanded corn production into western Canada, an area where CHU are limited (Chibisa and Beauchemin 2018). Recent studies have demonstrated that short-season corn varieties have the potential to yield up to 40% more than barley (Lardner et al. 2017). In addition to greater yield, the starch concentration of short-season corn silage is greater than for barley silage (Miorin et al. 2018; Johnson et al. 2020a). However, there are conflicting results on the effects of short-season corn silage on DMI of growing beef cattle. For example, Chibisa and Beauchemin (2018) reported reduced DMI with increasing corn silage inclusion whereas, Sutherland et al. (in review) reported greater DMI for corn silage-fed steers than those fed barley silage. Thus, studies are warranted to understand how short-season corn silage may affect DMI, ruminal fermentation, and nutrient digestibility.

Although recent studies have evaluated the use of short-season corn for backgrounding (Chibisa and Beauchemin 2018) or finishing cattle (Johnson et al. 2020a), few studies have evaluated whether cereal silage source and cereal grain source interact to affect ruminal fermentation and total tract digestibility for growing cattle. Recently, Johnson et al. (2020b) reported that the cereal silage source (barley vs. corn silage) and cereal grain source (dry-rolled barley, corn, or a BCG) affected the extent of ruminal pH reduction and the molar proportions of short-chain fatty acids in diets for finishing cattle. Dry-rolled barley is fermented at a greater rate and to a greater extent than dry-rolled corn grain (Johnson et al. 2020b) which may reduce NDF digestibility if ruminal pH declines below the levels that are favourable for digestion (Beauchemin et al. 2001). Moreover, given the greater starch concentration for corn silage than barley silage (Sutherland et al. in review; Johnson et al. 2020a) and the greater inclusion of silage in diets for backgrounding cattle than used in the study of Johnson et al. (2020b) for finishing cattle, it is possible that the silage source and cereal grain source may affect ruminal fermentation, microbial N production, and nutrient digestibility.

I hypothesized that feeding corn silage would increase DMI, SCFA concentration, and microbial protein supply to the small intestine, while decreasing ruminal pH, as compared to barley silage, and that this effect will be greater when fed barley grain than corn grain or a BCG of barley and corn grain. The objective of this study was to determine the effect of barley and corn silage

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when included with dry-rolled barley, corn, or a combination of barley and corn grain on DMI, ruminal fermentation, microbial protein synthesis, and total tract digestibility for growing cattle.

4.3 Materials and Methods

4.3.1 Silage Production

The corn for silage (Pioneer 7213R, Dupont Pioneer, Mississauga, ON) was planted May 27, 2016 (32000 plants/acre) as previously described (Sutherland et al. in review; Johnson et al. 2020a, 2020b). The corn was harvested and ensiled on August 31, 2016 (Biomax 5, 1 g/t) and received 1940 corn heat units (CHU) and 715 growing degree days (GDD) during the growing season. Barley grown for silage (CDC Copeland, Crop Development Centre, Saskatoon, SK, Canada) was seeded on May 19, 2016, received 855 GDD, and was cut and ensiled between July 27 to 30, 2016 as previously described (Sutherland et al. in review; Johnson et al. 2020a, 2020b). The composition of barley and corn silage are reported in Table 4.1.

4.3.2 Animal Management, Experimental Design, and Dietary Treatments

Use of heifers in this experiment was approved by University of Saskatchewan Animal Research Ethics Board (protocol 20100021) in accordance with the policies of the Canadian Council on Animal Care (Ottawa, ON). This study used 5 ruminally cannulated (9-cm cannula, model 9C, Bar Diamond Inc., Parma, ID) yearling heifers in an incomplete 6 × 6 Latin square design balanced for carry-over effects. Heifers were housed in individual pens (3 × 3 m) with rubber mats on the floor, an individual water bowl, and a suspended ball for environmental enrichment. Pens were scraped and washed daily with the exception of sampling days to avoid contamination of feces. Heifers were provided exercise in an outdoor dry lot pen on a daily basis except during data and sample collection.

Each period of the Latin square was 25 d in duration including 5 d for dietary transition, 13 d for adaptation, and 7 d of data and sample collection. For the dietary transition, heifers were gradually transitioned to their treatment diet by offering the previous and new diets at ratios of 67:33 and 33:67 on d 1 and 3, respectively. The final treatment diet was fed on d 5 of each period. Refusals were collected and recorded at 0800 h daily with the amount of TMR provided to ensure refusals equated to 5 to 10% of the original weight of the feed offered. Fresh feed was provided daily at 0930 h All treatments contained 55% (DM basis) of either barley or corn silage and were fed in combination with dry-rolled barley grain, dry-rolled corn grain, or an equal

Table 4.1. Ingredient and chemical composition of diets containing barley silage (BS) or corn silage (CS) in combination with dry-rolled barley grain (BG), dry-rolled corn grain (CG), or an equal blend of barley and corn (BCG).

Ingredient, %DM	BS			CS		
	BG	CG	BCG	BG	CG	BCG
Barley silage	55.00	55.00	55.00	-	-	-
Corn silage	-	-	-	55.00	55.00	55.00
Barley grain	31.44	-	15.61	31.18	-	15.48
Corn grain	-	30.90	15.61	-	30.72	15.48
Canola meal	8.00	8.00	8.00	8.00	8.00	8.00
Urea	-	0.48	0.23	0.27	0.72	0.50
Premix pellet[1]	5.56	5.56	5.56	5.56	5.56	5.56
Diet specifications[2]						
DM, %	55.08 ±0.87	54.52 ± 1.14	54.86 ± 1.21	49.36 ± 1.59	49.20 ± 1.77	48.76 ± 1.87
OM, % DM	93.04 ± 0.24	92.88 ± 0.30	93.58 ± 0.19	93.17 ± 0.28	93.60 ± 0.27	93.67 ± 0.27
CP, % DM	13.26 ± 0.19	13.64 ± 0.38	13.71 ± 0.20	13.53 ± 0.22	13.86 ± 0.20	13.71 ± 0.18
aNDFom[3], %DM	34.48 ± 1.33	31.95 ± 1.81	31.76 ± 1.04	33.07 ± 0.79	30.56 ± 1.14	31.81 ± 0.94
ADF, % DM	20.76 ± 1.14	20.22 ± 1.04	18.91 ± 0.88	19.00 ± 0.91	18.46 ± 0.91	18.73 ± 0.90
Starch, %DM	30.98 ± 0.82	34.26 ± 1.51	36.16 ± 1.18	34.67 ± 0.97	37.96 ± 1.43	36.34 ± 1.14
Ether extract, %DM	3.04 ± 0.24	3.65 ± 0.50	2.96 ± 0.15	2.61 ± 0.04	3.21 ± 0.35	2.91 ± 0.18
Ca, %	0.80 ± 0.02	0.79 ± 0.02	0.77 ± 0.01	0.75 ± 0.04	0.75 ± 0.04	0.75 ± 0.04
P, %	0.38 ± 0.01	0.37 ±0.02	0.38 ± 0.01	0.37 ± 0.04	0.36 ± 0.06	0.36 ± 0.05
NE_M, Mcal/kg[4]	1.62 ± 0.05	1.67 ± 0.06	1.67 ± 0.04	1.64 ± 0.04	1.70 ± 0.04	1.67 ± 0.04
NE_G, Mcal/kg[4]	1.01 ± 0.04	1.05 ± 0.06	1.06 ± 0.04	1.04 ± 0.03	1.08 ± 0.04	1.06 ± 0.03

[1]Premix pellet contained calcium 9.20%, phosphorus 0.32%, sodium 1.64%, magnesium 0.28%, potassium 0.60%, sulfur 0.12%, cobalt 4.9 mg/kg, copper 185 mg/kg, iodine 16.6 mg/kg, iron 84 mg/kg, manganese 500 mg/kg, zinc 558 mg/kg, fluorine 100 mg/kg, vitamin A 40000 IU/kg, vitamin D3 5000 IU/kg, vitamin E 600 IU/kg, selenium 2.00 mg/kg, and monensin (Elanco, Greenfield, IN) 550 mg/kg.

[2]Values represent the means ± SD of six samples.

[3]Neutral detergent fiber analyzed using α-amylase and sodium sulphite and corrected for ash

[4]Values were calculated from feed samples using the National Research Council (2001) equations.

Table 4.2. Chemical composition of ingredients.

Variable[2]	Ingredient						
	Barley silage	Corn silage	Corn grain	Barley grain	Premix[1]	Canola meal	Urea
DM, %	41.35 ± 1.12	35.59 ± 1.64	89.87 ± 0.46	89.85 ± 0.47	92.15 ± 0.76	92.07 ± 0.86	99.42 ± 0.06
OM, %DM	92.94 ± 0.44	94.55 ± 0.45	98.4 ± 0.32	97.31 ± 0.14	71.45 ± 0.47	92.48 ± 0.11	
CP, %DM	10.37 ± 0.57	9.50 ± 0.33	8.75 ± 0.29	11.68 ± 0.49	9.95 ± 0.24	41.75 ± 0.27	285.13 ± 2.6
aNDFom, %DM[3]	47.10 ± 3.18	44.60 ± 1.93	10.00 ± 0.76	17.88 ± 1.85	15.27 ± 0.94	26.40 ± 1.48	
ADF, %DM	30.52 ± 2.22	27.33 ± 1.6	4.47 ± 1.11	6.12 ± 0.81	6.28 ± 0.38	21.37 ± 0.86	
Starch, %DM	19.37 ± 1.47	26.68 ± 2.07	69.53 ± 3.05	57.95 ± 1.81	33.38 ± 0.44	0.87 ± 0.14	
Ether extract, %DM	3.41 ± 0.44	2.63 ± 0.08	4.21 ± 1.06	2.22 ± 0.21	3.82 ± 1.15	3.22 ± 0.26	0.50 ± 0.09
Ca, %DM	0.32 ± 0.04	0.24 ± 0.07	0.03 ± 0.01	0.05 ± 0.00	9.69 ± 0.16	0.88 ± 0.02	
P, %DM	0.26 ± 0.01	0.24 ± 0.07	0.35 ± 0.08	0.37 ± 0.01	0.48 ± 0.01	1.22 ± 0.03	
NE_M, Mcal/kg[4]	1.48 ± 0.09	1.54 ± 0.07	2.14 ± 0.02	1.94 ± 0.03	1.24 ± 0.06	1.54 ± 0.03	
NE_G, Mcal/kg[4]	0.89 ± 0.09	0.94 ± 0.06	1.46 ± 0.03	1.30 ± 0.03	0.67 ± 0.05	0.94 ± 0.02	

[1]Premix pellet contained calcium 9.20%, phosphorus 0.32%, sodium 1.64%, magnesium 0.28%, potassium 0.60%, sulfur 0.12%, cobalt 4.9 mg/kg, copper 185 mg/kg, iodine 16.6 mg/kg, iron 84 mg/kg, manganese 500 mg/kg, zinc 558 mg/kg, fluorine 100 mg/kg, vitamin A 40000 IU/kg, vitamin D3 5000 IU/kg, vitamin E 600 IU/kg, selenium 2.00 mg/kg, and monensin (Elanco, Greenfield, IN) 550 mg/kg.

[2]Values represent the means ± SD of six samples.

[3]Neutral detergent fiber analyzed using α-amylase and sodium sulphite and corrected for ash.

[4]Values were calculated from feed samples using the National Research Council (2001) equations.

blend of dry-rolled barley and corn gran (Table 4.2). The CG was dry rolled to allow for 5% of the processed sample to pass through a 1.18-mm screen and the barley grain was processed to achieve a processing index of 66%. The resulting dry-rolled corn had a processing index of 83%.

4.3.3 Body Weight and Dry Matter Intake

Heifers were weighed on two consecutive days at the start and end of each period. The amount of feed offered and refused were recorded daily and data from d 20 to 23 of each period were used to determine DMI based on the difference between the quantity of DM offered and refused. To determine dietary DM, ingredient samples (500 g) were collected daily from d 20 to 23 and refusal samples were composited for each heifer proportionally to the amount refused. The ingredient and refusal samples were dried in a forced-air oven at 55°C until achieving a constant weight to determine DM concentration. Subsequently, samples were ground to pass through a 1-mm sieve and sent to Cumberland Valley Analytical (Waynesboro, PA) for chemical analysis (OM, CP, aNDFom (neutral detergent fibre determined using sodium sulphate and α-amylase and then corrected for ash content), ADF, starch, ethanol soluble carbohydrates, ether extract, Ca, and P as described by Johnson et al. (2020a).

4.3.4 Ruminal Fermentation

Ruminal pH was determined using indwelling pH meters (Penner et al. 2009) placed in the ventral sac of the rumen on the first day of the sampling period (d 20) immediately prior to feeding and removed at the completion of total collections (d 23). Prior to insertion, pH meters were standardized in pH buffers 7 and 4 at 39°C to determine the linear relationship between mV readings and pH. The pH meters were programmed to collect a measurement every 5 min over the 4-d duration. Following removal, the pH meters were rinsed in warm tap water, standardized in pH buffers 7 and 4 as previously described, and data were downloaded. Data were converted from mV to pH using the regressions determined prior to insertion into the rumen and following removal from the rumen using a linear offset to account for electrode drift as described by (Penner et al. 2006). Ruminal pH data were used to determine the minimum, mean, and maximum pH values and to determine the duration and area that pH was < 5.5.

On d 25, ruminal digesta was sampled every 3 h over a 24 h duration. At each timepoint, 3 spot samples (250 mL/region) of mixed ruminal digesta were collected from the caudal, central, and cranial regions of the rumen at the ruminal-fluid ruminal-mat interface. Digesta from the 3 regions were composited and strained through two-layers of cheese cloth. Using a pipette, 10 mL

of strained ruminal fluid was transferred into vials containing either 2 mL of metaphosphoric acid (25% wt/v) or 2 mL of sulfuric acid (1%). Samples were then frozen at –20°C until being analyzed for SCFA and ammonia-N concentrations according to Khorasani et al. (1996) and Fawcett and Scott (1960), respectively.

4.3.5 Total Tract Digestibility, Nitrogen Balance, and Fecal Kernel Assessment

On d 19, indwelling bladder catheters (2-way Foley catheter, C. R. Bard, Inc., Murray Hill, NJ) were inserted and 70 mL of saline was added to inflate the balloon. Each heifer was tethered before sampling was initiated and throughout the total collection period. At 0800 h on d 20, the bladder catheters were attached to tubing to divert the urine into a 20-L carboy (Thermo Fisher Scientific, Waltham, MA). Each carboy contained 200 mL of hydrochloric acid (Sigma Aldrich, Oakville, ON, Canada). Urine was collected at 0800 h on each sampling day and the total weight was recorded. In addition, urine pH was determined to ensure adequate acidification (pH < 3), and a 35-mL sample was collected and stored at -20°C until being analyzed for purine derivative (PD) analysis. Uric acid analysis was conducted using a colorimetric assay (Cayman Chemical, Ann Arbor, MI) and the concentration of allantoin was determined as described by Chen and Gomes (1995). Microbial nitrogen flow was determined with the following formulas:

Microbial PD absorbed = (total PD excreted – $0.385 \times BW_{0.75}$) / 0.85

where the total PD (mmol/d) excreted was the sum of allantoin and uric acid as determined by the assays described above. The assumed efficiency of PD absorption was 0.85.

To calculate the microbial nitrogen flow (g N/d) the following formula was used:

Microbial N flow = (microbial PD absorbed $\times$ 70) / ($0.116 \times 0.83 \times 1000$)

where 70 (mg/mmol) was the assumed N content of purines, 0.116 accounted for the mixed rumen microbes ratio of purine N:total N, and 0.83 was the assumed digestibility coefficient of the microbial purines as described by Chen and Gomes (1995). Total urinary nitrogen output was determined using the Kjeldahl procedure (2400 Kjeltec Auto Sampler System, FOSS, Hoganas, Sweden; method 984.13, AOAC 2006).

Prior to 0800 h on d 20, all feces were scraped out of the pens and discarded. Feces were then collected every 6 h for 4 d. At each 6-h interval, feces were collected from the pen floor and the weight of the feces was recorded. Fecal samples were then mixed well and a 100-g sample was placed in a container and an equal weight of water purified via reverse-osmosis water was added. The sample was stirred and pH was measured using a portable pH meter (Accumet AP115 portable

pH meter, Fisher Scientific, Hampton, NH). In addition, a representative sample of feces (10% of the fecal weight at each collection) was collected at each collection timepoint and was placed in the freezer at -20°C until the end of the sampling period. The fecal composite for each heifer was thawed, mixed, and a 250-mL sub-sample was used for fecal sieving as explained by Sutherland et al. (in review). The fecal sieving was used to determine the cereal grain type excreted in feces and whether the cereal grain was excreted as whole or partial kernels. A second representative sample (1 kg) was dried at 55°C in a forced-air oven until achieving a constant weight. The feces were routinely mixed during drying. Samples were then ground to pass through a 1-mm sieve and sent to Cumberland Valley Analytical (Waynesboro, PA) for chemical analysis (as described above). In addition, gross energy of duplicate feed, fecal, and refusal samples ground through a 1-mm screen was determined using bomb calorimetry (6400 Automatic Isoperibol Calorimeter, Parr Instruments Company, Moline, IL).

4.3.7 Statistical Analysis

Data were analysed as an incomplete Latin square using the mixed model of SAS (SAS version 9.4, SAS Institute, Cary, NC) to account for the fixed effects of silage source, grain source, and their interaction. The model also included the random effects of heifer and period. All data and their residuals were tested for normality and if the values were not normally distributed the data were transformed via log base 10 or base 100. In cases of were data were not normally distributed, the presented P values are from the transformed data while the means and SEM were non-transformed data. When the P value for grain type or the interaction was < 0.05, means were separated using the Tukey's mean separation test.

Ruminal SCFA data were analyzed using the mixed procedure of SAS (SAS version 9.4, SAS Institute, Cary, NC) with the fixed effects of silage source, grain source, time, and the relevant 2- and 3-way interactions. Time (h) was included as a repeated measure using compound symmetry as the covariance error structure as it yielded the lowest Akaike's and Bayesian Information Criterion values. The model also included the random effects of heifer and period.

Fecal kernel data were analysed using the mixed procedure of SAS (SAS version 9.4, SAS Institute, Cary, NC) accounting for fixed effects of silage source, grain source, and their interaction along with the random effects of heifer and period. Treatments were excluded if there was no possibility of the grain type being in the sample (e.g. CS-CG would not contain whole barley or partial barley). All data was tested for normality if normal the data were analyzed. If the normality

assumptions were not met data were analyzed using the GlimMix procedure of SAS (version 9.4 Cary, NC) with binomial error structure and logit transformation. Presented means and SEM were reverse transformed for data presentation. Significance for all variables was declared when $P <$ 0.05 tendencies were declared when $P < 0.1$ and means were separated using the Tukey's mean separation test.

4.4 Results

4.4.1 Dry Matter Intake and Ruminal Fermentation

Dry matter intake tended to be greater for CS while mean, minimum, and maximum pH did not differ among silage source, grain source, or their interaction (Table 4.3). Total SCFA concentration did not differ among silage or grain sources. The total concentration of SCFA in ruminal fluid was greater for BS than CS-based diets (silage, $P = 0.002$), but did not differ among grain source. The molar proportion of acetate was greater for the CG and BCG diets than BG (grain, $P < 0.001$) with no effect of silage source. Interactions ($P \leq 0.05$) among cereal silage source and cereal grain source were detected for the molar proportions of propionate, isobutyrate, butyrate, isovalerate, valerate, and caproate. For propionate, concentration was greater for BG than CG and BCG when fed with BS, while when fed CS, the molar proportion was lesser for BCG than for BG or CG. Isobutyrate was greatest for BS-BG with BS-CG and BS-BCG being intermediate but not different and CS-BG, CS-CG and CS-BCG being least. Butyrate concentrations ranked greatest to least: CS-BCG > BS-BG, CS-BG > BS-CG > BS-BCG > CS-CG. The CS-CG treatment was less than the BS-CG treatment with the BS-BCG treatment being intermediate to the CS-CG and BS-CG but not different. Ammonia concentrations were greater (grain, $P < 0.001$) for CG than BCG and BG while silage source had no effect. Fecal pH was greater for BS compared to CS (silage, $P = 0.014$) and pH was greatest for BG, intermediate for CG, and least for BCG ($P = 0.029$).

4.4.3 Nitrogen Balance

Microbial nitrogen flow to the small intestine was greater (silage, $P = 0.022$) for cattle fed CS than BS, but was not affected by grain source (Table 4.4). Fecal excretion of nitrogen (g/d) was greater for heifers fed CS than BS (silage, $P = 0.042$), and fecal excretion of nitrogen (g/d) was greatest for CG, intermediate for BCG, and least for BG (grain, $P = 0.049$). When expressed as a percentage fecal nitrogen, excretion was greater for CG and BCG than for BG (grain, $P = 0.006$). Apparent N digestion (% of N intake) was greater for the BG treatments compared to the CG and

Table 4.3. Effect of feeding beef heifers a diet containing barley silage (BS) or corn silage (CS) when fed in combination with dry-rolled barley grain (BG), dry-rolled corn grain (CG), or an equal blend of barley and corn grain (BCG) on DMI, ruminal fermentation, and fecal pH.

Variable	BS			CS			SEM	P values		
	BG	CG	BCG	BG	CG	BCG		Silage	Grain	S×G[1]
DMI, kg	8.22	8.20	8.19	8.75	8.76	8.76	0.422	0.065	1.00	1.00
Ruminal pH										
Minimum	5.95	5.91	5.99	5.97	5.73	6.00	0.16	0.72	0.51	0.77
Mean	6.51	6.57	6.65	6.65	6.49	6.76	0.129	0.62	0.36	0.64
Maximum	6.96	7.16	7.21	7.16	7.05	7.27	0.143	0.67	0.45	0.52
Total SCFA, mM	107.8	106.4	108.1	104.4	99.3	103.5	2.6	0.002	0.19	0.61
Acetate, mol/100 mol	57.23$_b$	60.60$_a$	60.65$_a$	56.97$_b$	60.55$_a$	59.39$_a$	0.832	0.21	< 0.001	0.44
Propionate, mol/100 mol	25.50$_z$	23.22$_{xw}$	23.49$_{yxw}$	25.08$_{zy}$	24.3$_{zyx}$	21.99$_w$	0.810	0.44	< 0.001	0.014
Isobutyrate, mol/100 mol	0.97$_z$	0.94$_{zy}$	0.86$_{yx}$	0.75$_x$	0.73$_x$	0.77$_x$	0.028	< 0.001	0.16	0.013
Butyrate, mol/100 mol	13.19$_{zy}$	11.97$_y$	11.79$_{yx}$	13.39$_{zy}$	11.63$_x$	14.43$_z$	0.546	0.16	0.002	0.033
Isovalerate, mol/100 mol	1.42$_{zyx}$	1.65$_z$	1.55$_{zy}$	1.54$_{zy}$	1.26$_x$	1.37$_{yx}$	0.085	0.005	0.92	< 0.001
Valerate, mol/100 mol	1.37$_{zy}$	1.24$_{xy}$	1.24$_{xy}$	1.46$_z$	1.19$_x$	1.44$_z$	0.300	0.052	< 0.001	0.002
Caproate, mol/100 mol	0.32$_y$	0.38$_y$	0.40$_y$	0.33$_y$	0.34$_y$	0.62$_z$	0.027	0.002	< 0.001	< 0.001
NH$_3$-N, mg/dL	4.94$_b$	7.44$_a$	5.88$_b$	5.28$_b$	6.59$_a$	5.42$_b$	0.443	0.39	< 0.001	0.43
Fecal pH	6.92$_a$	6.72$_{ab}$	6.56$_b$	6.68$_a$	6.33$_{ab}$	6.43$_b$	0.132	0.014	0.029	0.54

[1] S×G = silage by grain interaction

abcMeans within a row with uncommon superscripts differ among grain source ($P < 0.05$).

zyx Means within a row with uncommon superscripts differ silage × grain interaction ($P < 0.05$).

Table 4.4. Effect of diets based on barley silage (BS) or corn silage (CS) when fed in combination with dry-rolled barley grain (BG), dry-rolled corn grain (CG), or an equal blend of barley and corn grain (BCG) on microbial nitrogen flow, nitrogen excretion and nitrogen digestibility.

	BS			CS				*P* values		
Variable	BG	CG	BCG	BG	CG	BCG	SEM	Silage	Grain	S×G
N intake, g	178.34	183.65	179.29	190.02	198.34	184.17	9.754	0.12	0.47	0.81
Bacterial N production, g/d[1]	51.65	56.60	45.20	63.79	57.77	64.12	6.961	0.022	0.82	0.25
Nitrogen excretion, g/d										
Fecal	54.23[b]	62.32[a]	61.69[ab]	60.74[b]	69.62[a]	65.28[ab]	4.610	0.042	0.049	0.83
Urine	76.07	82.80	75.24	81.33	81.12	77.07	4.923	0.62	0.44	0.74
Total	130.30	145.11	136.93	142.07	150.74	142.36	8.357	0.19	0.24	0.87
Nitrogen excretion, % of N intake										
Fecal	30.27[b]	33.86[a]	33.97[a]	32.21[b]	35.19[a]	35.71[a]	1.400	0.07	0.006	0.96
Urine	42.37	44.14	42.28	43.13	41.04	41.90	2.330	0.50	0.91	0.48
Total	72.64	78.00	76.26	75.34	76.23	77.61	2.769	0.63	0.21	0.50
Apparent N digestion										
g/d	123.67	121.42	117.97	129.09	129.19	118.59	8.14	0.32	0.31	0.81
% of N intake	69.45[a]	66.19[b]	66.08[b]	67.89[a]	65.08[b]	64.09[b]	1.41	0.09	0.007	0.92
N retained										
g/d	47.11	38.43	42.22	47.87	48.73	41.94	5.775	0.30	0.42	0.39
% of N intake	27.31	21.90	23.28	24.84	23.92	22.68	2.874	0.82	0.20	0.51

[abc]Means within a row with uncommon superscripts differ among grain source (*P* < 0.05).

[1]Based on calculation by Ørskov and Mcdonald (1979).

BCG treatments (grain, $P = 0.007$). Nitrogen intake, urinary nitrogen excretion, and nitrogen retention were not affected by silage, grain or the S × G interaction.

4.4.4 Total Tract Digestibility and Fecal Kernel Assessment

No differences were detected among silage sources for apparent total tract digestibility (Table 4.5). However, BG had greater DM, OM, starch, and GE digestibility ($P < 0.043$) with the BCG being intermediate and CG being the least. No differences were found between treatments in terms of aNDFom, ADF, CP, and EE for the effects of grain, silage or the S×G interaction ($P > 0.21$).

Fecal output and wet fecal weight were not affected by silage or grain source ($P > 0.27$). Fecal DM and fecal starch were greatest for the CG treatments and least for BG with BCG being intermediate ($P < 0.001$). Fecal DM and fecal starch were greatest for BS compared to CS ($P < 0.034$). Dry matter retained was greatest for BS compared to CS ($P = 0.010$) with no differences between grain treatments. The percentage of whole barley kernels in feces was greatest for the BG diets and least for CG and BCG diets (grain, $P < 0.001$; Table 4.6). Whole barley kernels were greatest in the BS diets when compared to the CS diets as no barley was present in the CS (silage, $P < 0.001$). Partial barley kernels were greater for the BS-BCG diet than BS-CG and CS-BCG with other treatments being intermediate (S×G, $P = 0.019$). The percentage of whole corn kernels in the feces was not affected by silage, grain, or the S×G interaction. Presence of partial corn kernels in feces was greatest for diets containing CG and least for those containing BG with the BCG diets being intermediate (grain, $P < 0.001$). The proportion of fines in feces was greatest for heifers fed diets with BG, intermediate with BCG, and least with CG (grain, $P < 0.001$).

4.5 Discussion

For backgrounding cattle, efficient digestion of forage and cereal grain sources are needed to optimize nutrient supply. As such, forage quality and cereal grain digestibility may impact nutrient supply and availability (Beauchemin and Yang 2005; Safaei and Yang 2017). For example, CS has greater starch concentration than BS and greater starch digestibility (Johnson et al. 2020b) thereby supplying a more fermentable starch source. However, BG has less starch but a more rapid rate of fermentation and greater extent of starch digestion than CG (Johnson et al. 2020b). Given the differences in starch concentration and the rates of starch digestion among BS and CS and BG and CG, it was hypothesized that interactions among the cereal silage and cereal grain source would occur. Moreover, previous research has demonstrated that for finishing diets   positive

Table 4.5. Effect of diets based on barley silage (BS) or corn silage (CS) when fed in combination with dry-rolled barley grain (BG), dry-rolled corn grain (CG), or an equal blend of barley and corn grain (BCG) on nutrient digestibility.

	BS			CS				P values		
	BG	CG	BCG	BG	CG	BCG	SEM	Silage	Grain	S×G
Nutrient digestibility (% DM)										
DM, %	71.02a	67.78b	68.97ab	70.10a	68.23b	69.81ab	1.315	0.87	0.043	0.61
OM	72.64a	69.00b	70.19ab	71.36a	69.79b	70.05ab	1.327	0.79	0.042	0.57
CP	69.32	66.05	65.68	67.01	65.30	64.78	1.366	0.17	0.043	0.75
aNDFom[1]	52.83	51.77	51.38	51.33	48.54	50.73	2.385	0.25	0.59	0.78
ADF	46.94	48.99	46.47	44.45	46.81	46.47	2.137	0.27	0.43	0.73
Starch	95.26a	87.63b	92.46ab	95.19a	92.16b	93.60ab	1.499	0.14	0.008	0.31
Ether extract	75.97	75.63	75.75	71.86	74.05	77.16	2.221	0.25	0.25	0.21
GE	69.67a	66.39b	67.59ab	69.97a	66.96b	68.69ab	1.392	0.38	0.010	0.90

[abc]Means within a row with uncommon superscripts differ among grain source ($P < 0.05$).

[1]aNDFom – determined using amylase, sodium sulphite, and corrected for ash content.

Table 4.6. Effect of diets based on barley silage (BS) or corn silage (CS) when fed in combination with dry-rolled barley grain (BG), dry-rolled corn grain (CG), or an equal BCG of barley and corn grain (BCG) on undigestible cereal grain in feces.

% of total	BS			CS			SEM	P values		
	BG	CG	BCG	BG	CG	BCG		Silage	Grain	S×G
Fecal output, kg DM/d	2.4	2.7	2.6	2.5	2.8	2.6	0.20	0.52	0.27	0.95
Fecal DM, %	17.9c	20.4a	19.0b	17.0c	20.0a	18.2b	0.45	0.013	< 0.001	0.69
Fecal starch, % DM	2.1c	10.6a	5.8b	0.7c	8.5a	4.3b	1.15	0.034	< 0.001	0.93
Wet fecal weight, g/250 mL	235.6	240.1	235.7	240.7	238.2	238.9	7.27	0.59	0.93	0.75
DM retained, g/250 mL	76.1	80.9	68.2	70.3	57.2	66.0	5.94	0.010	0.39	0.06
Whole barley, % retained	18.5a	5.4b	12.9b	9.8a	NP	3.2b	2.26	< 0.001	< 0.001	0.81
Partial barley, % retained	1.4zy	0.5y	2.1z	1.5zy	NP	0.4y	0.38	0.037	0.015	0.019
Whole corn, % retained	NP	1.0	0.8	0.9	1.7	0.6	0.86	0.66	0.50	0.47
Partial corn, % retained	NP	33.8a	20.0b	1.3c	34.9a	16.9b	3.15	0.70	< 0.001	0.41
Total fines, % retained	80.1a	59.2c	64.6b	85.3a	64.0c	78.8b	3.52	< 0.001	< 0.001	0.16

abcMeans within a row with uncommon superscripts differ among grain source (*P* < 0.05).

zyx Means within a row with uncommon superscripts differ silage × grain interaction (*P* < 0.05).

1NP was used to denote when it was not possible for a specific grain source to be present.

associative effects have been detected when feeding cereal grain sources that differ markedly in ruminal fermentation in finishing diets (Kreikemeier et al. 1987; Stock et al., 1987b; Huck et al. 1998). Despite evidence to support potential for interactions among the cereal silage and cereal grain sources, interactions were limited to the molar proportions of propionate, butyrate, isobutyrate, valerate and iso-valerate. This response was similar to that observed by Johnson et al. (2020b) using finishing diets. The magnitude of change in SCFA concentrations was greater for CS-based diets, when the grain source was changed as opposed to BS based diets, further supporting the concept that the starch concentration in the silage source may affect the fermentation response for the cereal grain source.

4.5.1 Effects of Cereal Silage Source

Corn silage was more degradable when compared to BS based on greater bacterial N production, and lower fecal starch. However, I did not observe any differences for apparent total tract digestibility between these silages. The lack of a digestibility response may be, in part due to numerically greater DMI for cattle fed CS than BS. Other studies comparing CS and BS have reported greater SCFA concentration and lower ruminal pH for cattle fed CS compared to BS while having no effect on digestibility aside from CP which, was greater for barley fed steers (Beauchemin and McGinn 2005). In dairy cattle, feeding CS as opposed to BS increased starch, DM, OM, ether extract, and gross energy digestibility with no effect on total SCFA concentration or ruminal pH (Benchaar et al. 2014). Despite an apparently more fermentable silage source, the total SCFA concentration was less for heifers fed CS than those fed BS. While it is not clear why CS-fed heifers would have lower SCFA concentrations given the greater fermentability, it is possible that rumen volume differed among CS- and BS-fed heifers. For example, DMI tended ($P = 0.065$) to be 0.56 kg/d greater for heifers fed CS. I have also reported greater DMI for growing cattle fed CS over BS (Sutherland et al. in review). Greater DMI may result in greater rumen volume and hence a dilution effect on ruminal SCFA concentration (Hall et al. 2015).

Feeding CS increased microbial protein production, an observation that likely reflects greater fermentability described above. Benchaar et al. (2014) observed greater starch and NDF digestibility as well as increased retained N further supporting greater microbial protein supply for the cattle fed CS compared to those fed BS.

Though ruminal pH was not affected by silage source, fecal pH was greater for heifers fed BS than CS treatments. Lower fecal pH is interpreted to suggest that CS provided a greater supply of

fermentable carbohydrate to the large intestine than BS. The greater supply of fermentative substrates for CS relative to BS may have led to reduced fecal starch and increased fecal N output. Post ruminal digestion of starch through fermentation in the large intestine may lead to an increased fecal N output (Kung et al. 1992). Benchaar et al. (2014), in a study with dairy cattle, reported increased fecal N (g/d) for cattle fed CS compared to those fed BS, supporting the concept that CS may have increased intestinal fermentation.

4.5.2 Effects of Cereal Grain Source

Despite the expectation for greater rates and extents of starch digestion for dry-rolled BG than CG (Khorasani et al. 2001), ruminal pH was not affected by grain source. With finishing diets, Johnson et al. (2020b) found that when heifers were fed dry-rolled barley, corn, or a blend of barley and corn, heifers fed BG had greater maximum ruminal pH. The lack of pH response observed in the present study could be due to the low inclusion of grain in the present study and the decreased digestibility for DM, OM, CP, and starch for CG relative to BG due to processing. Additionally, I did not observe any associative effects when combining BG and CG, which is similar to that previously reported for finishing cattle (Johnson et al., 2020b). Generally, responses for BCG-fed cattle were intermediate to BG and CG or similar to CG responses.

Acetate concentrations were greatest for CG and BCG diets as could be expected given that BG has been reported to have greater rates and extents of ruminal digestion than CG (Johnson et al., 2020b). Contradictory to my results Beauchemin and McGinn (2005), also found increased acetate concentrations in the BG diets but they also reported greater total SCFA concentration in these diets which I did not see in the current study. The increase in the molar proportion of propionate with the BG diets mirrors the reduction in acetate concentrations as would be expected. The greater degradability of the starch in the BG allows greater propionate production in the rumen (Taylor and Allen 2005; Garcia et al., 2000).

Heifers fed CG had the greatest concentration of rumen ammonia, but CG did not affect bacterial N production. The greater rumen ammonia is likely in response to greater urea inclusion with corn-based diets than with diets containing BG or BCG: a strategy that was used to ensure diets were isonitrogenous. Koenig and Beauchemin (2013) found when supplementing urea, rumen ammonia spiked immediately after feeding and remained slightly elevated compared to those not fed supplemental urea. Another likely cause of the greater rumen ammonia concentration may be due to a slower rate and lesser ruminal (Odle and Schaefer 1987) and total tract starch digestion of

the CG compared to the BG. Decreased rates and extents of starch digestion may reduce the demand for ruminal ammonia to combine with carbon skeletons to synthesize amino acids, even though there was no difference in bacterial N production. Supporting this concept, Garcia et al. (2000) reported increased rumen ammonia concentration for CG-fed cattle compared to those fed BG.

However, fecal pH and total tract starch digestibility, along with the greater starch supply for heifers fed CG support previous research that the ruminal digestibility for dry-rolled BG is greater than CG (Boss and Bowman 1996; Sutherland et al. in review; Johnson et al. 2020a, 2020b). Heifers fed CG had a greater appearance of partial corn kernels in feces compared to the BG fed heifers, an observation that aligns with the higher fecal starch content. These data indicate that a greater proportion of the corn kernels passed out of the heifers undigested when compared to the BG fed heifers. As was described for CS, CG also increased fecal nitrogen excretion (g/d) as a result of a greater supply of fermentative substrates in the large intestine. The greater supply of starch and lesser ruminal starch digestion in the rumen likely explains the reason for lower fecal pH with corn grain. Due to the nature of the BG pericarp, which is easily broken with dry rolling, dry rolling BG adequately to exposes the starch in the endosperm to rumen degradation. In contrast, corn grain possesses a vitreous endosperm in which starch and protein are tightly bound, limiting microbial digestion. While I did not evaluate vitreousness of corn in the present study, the reduction in fecal pH and greater fecal starch for heifers fed diets containing corn grain over barley grain is supported by a previous study (Johnson et al., 2020b). Another factor influencing the degradability of the grain may have been the greater PI. While processing goals differed among BG and CG, the resulting PI of 66% for BG as compared to 83% for CG may have further limited the degradation of corn starch in the rumen.

Grain source had no effect on the microbial protein flow which is surprising considering that BG has been reported to have a greater rate and extent of ruminal degradation (Garcí et al. 2000), resulting in a higher total tract starch digestibility for BG than for CG. In a backgrounding study by Garcia et al. (2000), N flow to the small intestine was numerically greater for diets containing ground CG compared to ground BG, and consequently the fecal N was greater for CG. In the current study, greater fecal N in the CG treatments was observed as well as the numerical increase in N intake. The slight increase in N intake amplifies the difference in N excretion for cattle fed CG compared to BG with the BCG being intermediate. The slightly lower N intake for BG

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treatments may have limited bacterial N production as I would have expected to see increased bacterial N production in cattle fed BG over the cattle fed CG treatments.

Barley grain, when dry rolled, has greater starch digestibility when compared to dry rolled CG (Herrera-Saldana et al. 1990a). Overall, digestibility of the BG was greater than CG with the BCG treatment being intermediate; however, as mentioned above, the severity of the processing was also greater with BG than for CG. It is widely accepted that processing strategies to maximize digestibility of CG should include moisture and ensiling as occurs with high-moisture corn (Cooper et al. 2002) or moisture and heat as with steam-flaking (Zinn et al. 2002). The use of these processing methods disrupts the starch and protein matrix allowing greater microbial access. Based on the assessment of grain kernels excreted in feces, I observed that very little of the fecal corn particles consisted of whole corn with approximately 34% being partial kernels. This lack of whole corn in the feces indicates that while processed to a lower index, corn was rolled to an extent that none of the kernels were fed whole, but that the assumed vitreousness of the endosperm in CG limited starch digestion.

5.0 GENERAL DISCUSSION

5.1 Cereal Silage and Cereal Grain Source Interaction

The objective of the two studies within this thesis was to determine whether cereal grain and cereal silage sources would interact to affect DMI, ruminal fermentation, nutrient digestibility, and growth performance. The intention of the combinations of grain and silage sources were to balance ruminal fermentation and the intestinal supply of starch to improve the efficiency of feed utilization. It was hypothesized that dry rolled CG, which ferments slowly in the rumen, when paired with a more rapidly degraded starch source (i.e. BG) would promote ruminal fermentation and allow for more intestinal starch digestion. However, there were no interactions detected when evaluating growth performance (Chapter 3) and only subtle interactions affecting ruminal fermentation and the proportion of undigestible cereal grain in the feces in Chapter 4. The reasons behind the general lack of interactions are difficult to explain but may be related to the cereal grain inclusion rates, and that the low extent of the starch digestibility of the CG. Thus, the insufficient digestion of starch in the rumen may have dampened the ability to detect grain source and silage source interactions. In terms of inclusion rates, the diets only contained 30% as grain (DM basis) but, I was able to detect interactions among the silage and grain sources for the molar proportion of SCFA, but differences were relatively small. Perhaps this result is not surprising given that there was no differences in the growth performance among diets.

Fermentability of the grain can have an impact on rumen pH, where grains with a higher rate and extent of ruminal digestion could potentially cause lower pH more than a slowly fermented grain source. However, at low inclusion rates, Garcí et al. (2000) compared ground BG (35% of DM) and ground CG (29% of DM) and reported no differences in mean ruminal pH or starch digestibility between the two grain sources. Diets with greater starch content typically have a lower ruminal pH compared to those with a lower starch content (Oba and Allen 2003). For Study 1 and 2 (Chapter 3 and 4) the starch content was greater for the diets where CG was fed compared to the BG diets (Study 1 BG 34.40%, CG 38.27%; Study 2 BG 32.83%, CG 36.11%), but this difference in starch did not affect ruminal pH in Study 2 (Chapter 4). Though the starch concentrations did not affect ruminal pH the total tract digestibility of the starch was lower for CG diets in Study 1 and 2 (Chapter 3 and 4) as reflected by higher fecal starch concentrations for cattle fed CG.

As for the increase in propionate and isobutyrate for BS-BG, butyrate and caproate for CS-BCG, isovalerate for BS-CG, and valerate for CS-BG and CS-BCG, these were expected due to the pairing of NFC (non-fiber carbohydrates) with different NDF contents, as this would change the SCFA pool in the rumen (Hall and Herejk 2001). These changes were of a minor nature and were too small to impact performance outcomes.

5.2 Cereal Silage Risk and Opportunity

Corn in western Canada is a high-risk high-reward crop. The input costs for corn are higher than barley but the yield potential is also much greater. According to a study by Lardner et al. (2017), corn yielded 10.6 t/ha compared to 6.8 t/ha for barley at four sites across Saskatchewan and Alberta over two years. The Government of Manitoba (2020) released a cost of production spread sheet comparing CS and BS including operating costs, fixed costs, and labour costs. Barley silage costs were \$118.31/ha compared to \$180.97/ha for CS. A major portion of the production cost was related to operating costs where corn and barley were valued at \$116.03/ha and \$61.51/ha, respectively. Thus, a significantly greater yield is required for corn compared to barley for corn to be cost effective. Using the yield values from Lardner et al. (2017), it can be estimated that BS cost \$17.40/t and CS cost \$17.07/t. A study by Baron et al. (2014) also found greater yield for whole-plant corn than whole-plant barley with corn yields being 32% greater. However, the carrying capacity of whole plant corn when grazed by cattle was 45% greater (1004 cow/d/ha vs. 554 cow/d/ha) due to the greater (65%) total digestible nutrients (TDN) yield and similar CP yield of the corn crop compared to the barley forage. Given the markedly differing yield but relatively similar forage cost, there may be greater benefit to growing corn in situations where the land base is limiting.

Part of the risk for corn is the susceptibility to frost which can terminate plant growth and maturation, limiting starch fill of the kernels if the CHU requirement are not met before the first killing frost (Baron et al. 2003). The high input costs of corn and reliance on high yield enhances concern over extreme weather conditions. While corn as a C4 plant is drought tolerant, if too much moisture is present during the spring the plant may become damaged and is then susceptible to disease such as stalk rot which will also limit the yield potential of the plant or cause early death (Gatch and Munkvold 2002). Short season corn requires a given quantity of CHU in order to reach full maturity. If insufficient CHU are received, starch fill of the kernels will be limited and the quality of the forage will be in turn be lower (Baron et al. 2003). To ensure adequate starch fill,

varieties are classified based on the quantity of CHU required to reach maturity such that growers can match corn varieties with the amount of anticipated CHU within region (Lardner et al. 2017). However, the basal method for reporting CHU among companies differs making direct comparisons among companies and varieties challenging. For example, some varieties are evaluated based on the maturity for silage while others are evaluated based on the number of CHU that would be needed to harvest the CG. Silage varieties are harvested at a more immature state and therefore would require less CHU than a variety being harvested for grain. The equation to calculate the CHU varies with region as well. For example, the CHU in the Atlantic provinces, for example, does not start accumulating until the mean temperature is 11°C and continues until 0°C is reached in the fall. The previously stated approach is different than the CHU calculation for ON and QC (Major et al. 1983). In Saskatchewan, the following formula was used to calculate CHU:

Daily CHU $= \frac{[1.8\,(\text{Min temp}-4.4)+3.3\,(\text{Max temp}-10)-0.084\,(\text{Max temp}-10)^2]}{2}$. Corn heat units continue to

accumulate from planting until harvested or until the first killing frost of -2°C. With the varieties developed, it is important to know what the intended use of the crop is as well as the region it is designed for in order to ensure adequate maturity for the intended purpose. The difference in CHU accumulation year over year is important to note as one year may be much higher than the average, impacting the selection of an appropriate variety. When selecting corn varieties for silage choose a variety that fits with the long term average CHU should be selected, not just based on CHU in the previous year (Beauchemin et al. 2018).

5.3 Forage Selection for Backgrounding Diets

Nutrient content of the forage is important for backgrounding cattle, particularly given the relatively high inclusion rates. In the present study, and as expected, corn had greater starch but lower CP and aNDFom than BS. A study by Chibisa and Beauchemin (2018) comparing CS to BS in backgrounding diets, noted the greater starch content of the CS allowed a greater amount of CS to replace of BG in the diets as compared to diets where BS is replaced BG. In Table 5.1, data from 8030 barley silage samples and 7264 corn silage samples from western Canada were collected and summarized using the Cumberland Valley Analytical (2019) database. These data highlight that the forages grown in the present study and the five-year averages were similar. Barley silage had greater CP, ADF, and NDF but lower starch concentrations compared to CS. Feeding BS and CS with high NDF digestibility to backgrounding cattle has the potential increase

Table 5.1. Comparison of barley silage and corn silage nutrient composition in the current study and a five-year average across Canada.

	Canada (2014-2019)[1]		Study 1 and 2	
	BS[2]	CS[3]	BS[4]	CS[4]
CP, %DM	11.6	8.6	10.3	9.4
ADF, %DM	29.2	26.7	30.3	26.9
NDF, %DM	48.4	45.7	47.8	44.1
Starch, %DM	17.9	25.3	20.4	28.0

[1]Values were obtained from Cumberland Valley Analytical (2019) from 01/01/2014 – 01/01/2019.

[2]N= 8030.

[3]N= 7264.

[4]N = 9.

DMI due to increased ruminal turnover and increased energy availability (Nair et al. 2016).

Varieties of barley such as CDC Cowboy had the greatest NDF content but also the greatest NDF digestibility, suggesting that selecting for or against NDF concentration alone will not ensure improved forage quality (Nair et al. 2016). Corn varieties such as the BMR varieties are lower in lignin allowing greater digestibility of the fibrous portion of the feed. Saunders et al. (2015) compared BMR CS to conventional CS for backgrounding beef cattle and while the chemical composition was similar between the two corn types, feeding the BMR CS led to greater total SCFA concentrations, improved ADG as well as a lower ruminal pH, but did not affect DMI. Chibisa and Beauchemin (2018) observed lower DMI for cattle fed CS, which they attributed to a greater NDF content compared to BS. The increase in the NDF and reduced digestibility of the NDF was attributed to causing the reduced performance in cattle fed high CS rations. The silage for Study 1 (Chapter 3) and Study 2 (Chapter 4) were from the same silage pit so there was very little variation in the nutrient composition of the silage used in these two studies. When comparing CS to BS, the CS had a lower fiber content compared to the BS which was likely due to the higher starch content of the CS. Cattle in Study 1 (Chapter 3) had greater NDF digestibility values for the CS compared to those fed the BS, resulting in a greater final BW for the cattle fed CS. In Study 2 (Chapter 4), there was no differences in the digestibility of the two silage sources. As the digestibility values in Chapter 3 were estimated using NIR, in Chapter 4 they were determined using wet chemistry, the wet chemistry values are more accurate.

Corn silage for backgrounding cattle provides a forage source with a higher starch content than BS (Table 5.1). The starch provides a fermentable energy source which may reduce the reliance on additional grain in the diet to promote growth. Processing of the kernels in the CS at the time of ensiling allows for greater starch digestibility and a more uniform feed (Cooke and Bernard 2005; Miorin et al. 2018). Processing the kernels also decreases the particle size of the forage portion of the silage creating a more uniform particle size for the whole product. The starch digestibility was greater for CS fed steers than that of the BS fed steers in Study 1 (Chapter 3) though there were no differences in starch digestibility between silage sources in Study 2 (Chapter 4). The differences observed between the Study 1 (Chapter 3) and Study 2 (Chapter 4) may be due to the difference in analysis as previously stated the values from Chapter 3 were obtained using NIR while Chapter 4 values were obtained from wet chemistry. Particle size of the silage is a factor that may influence digestibility. Miorin et al. (2018) observed particle size effects such that the

smaller (ground) particles had greater starch disappearance compared to the medium (chopped) and large (hammer mill) particles. In the study by Miorin et al. (2018) the forage was not ensiled but was kept whole dried. According to Miorin et al. (2018), the ensiling process may have increased the digestibility of the starch by 8 to 10%, which puts it in the range of my studies.

Kernel processing is a common practice when preparing CS but not with BS. A study by Eun et al. (2004) found no effect of kernel processing on the digestibility of starch in BS when it was chopped at a theoretical cut of 0.95 cm and processed through a 1 mm roller gap. Likewise, a recent study reported no beneficial effect of kernel processing wheat silage whether harvested at early dough or soft/hard dough stages (Randby et al. 2019), suggesting that small cereal grains do not require kernel processing. In Study 1 (Chapter 3), fecal starch for cattle fed BS did not differ from that of cattle fed CS, although for Study 2 (Chapter 4) fecal starch was greater for barley fed cattle. Fecal kernel analysis for both Study 1 and 2 (Chapter 3 and 4) indicated that the BS would have benefited from the use of a kernel processor as the percentage of whole barley kernels in the feces was increased in steers fed BS regardless of the cereal grain source. The CS used in the studies within this thesis was processed through a kernel processor with a 2 mm gap to ensure sufficient digestibility of the corn kernels. Both silages were cut to the same theoretical chop length (9.53 mm). Fecal starch was not different for the silage sources due to the partial barley kernel inclusion which was 0.6% and 0.5% for Study 1 (Chapter 3) and Study 2 (Chapter 4) respectively for the BS which was calculated using the values from BS-CG treatment. Partial corn kernels from corn silage was 5% for the feedlot and 1.3% (calculated using values from CS-BG treatments) meaning these kernels were broken but passed undigested. Several studies (Andrae et al. 2001; Cooke and Bernard 2005; Miorin et al. 2018) report increased starch digestibility as a result of the kernel processing of CS. Others (Bal et al. 2000; Johnson et al. 2003) found no effect of processing on the digestibility of starch in CS. The results of kernel processing CS are variable and are more pronounced with advancing maturity, depend on the growing conditions, variety and overall particle size of the forage.

The protein content of corn is much lower than barley and thus producers may need to consider added dietary cost of protein supplementation when feeding corn-based diets to backgrounding cattle. For the studies in this thesis, the target CP level was 13.5%. Given that both the BS and CS had CP concentrations that were less than the dietary target, CP supplementation was required for both diets. Although the cattle weighing 350 kg gaining at 1 kg per day with a

DMI of 2.5% BW are predicted to only require 12% to 13% CP (NASEM 2016) in the diet, a dietary concentration of 13.5% CP was chosen so that all diets required some degree of protein supplementation. Protein sources used in this study included canola meal and urea. While increasing the CP, they may have also altered the rumen degradable protein (RDP):rumen undegradable protein (RUP) ratio, a parameter not investigated in the present study.

Voluntary DMI of backgrounding cattle is likely limited by physical fill. It is thought that NDF intake, NDF digestibility, and passage rate are the primary determinants of physical fill (Allen, 1996). The cattle in Study 1 (Chapter 3) had NDF intakes equating to 1.1% of BW for the BS and 1.0% of BW for the CS treatments. These values are within the expected biological ranges for growing beef cattle (1.1% to 1.3% of BW; NASEM 2016). At the beginning of the trial when the steers were lighter, the NDF intake was 1.3 and 1.2% of BW for BS and CS respectively. If the NDF in the diet was too great, I would expect to see decreased DMI for these cattle. Smaller particle size promotes increased passage rate and the particle size of the silage in these studies was similar for both CS and BS so no differences in passage rate due to particle size would be expected.

5.4 Short-season and Conventional Corn

Western Canada is a relatively new corn growing region due to the cooler temperatures, and short growing seasons. The early maturing varieties that have been developed allow producers to grow this high yielding crops in areas where it previously could not grow. These varieties were not only developed for cool climates, but also for areas that can grow corn in a double or triple cropping programs. A study by Jemison et al. (2012) evaluated short-season corn hybrids double cropped with wheat, barley, or triticale as compared to conventional corn in yield. Jemison et al. (2012) observed the double cropping short season corn with a cereal such as wheat, barley or triticale had the potential to increase the forage yield compared to a full season corn variety. This study focused on organic production where weeds are difficult to control as chemicals can not be used. Being able to plant another crop on that soil allows the winter crop to compete with the weeds instead of using tillage to eliminate the weeds or attempting to have the new spring crop trying to out compete weeds (Jemison et al. 2012). Double cropping using the short-season corn varieties would give organic and non-organic producers another option in terms of forage production and land management.

The current limitations of growing corn for grain in western Canada lies in the equipment and heat potential. To plant corn, a row planter is required to control row spacing and seed depth.

The standard row spacing is 76 cm (Baron et al. 2006) and depth is 7.6 cm (Alessi and Power 1971). Current recommendations for short-season corn are based on the leaf area and plant size with both being smaller than traditional corn varieties. Thus, seeding rates of short-season varieties are higher compared to conventional corn varieties. A study conducted by Baron et al. (2006) determined that short-season corn varieties had greater yield with a narrow (38 cm) row spacing and at 100,000 plant/ha density (compared to 75,000 plants/ha).

For silage, corn has greater digestibility potential if a kernel processor is used during the chopping phase. Harvesting is another area where proper equipment is required as the equipment used for cool season small-grain cereal crops is not designed for corn. Corn silage requires a specially designed corn header to properly harvest standing corn. To avoid considerable corn plant damage, row crop sprayers should be used in which tire width and tire spacing match the row spacing. Traditional sprayers can be fit with row tires to avoid plant damage, but the narrow row spacing for short-season corn could still lead to significant plant damage should this planting practice be adopted (Baron et al. 2006). The use of spray planes to treat crops is another way to remove weeds or eliminate a pest while avoiding plants damage.

Brown midrib corn is a corn variety with increased fiber digestibility due to lower lignin content as compared to conventional corn varieties (Ebling and Kung 2004). A study by Ebling and Kung (2004) compared BMR corn varieties to conventional corn varieties and found greater CP concentrations and lower lignin concentrations in BMR corn. The NDF digestibility for the BMR was greater compared to conventional CS even when the BMR silage was not run through a kernel processor. The cows fed BMR silage produced more milk and ate more feed compared to the cows fed conventional corn. A study by Keith et al. (1981) compared BMR CS to conventional CS in feedlot diets and found greater ADG and DMI but similar feed conversion for cattle fed BMR silage compared to the conventional silage. Carcasses from the cattle fed the BMR silage were not different from those fed the conventional CS. Consistent with the findings of Keith et al. (1981), Saunders et al. (2015) observed a tendency for an increase in ADG and G:F when steers were fed BMR corn silage over conventional corn silage in a backgrounding diet but no differences in DMI. Saunders et al. (2015) conducted an economic analysis comparing the feeding of BMR corn compared to conventional corn and found a greater net return per animal for the steers fed BMR CS due to the decreased feed cost per BW gain. Producers in Canada could benefit from a BMR variety to reduce the lignin content of the CS. However, the BMR trait is currently not

available in short-season varieties. Moreover, BMR corn does not yield as high as the conventional corn varieties. The low lignin content makes the stalks of the plant more delicate and in an area that experiences high winds regularly, growing these BMR varieties poses a challenge (Barrière and Argillier 1993).

The lignin and NDF content of the CS in western Canada is high (3% DM, 46 % DM; Cumberland Valley Analytical 2019) compared to conventional corn in the USA. Corn grown in the Upper Mid-west USA has a greater starch content and is lower in CP and fiber compared to short-season varieties. An increase in fiber digestibility would improve the efficiency of short-season CS. Short-season corn (85 d maturity) varieties are typically harvested at the ½ milk line stage: a point at which the DM digestibility (80%) is the greatest (Wiersma et al. 1993). For the studies in this thesis (Chapter 3 and 4), the DM digestibility of the diets containing short-season CS was 76.4% for Study 1 (Chapter 3) and 69.4% for Study 2 (Chapter 4). A study by Darby and Lauer (2002) using later maturing (100 to 110 d) corn hybrids found an average in vitro true digestibility of 67% for 100 d and 110d corn varieties. These digestibility values suggest that the conventional varieties may have lower digestibility compared to short-season varieties due to the difference in DM digestibility between the current studies (Chapter 3 and 4) and the values from Darby and Lauer (2002). In the study by Darby and Lauer (2002) they indicate that the varieties that mature at 100 d had a numerically lower digestibility than those that matured at 110 d. As the plant matures the digestibility decreases, especially after the plant exceeds 36% DM. The typical harvesting DM content for silage is between 33% and 36% DM (Johnson et al. 1999). Across studies, the DM digestibility of the silage was not consistent with some observing decreases in digestibility while others observed no differences in digestibility between different plant maturities. The inconsistencies may be due to hybrid variety, growing conditions, animal diets, and intakes. In a study by Bal et al. (1997) that compared stages of maturity dairy cows exhibited similar total-tract digestibility for DM, OM, and CP from early dent to 2/3 milk line, but digestibility declined significantly from 2/3 milk line to the black layer stage. ADF and starch digestibility decreased consistently as the plant matured. Harvesting at a more immature state would result in greater fiber and starch digestibility without compromising DM, OM, and CP digestibility.

5.5 Cereal Grain Processing

Adequate processing of cereal grains for cattle is necessary to allow optimal fermentation of the grain. Feeding whole BG to beef cattle can reduced gains by up to 50% and the amount of

feed required has the potential to double due to the decrease in starch digestibility (37%) (Mathison 1996). Feeding whole corn to cattle results in a 15% reduction in starch digestibility compared to feeding ground or rolled CG (Corona et al. 2005). If cereal grains are not processed adequately, the starch passes through the animal undigested. While achieving feces that are completely devoid of starch is the ultimate goal to ensure maximal nutrient utilization, such a goal is likely not realistic. The processing required to achieve 100% starch digestibility would have other negative impacts on the animal such as ruminal acidosis. In the current studies, fecal starch values of 16.9% for CG, 8.6% for BG, and 14.0% for the BCG treatments were observed in Chapter 3. For Chapter 4, fecal starch values were 9.6% for CG, 1.4% for BG, and 7.2% for BCG despite being fed the same silage and cereal grain sources at the same time. The fecal starch values from Chapter 3 are high for backgrounding cattle as the starch content of the diet was only 38% for the CG, 34% for the BG, and 36% for BCG. The fecal starch concentrations in Chapter 4 are similar the average value of 6.3% previously reported for 149 samples collected in commercial feedlots in Alberta (Jancewicz et al. 2017a). Fecal starch represents a lost opportunity. The relatively high fecal starch observed in Chapter 3 is likely because both grain sources were dry rolled with the BG having a processing index of 66% and the CG having a processing index of 83%. Barley grain has a hull, but it is easily shattered by processing, allowing microbial access to the starch in the endosperm (McAllister and Cheng 1996). Dry rolling is a common method for BG and the severity of processing imposed in the present studies should have been appropriate to optimize starch digestibility (Ahmad et al. 2010). Past studies have, reported improvements in digestibility by sorting barley kernels based on size and imposing strategic processing for those kernels (Ahmad et al. 2010). As such, it is possible that while a sufficient severity of grain processing was imposed, variability in the barley kernel size may have allowed some kernels to pass through the roller mill without sufficient processing. Support for this has been provided by evaluating appearance of kernels in feces as evidence of incomplete rolling.

In contrast to barley, the PI for corn was likely not sufficient to promote microbial attachment and digestion as corn should be ground to a PI of 77% (Joy et al. 1997). That said, for vitreous corn, the severity of grinding has little effect on starch digestibility (Corona et al. 2006). While vitreousness was not evaluated for the corn used in this thesis, it could be expected that it may have limited corn starch digestion. Clearly, steam-flaking CG in the present studies would have increased starch digestibility; but steam-flaking infrastructure is not common in western

Canadian feedlots and CG used in western Canada is often dry-rolled. Moreover, steam-flaking would have reduced the magnitude of difference between the rate of degradation and extent of digestion between corn and barley, thereby likely reducing potential for treatment differences (Safaei and Yang 2017).

While there are logical reasons for high fecal starch contents in Chapter 3, the reasons for differences in fecal starch content among Chapter 3 and Chapter 4 are not apparent. The fecal starch in Chapter 3 was predicted using NIR while the fecal starch in Chapter 4 was determined using wet chemistry. NIR calibrations are determined by using a calibration set, which have their chemical composition determined using wet chemistry. The calibrations used for the current study were determined using feedlot steers on digestibility trials where both wet chemistry as well as NIR were utilized (Jancewicz et al. 2017b). According to Jancewicz et al. (2017b) predictability of fecal starch was most accurate for high grain diets, but when grain was included at less than 44% of dietary DM the prediction of fecal starch was less accurate. The fecal starch in Chapter 3 was potentially over-estimated as the grain content of the diets was 30% of dietary DM suggesting that prediction of starch digestibility may have been less precise.

5.6 Limitations of the Experimental Model

The studies within this thesis have addressed a significant gap in the literature: whether silage source and cereal grain sources interact in diets for backgrounding cattle and the main effects of BS vs. short-season CS, and a comparison of dry-rolled BG vs. CG vs. a blend of BG and CG. That said, the current studies have some limitations that should be considered. Firstly, the projects were conducted within a single cropping year. The concern with the use of a single crop year is that there is substantial year-to-year variability in growing conditions. The nutrient profile of corn and barley are influenced by CHU (or growing degree days (**GDD**) for barley; Rosser et al. 2013; Beauchemin et al. 2018), hybrid/variety (Andrae et al. 2001; Nair et al. 2016), stage of maturity at harvest (Andrae et al. 2001; Rosser et al. 2013), and other environmental considerations (e.g. amount and timing of precipitation) during the growing season. That said, anecdotally the silages in this thesis appear to be similar to the 5-year average as reported by Cumberland Valley Analytical (2019). While use of a single-crop production year could be a source of criticism, using the same ingredients for the studies in Chapter 3 and 4 also allowed greater control over the nutrient composition of the diets in both studies and hence provided the opportunity to use Chapter 4 to help explain outcomes observed in Chapter 3.

5.7 Future Research Considerations

Future research needs include more work on comparing short-season corn varieties in backgrounding diets to the use of barley silage. As stated throughout this thesis, research evaluating short-season corn is limited yet corn acreage and use of CS is increasing. Most of the research evaluating short-season corn is based on using CS as a winter feed for beef cattle or is based on in situ or in vitro digestibility (Lardner et al. 2017; Guyader et al. 2018; Miorin et al. 2018). Including larger scale feedlot studies with industry standard stocking density and management over multiple years may provide a more rounded understanding of the effects of CS, and BS combined with CG, BG, or BCG on backgrounding cattle performance. The research in this thesis also highlighted that it might be desirable to process BS using a kernel processor. There is only one study, known to the author, that has evaluated kernel processing of BS. Given the appearance of kernels in feces that I could attribute to BS, this may be an area of interest for the beef and dairy industry in Canada as a strategy to increase the value and digestibility of BS.

6.0 GENERAL CONCLUSION

Development of short-season corn has increased the use of corn for grain and forage purposes in Western Canada. Even with these developments the data on cattle fed short-season corn silage is limited and comparisons to feeds already fed to backgrounding cattle in Western Canada is even more limited. Data on rolled corn grain is limited for finishing and backgrounding cattle as steam-flaking is the processing method of choice in the USA.

Corn silage may have the ability to improve final BW, total tract digestibility, and bacterial N production for cattle fed CS over BS. While BS was able to improve SCFA concentration in the rumen this did not translate into improved growth performance. The increase in grain kernels in the feces, particularly whole barley kernels leads to an increase in fecal starch that could potentially be reduced with kernel processing of BS. While there were no fermentation or performance benefits to feeding rolled CG and rolled BG as a mixture, as I hypothesized feeding BG with either silage source improved total tract digestibility and N digestion over CG. BG also increased total fines in the feces and whole barley kernels in the feces while partial corn kernels in the feces were increased when feeding CG. Improvement in the performance of the CG fed cattle may be achieved with alternate processing methods such as steam flaking to disrupt the starch protein matrix, improving digestibility.

When combining silage with grain sources my data are interpreted to suggest that interactions between the source of cereal silage and the cereal grain source do not occur in diets for backgrounding cattle. Moreover, there does not appear to be associative effects when combining dry rolled BG or CG. Though feeding BG resulted in digestibility improvements that did not improve growth performance there is potential for improvement with a greater inclusion rate.

7.0 LITERATURE CITED

Aboagye, I.A., Baron, V.S., Oba, M., Guyader, J., and Beauchemin, K.A. 2019. In vitro degradation and methane production of short-season corn hybrids harvested before or after a light frost. Can. J. Anim. Sci. **99**: 741–753. doi:10.1139/cjas-2018-0188.

Acosta, Y.M., Stallings, C.C., Polan, C.E., and Miller, C.N. 1991. Evaluation of barley silage harvested at boot and soft dough stages. J. Dairy Sci. **74**: 167–176. doi:10.3168/jds.S0022-0302(91)78158-7.

Ahmad, M., Gibb, D.J., McAllister, T.A., Yang, W.Z., Helm, J., Zijlstra, R.T., and Oba, M. 2010. Adjusting roller settings based on kernel size increased ruminal starch digestibility of dry-rolled barley grain in cattle. Can. J. Anim. Sci. **90**: 275–278. doi:10.4141/cjas09062.

Alessi, J., and Power, J.F. 1971. Corn emergence in relation to soil temperature and seeding depth. Agron. J. **63**: 717. doi:10.2134/agronj1971.00021962006300050018x.

Allen, M.S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. **83**: 1598–1624. doi:10.3168/jds.S0022-0302(00)75030-2.

Andrae, J.G., Hunt, C.W., Pritchard, G.T., Kennington, L.R., Harrison, J.H., Kezar, W., and Mahanna, W. 2001. Effect of hybrid, maturity, and mechanical processing of corn silage on intake and digestibility by beef cattle. J. Anim. Sci. **79**: 2268–2275. doi:10.2527/2001.7992268x.

AOAC 2000. Official methods of analysis of AOAC International. 17th editi. Assoc. Off. Anal. Chem., Caithersburg, MD.

AOAC 2006. Official Methods of Analysis of AOAC International 984.13. 15th Editi. AOAC International, Rockville Maryland.

Bal, M.A., Coors, J.G., and Shaver, R.D. 1997. Impact of the maturity of corn for use as silage in the diets of dairy cows on intake, digestion, and milk production. J. Dairy Sci. **80**: 2497–2503. doi:10.3168/jds.S0022-0302(97)76202-7.

Bal, M.A., Shaver, R.D., Jirovec, A.G., Shinners, K.J., and Coors, J.G. 2000. Crop processing and chop length of corn silage: Effects on intake, digestion, and milk production by dairy cows. J. Dairy Sci. **83**: 1264–1273. doi:10.3168/jds.S0022-0302(00)74993-9.

Baron, V.S., Doce, R.R., Basarab, J., and Dick, C. 2014. Swath grazing triticale and corn compared to barley and a traditional winter feeding method in central Alberta. Can. J. Plant Sci. **94**: 1125–1137. doi:10.4141/CJPS2013-412.

Baron, V.S., Najda, H.G., McCartney, D.H., Bjorge, M., and Lastiwka, G.W. 2003. Winter weathering effects on corn grown for grazing in a short-season area. Can. J. Plant Sci. **83**: 333–341. doi:10.4141/P01-202.

Baron, V.S., Najda, H.G., and Stevenson, F.C. 2006. Influence of population density, row spacing and hybrid on forage corn yield and nutritive value in a cool-season environment. Can. J. Plant Sci. **86**: 1131–1138. doi:10.4141/P05-136.

Barrière, Y., and Argillier, O. 1993. Brown-midrib genes of maize : a review. Agronomie **13**: 865–876. doi:hal-00885517.

Beauchemin, K., Baron, V., and Guyader, J. 2018. Keys to producing high quality corn silage in western Canada getting the agronomics right corn heat unit (CHU) system. Pages 147–159 *in* WCDS Advances in Dairy Technology.

Beauchemin, K.A., Colombatto, D., and Morgavi, D.P. 2004. A rationale for the development of feed enzyme products for ruminants. Can. J. Anim. Sci. **84**: 23–36. doi:10.4141/A02-103.

Beauchemin, K.A., Jones, S.D.M., Rode, L.M., and Sewalt, V.J.H. 1997. Effects of fibrolytic enzymes in corn or barley diets on performance and carcass characteristics of feedlot cattle.

Can. J. Anim. Sci. **77**: 645–653. doi:10.4141/A97-050.

Beauchemin, K.A., and McGinn, S.M. 2005. Methane emissions from feedlot cattle fed barley or corn diets. J. Anim. Sci. **83**: 653–661. doi:10.2527/2005.833653x.

Beauchemin, K.A., and Yang, W.Z. 2005. Effects of physically effective fiber on intake, chewing activity, and ruminal acidosis for dairy cows fed diets based on corn silage. J. Dairy Sci. **88**: 2117–2129. doi:10.3168/jds.S0022-0302(05)72888-5.

Beauchemin, K.A., Yang, W.Z., and Rode, L.M. 2001. Effects of barley grain processing on the site and extent of digestion of beef feedlot finishing diets. J. Anim. Sci. **79**: 1925–1936. doi:10.2527/2001.7971925x.

Der Bedrosian, M.C., Nestor, K.E., and Kung, L. 2012. The effects of hybrid, maturity, and length of storage on the composition and nutritive value of corn silage. J. Dairy Sci. **95**: 5115–5126. doi:10.3168/jds.2011-4833.

Benchaar, C., Hassanat, F., Gervais, R., Chouinard, R.Y., Petit, H. V, and Masse, D.I. 2014. Methane production, digestion, ruminal fermentation, nitrogen balance, and milk production of cows fed corn silage- or barley silage-based diets. J. Dairy Sci. **97**: 961–974. doi:10.3168/jds.2013-7122.

Bernardes, T.F., Daniel, J.L.P., Adesogan, A.T., McAllister, T.A., Drouin, P., Nussio, L.G., Huhtanen, P., Tremblay, G.F., Bélanger, G., and Cai, Y. 2018. Silage review: unique challenges of silages made in hot and cold regions. J. Dairy Sci. **101**: 4001–4019. doi:10.3168/jds.2017-13703.

Bock, B.J., Brandt, R.T., Harmon, D.L., Anderson, S.J., Elliott, J.K., and Avery, T.B. 1991. Mixtures of wheat and high-moisture corn in finishing diets: feedlot performance and in situ rate of starch digestion in steers. J. Anim. Sci. **69**: 2703–2710. doi:10.2527/1991.6972703x.

Boss, D.L., and Bowman, J.G.P. 1996. Barley varieties for finishing steers: II. ruminal characteristics and rate, site, and extent of digestion. J. Anim. Sci. **74**: 1973–1981. doi:10.2527/1996.7481973x.

Burakowska, K., Radke, L.A., and Penner, G.B. 2019. Steam-flaking conditions affect starch reactivity of barley grain. Page 351 *in* Western Canadian Dairy Seminar.

Burger, H., and Rheeder, P. 2017. Important mycotoxins relevant to maize. [Online] Available: https://www.grainsa.co.za/important-mycotoxins-relevant-to-maize [2019 Oct. 24].

Campling, R.C. 1991. Processing cereal grains for cattle - a review. Livest. Prod. Sci. **28**: 223–234. doi:10.1016/0301-6226(91)90144-F.

CanFax 2019. Feedlot Statistics.

Castillo-Lopez, E., Wiese, B.I., Hendrick, S., McKinnon, J.J., McAllister, T.A., Beauchemin, K.A., and Penner, G.B. 2014. Incidence, prevalence, severity, and risk factors for ruminal acidosis in feedlot steers during backgrounding, diet transition, and finishing. J. Anim. Sci. **92**: 3053–3063. doi:10.2527/jas.2014-7599.

Chen, X.B., and Gomes, M.J. 1992. Estimation of microbial protein supply to sheep and cattle based on urinary excretion of purine derivatives - an overview of the technical details. Res. Inst. Bucksburn Aberd. AB2 9SB UK. 1-19.

Chibisa, G.E., and Beauchemin, K.A. 2018. Effects of feeding corn silage from short-season hybrids and extending the back-grounding period on production performance and carcass traits of beef cattle. J. Anim. Sci. **96**: 2490–2503. doi:10.1093/jas/sky099.

Cooke, K.M., and Bernard, J.K. 2005. Effect of length of cut and kernel processing on use of corn silage by lactating dairy cows. J. Dairy Sci. **88**: 310–316. doi:10.3168/jds.S0022-0302(05)72689-8.

Cooke, K.M., Bernard, J.K., and West, J.W. 2009. Performance of lactating dairy cows fed ryegrass silage and corn silage with ground corn, steam-flaked corn, or hominy feed. J. Dairy Sci. **92**: 1117–1123. doi:10.3168/jds.2008-1481.

Cooper, R.J., Milton, C.T., Klopfenstein, T.J., Scott, T.L., Wilson, C.B., and Mass, R.A. 2002. Effect of corn processing on starch digestion and bacterial crude protein flow in finishing cattle. J. Anim. Sci. **80**: 797–804. doi:10.2527/2002.803797x.

Corona, L., Owens, F.N., and Zinn, R.A. 2006. Impact of corn vitreousness and processing on site and extent of digestion by feedlot cattle. J. Anim. Sci. **84**: 3020–3031. doi:10.2527/jas.2005-603.

Corona, L., Rodriguez, S., Ware, R.A., and Zinn, R.A. 2005. Comparative effects of whole, ground, dry-rolled, and steam-flaked corn on digestion and growth performance in feedlot cattle. Prof. Anim. Sci. **21**: 200–206. doi:10.15232/S1080-7446(15)31203-1.

Cumberland Valley Analytical 2019. Laboratory results. [Online] Available: www.foragelab.com [2019 Aug. 13].

Damiran, D., and Yu, P. 2012. Metabolic characteristics in ruminants of the proteins in newly developed hull-less barley varieties with altered starch traits. J. Cereal Sci. **55**: 351–360. doi:10.1016/j.jcs.2012.01.006.

Darby, H.M., and Lauer, J.G. 2002. Planting date and hybrid influence on corn forage yield and quality. Agron. J. **94**: 281–289. doi:10.2134/agronj2002.0281.

Dehghan-banadaky, M., Corbett, R., and Oba, M. 2007. Effects of barley grain processing on productivity of cattle. Anim. Feed Sci. Technol. **137**: 1–24. doi:10.1016/j.anifeedsci.2006.11.021.

Ebling, T.L., and Kung, L. 2004. A comparison of processed conventional corn silage to unprocessed and processed brown midrib corn silage on intake, digestion, and milk production by dairy cows. J. Dairy Sci. **87**: 2519–2526. doi:10.3168/jds.S0022-0302(04)73376-7.

Einarson, M.S., Plaizier, J.C., and Wittenberg, K.M. 2004. Effects of barley silage chop length on productivity and rumen conditions of lactating dairy cows fed a total mixed ration. J. Dairy Sci. **87**: 2987–2996. doi:10.3168/jds.S0022-0302(04)73430-X.

Elferink, S.J.W.H.O., Driehuis, F., Gottschal, J.C., and Spoelstra, S.F. 2000. Silage fermentation processes and their manipulation. FAO Plant Prod. Prot. Pap.: 17–30.

Eun, J.S., Beauchemin, K.A., Hong, S.H., and Yang, W.Z. 2004. Effects of mechanical processing on the nutritive value of barley silage for lactating dairy cows. J. Dairy Sci. **87**: 4170–4177. Elsevier. doi:10.3168/jds.S0022-0302(04)73560-2.

Fawcett, J.K., and Scott, J.E. 1960. A rapid and precise method for the determination of urea. J. Clin. Pathol. **13**: 156–159. doi:10.1136/jcp.13.2.156.

Ferraretto, L.F., Crump, P.M., and Shaver, R.D. 2013. Effect of cereal grain type and corn grain harvesting and processing methods on intake, digestion, and milk production by dairy cows through a meta-analysis. J. Dairy Sci. **96**: 533–550. doi:10.3168/jds.2012-5932.

Ferraretto, L.F., Shaver, R.D., and Luck, B.D. 2018. Silage review: recent advances and future technologies for whole-plant and fractionated corn silage harvesting. J. Dairy Sci. **101**: 3937–3951. doi:10.3168/jds.2017-13728.

Firkins, J.L., Eastridge, M.L., St-Pierre, N.R., and Noftsger, S.M. 2001. Effects of grain variability and processing on starch utilization by lactating dairy cattle. J. Anim. Sci. **79**: E218. doi:10.2527/jas2001.79e-supple218x.

Foley, A.E., Hristov, A.N., Melgar, A., Ropp, J.K., Etter, R.P., Zaman, S., Hunt, C.W., Huber,

K., and Price, W.J. 2006. Effect of barley and its amylopectin content on ruminal fermentation and nitrogen utilization in lactating dairy cows. J. Dairy Sci. **89**: 4321–4335. doi:10.3168/jds.S0022-0302(06)72479-1.

Fox, D.G., Sniffen, C.J., O'Connor, J.D., Russell, J.B., and Van Soest, P.J. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. cattle requirements and diet adequacy. J. Anim. Sci. **70**: 3578–3596. doi:10.2527/1992.70113578x.

Garcí, S.C., Santini, F.J., and Elizalde, J.C. 2000. Sites of digestion and bacterial protein synthesis in dairy heifers fed fresh oats with or without corn or barley grain. J. Dairy Sci. **83**: 746–755. doi:10.3168/jds.s0022-0302(00)74937-x.

Gatch, E.W., and Munkvold, G.P. 2002. Fungal species composition in maize stalks in relation to European corn borer injury and transgenic insect protection. Plant Dis. **86**: 1156–1162. doi:10.1094/PDIS.2002.86.10.1156.

Gentry, W.W., Weiss, C.P., Meredith, C.M., McCollum, F.T., Cole, N.A., and Jennings, J.S. 2016. Effects of roughage inclusion and particle size on performance and rumination behavior of finishing beef steers. J Anim Sci **94**: 4759–4770. doi:10.2527/jas.2016-0734.

Gibb, D.J., Hao, X., and McAllister, T.A. 2008. Effect of dried distillers' grains from wheat on diet digestibility and performance of feedlot cattle. Can. J. Anim. Sci. **88**: 659–665. doi:10.4141/CJAS08040.

Górka, P., Castillo-Lopez, E., Joy, F., Chibisa, G.E., McKinnon, J.J., and Penner, G.B. 2015. Effect of including high-lipid by-product pellets in substitution for barley grain and canola meal in finishing diets for beef cattle on ruminal fermentation and nutrient digestibility. J. Anim. Sci.: 4891–4902. doi:10.2527/jas2015-9282.

Government of Manitoba 2020. Cereal silage cost of production. [Online] Available: www.gov.mb.ca › farm-management › pubs › cop-forage-cereal-silage [2020 Jan. 13].

Government of Saskatchewan 2016. Saskatchewan heat unit maps. [Online] Available: http://publications.gov.sk.ca/documents/20/83796-corn heat units maps.pdf. [2020 Jan. 7].

Guyader, J., Baron, V.S., and Beauchemin, K.A. 2018. Corn forage yield and quality for silage in short growing season areas of the canadian prairies. Agronomy **8**: 1–25. doi:10.3390/agronomy8090164.

Hall, M.B. 2009. Determination of starch, including maltooligosaccharides, in animal feeds: comparison of methods and a method recommended for AOAC collaborative study. J AOAC Int **92**: 42–49.

Hall, M.B., and Herejk, C. 2001. Differences in yields of microbial crude protein from in vitro fermentation of carbohydrates. J. Dairy Sci. **84**: 2486–2493. doi:10.3168/jds.S0022-0302(01)74699-1.

Hall, M.B., Nennich, T.D., Doane, P.H., and Brink, G.E. 2015. Total volatile fatty acid concentrations are unreliable estimators of treatment effects on ruminal fermentation in vivo. J. Dairy Sci. **98**: 3988–3999. doi:10.3168/jds.2014-8854.

Hedrick, H.B., Paterson, J.A., Matches, A.G., Thomas, J.D., Morrow, R.E., Stringer, W.G., and Lipsey, R.J. 1983. Carcass and palatability characteristics of beef produced on pasture, corn silage and corn grain. J Anim Sci **57**: 791–801. doi:10.2527/jas1983.574791x.

Herrera-Saldana, R., Gomez-Alarcon, R., Torabi, M., and Huber, J.T. 1990a. Influence of synchronizing protein and starch degradation in the rumen on nutrient utilization and microbial protein synthesis. J. Dairy Sci. **73**: 142–148. doi:10.3168/jds.S0022-0302(90)78657-2.

Herrera-Saldana, R.E., Huber, J.T., and Poore, M.H. 1990b. Dry matter, crude protein, and starch

degradability of five cereal grains. J. Dairy Sci. **73**: 2386–2393. doi:10.3168/jds.S0022-0302(90)78922-9.

Huck, G.L., Kreikemeier, K.K., Kuhl, G.L., Eck, T.P., and Bolsen, K.K. 1998. Effects of feeding combinations of steam-flaked grain sorghum and steam-flaked, high-moisture, or dry-rolled corn on growth performance and carcass characteristics in feedlot cattle. J. Anim. Sci. **76**: 2984–2990. doi:10.2527/1998.76122984x.

Hunt, C.W. 1996. Factors affecting the feeding quality of barley for ruminants. Anim. Feed Sci. Technol. **62**: 37–48. doi:10.1016/S0377-8401(96)01004-8.

Jancewicz, L.J., Penner, G.B., Swift, M.L., McKinnon, J.J., Waldner, C.L., and McAllister, T.A. 2016. Characterization of the variation in the daily excretion of faecal constituents and digestibility predictions in beef cattle fed feedlot diets using near-infrared spectroscopy. Can. J. Anim. Sci. **96**: 532–549. doi:10.1139/cjas-2015-0193.

Jancewicz, L.J., Penner, G.B., Swift, M.L., Waldner, C.L., Koenig, K.M., Beauchemin, K.A., and McAllister, T.A. 2017a. Predicting fecal nutrient concentrations and digestibilities and growth performance in feedlot cattle by near-infrared spectroscopy. J. Anim. Sci. **95**: 455–474. doi:10.2527/jas2016.0876.

Jancewicz, L.J., Swift, M.L., Penner, G.B., Beauchemin, K.A., Koenig, K.M., Chibisa, G.E., He, M.L., McKinnon, J.J., Yang, W.-Z., and McAllister, T.A. 2017b. Development of near-infrared spectroscopy calibrations to estimate fecal composition and nutrient digestibility in beef cattle. Can. J. Anim. Sci. **97**: 51–64. doi:10.1139/cjas-2016-0107.

Jemison, J.M., Darby, H.M., and Chris Reberg-Horton, S. 2012. Winter grain short-season corn double crop forage production for New England. Agron. J. **104**: 256–264. doi:10.2134/agronj2011.0275.

Johnson, J.A., Joy, F., McKinnon, J.J., and Penner, G.B. 2018. High-fibre high-lipid by-product pellets containing calcium oxide-treated oat hulls as a partial replacement for barley grain in finishing diets for beef cattle. Can. J. Anim. Sci. **98**: 656–666. doi:10.1139/cjas-2017-0111.

Johnson, J.A., Sutherland, B.D., Mckinnon, J.J., Mcallister, T.A., and Penner, G.B. 2020a. Use of barley or corn silage when fed with barley, corn, or a blend of barley and corn on growth performance, nutrient utilization, and carcass characteristics of finishing beef cattle. Transl. Anim. Sci. **4**. doi:10.1093/tas/txz168.

Johnson, J.A., Sutherland, B.D., McKinnon, J.J., McAllister, T.A., and Penner, G.B. 2020b. Effect of feeding barley or corn silage with dry rolled barley, corn, or a blend of barley and corn grain on rumen fermentation, total-tract digestibility, and nitrogen balance for finishing beef heifers. J. Anim. Sci. doi:10.1093/jas/skaa002.

Johnson, L., Harrison, J.H., Hunt, C., Shinners, K., Doggett, C.G., and Sapienza, D. 1999. Nutritive value of corn silage as affected by maturity and mechanical processing: A contemporary review. J. Dairy Sci. **82**: 2813–2825. Elsevier. doi:10.3168/jds.S0022-0302(99)75540-2.

Johnson, L.M., Harrison, J.H., Davidson, D., Hunt, C., Mahanna, W.C., and Shinners, K. 2003. Corn silage management: effects of hybrid, maturity, chop length, and mechanical processing on rate and extent of digestion. J. Dairy Sci. **86**: 3271–3299. Elsevier. doi:10.3168/jds.S0022-0302(03)73930-7.

Joy, F., Górka, P., McKinnon, J.J., Hendrick, S., Burciaga-Robles, L.O., and Penner, G.B. 2016. Evaluation of a phase-feeding strategy utilizing high-lipid high-fibre byproduct pellets in diets for feedlot steers. Can. J. Anim. Sci. **96**: 232–242. doi:10.1139/cjas-2015-0152.

Joy, M.T., DePeters, E.J., Fadel, J.G., and Zinn, R.A. 1997. Effects of corn processing on the site

and extent of digestion in lactating cows. J. Dairy Sci. **80**: 2087–2097. Elsevier. doi:10.3168/jds.S0022-0302(97)76154-X.

Keith, E.A., Colenbrander, V.F., Perry, T.W., and Bauman, L.F. 1981. Performance of feedlot cattle fed Brown Midrib-Three or normal corn silage with various levels of additional corn grain. J. Anim. Sci. **52**: 8–13. doi:10.2527/jas1981.5218.

Ketelaars, J.J.M.H., and Tolkamp, B.J. 1992. Toward a new theory of feed intake regulation in ruminants 1. Causes of differences in voluntary feed intake: critique of current views. Livest. Prod. Sci. **30**: 269–296. doi:10.1016/0301-6226(92)90039-7.

Khorasani, G.R., Okine, E.K., and Kennelly, J.J. 1996. Forage source alters nutrient supply to the intestine without influencing milk yield. J. Dairy Sci. **79**: 862–872. doi:10.3168/jds.S0022-0302(96)76435-4.

Khorasani, G.R., Okine, E.K., and Kennelly, J.J. 2001. Effects of substituting barley grain with corn on ruminal fermentation characteristics, milk yield, and milk composition of Holstein cows. J. Dairy Sci. **84**: 2760–2769. doi:10.3168/jds.S0022-0302(01)74730-3.

Klassen, J. 2019.March. Feed barley update. [Online] Available: https://www.canadiancattlemen.ca/2019/03/06/feed-barley-update/ [2019 Jul. 25].

Koenig, K.M., and Beauchemin, K.A. 2005. Barley- versus protein-supplemented corn-based diets for feedlot cattle evaluated using the NRC and CNCPS beef models. Can. J. Anim. Sci. **85**: 377–388. doi:10.4141/A04-029.

Koenig, K.M., and Beauchemin, K.A. 2013. Nitrogen metabolism and route of excretion in beef feedlot cattle fed barley-based finishing diets varying in protein concentration and rumen degradability. J. Anim. Sci. **91**: 2310–2320. doi:10.2527/jas.2012-5653.

Koenig, K.M., Beauchemin, K.A., and Rode, L.M. 2003. Effect of grain processing and silage on microbial protein synthesis and nutrient digestibility in beef cattle fed barley-based diets. J. Anim. Sci. **81**: 1057–1067. doi:10.2527/2003.8141057x.

Kononoff, P.J., and Heinrichs, A.J. 2003. The effect of corn silage particle size and cottonseed hulls on cows in early lactation. J. Dairy Sci. **86**: 2438–2451. doi:10.3168/jds.S0022-0302(03)73838-7.

Kononoff, P.J., Heinrichs, A.J., and Lehman, H.A. 2003. The effect of corn silage particle size on eating behavior, chewing activities, and rumen fermentation in lactating dairy cows. J. Dairy Sci. **86**: 3343–3353. doi:10.3168/jds.S0022-0302(03)73937-X.

Kreikemeier, K.K., Stock, R.A., Brink, D.R., and Britton, R.A. 1987. Feeding combinations of dry corn and wheat to finishing lambs and cattle. J. Anim. Sci. **65**: 1647–1654. doi:10.2527/jas1987.6561647x.

Kung, L. 2000. Silage fermentation and additives. Page *in* Direct-fed Microbial, Enzyme and Forage Additive Compendium, Milker Publishing Co., Minnetonka, MN. [Online] Available: https://www.researchgate.net/publication/267421247 [2019 Nov. 25].

Kung, L., Tung, R.S., and Carmean, B.R. 1992. Rumen fermentation and nutrient digestion in cattle fed diets varying in forage and energy source. Anim. Feed Sci. Technol. **39**: 1–12. doi:10.1016/0377-8401(92)90027-4.

Lardner, H.A., Pearce, L., and Damiran, D. 2017. Evaluation of low heat unit corn hybrids compared to barley for forage yield and quality on the Canadian prairies. Sustain. Agric. Res. **6**: 90. doi:10.5539/sar.v6n1p90.

Loerch, S.C., Gorocica-Buenfil, M., and Wooster, O.H. 2006. Advantages and disadvantages of feeding whole shelled corn. Pages 73–80 *in* Oklahoma State Beff Extension. [Online] Available: http://beefextension.com/proceedings/cattle_grains06/06-10.pdf [2020 Jan. 16].

Lopes, J.C., Shaver, R.D., Hoffman, P.C., Akins, M.S., Bertics, S.J., Gencoglu, H., and Coors, J.G. 2009. Type of corn endosperm influences nutrient digestibility in lactating dairy cows. J. Dairy Sci. **92**: 4541–4548. doi:10.3168/jds.2009-2090.

Major, D.J., Brown, D.M., Bootsma, A., Dupuis, G., Fairey, N.A., Grant, E.A., Green, D.G., Hamilton, R.I., Langille, J., Sonmor, L.G., Smeltzer, G.C., and White, R.P. 1983. An evaluation of the corn heat unity system for the short season growing regions across Canada. Can. J. Plant Sci. **63**: 121–130. doi:10.4141/cjps83-012.

Mathison, G.W. 1996. Effects of processing on the utilization of grain by cattle. Anim. Feed Sci. Technol. **58**: 113–125. doi:10.1016/0377-8401(95)00878-0.

May, M.L., DeClerck, J.C., Quinn, M.J., DiLorenzo, N., Leibovich, J., Smith, D.R., Hales, K.E., and Galyean, M.L. 2010. Corn or sorghum wet distillers grains with solubles in combination with steam-flaked corn: Feedlot cattle performance, carcass characteristics, and apparent total tract digestibility. J. Anim. Sci. **88**: 2433–2444. doi:10.2527/jas.2009-2487.

McAllister, T.A., and Cheng, K.J. 1996. Microbial strategies in the ruminal digestion of cereal grains. Anim. Feed Sci. Technol. **62**: 29–36. doi:10.1016/S0377-8401(96)01003-6.

McAllister, T.A., and Sultana, H. 2011. Effects of micronization on the in situ and in vitro digestion of cereal grains. Asian-Australasian J. Anim. Sci. **24**: 929–939. doi:10.5713/ajas.2011.10387.

McCartney, D., Fraser, J., and Ohama, A. 2008. Annual cool season crops for grazing by beef cattle. A Canadian review. Can. J. Anim. Sci. **88**: 517–533. doi:10.4141/CJAS08052.

McMillan, S., Penner, G.B., McKinnon, J.J., Larson, K., Añez-Osuna, F., Damiran, D., and Lardner, H.A. (Bart. 2018. Use of extensive winter feeding systems for backgrounding beef calves and the effect on finishing. Prof. Anim. Sci. **34**: 19–31. doi:10.15232/pas.2017-01614.

Mertens, D.R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. **80**: 1463–1481. Elsevier. doi:10.3168/jds.S0022-0302(97)76075-2.

Mickan, F. 2018. Guide to dry matter testing of silage. [Online] Available: https://www.afia.org.au/index.php/resources/silage-fact-sheets/making-quality-silage/142-guide-to-the-dry-matter-testing-of-silage [2020 Jan. 15].

Miorin, R.L., Holtshausen, L., Baron, V., and Beauchemin, K.A. 2018. In situ rumen degradation of kernels from short-season corn silage hybrids as affected by processing. Transl. Anim. Sci. **2**: 428–438. doi:10.1093/tas/txy084.

Mowat, D.N., and Slumskie, R.A. 1971. Barley silage, ground whole plant barley and corn silage for finishing beef cattle. Can. J. Anim. Sci. **51**: 201–207. doi:10.4141/cjas71-027.

Muck, R.E., Nadeau, E.M.G., McAllister, T.A., Contreras-Govea, F.E., Santos, M.C., and Kung, L. 2018. Silage review: recent advances and future uses of silage additives. J. Dairy Sci. **101**: 3980–4000. doi:10.3168/jds.2017-13839.

Murphy, M., Åkerlind, M., and Holtenius, K. 2000. Rumen fermentation in lactating cows selected for milk fat content fed two forage to concentrate ratios with hay or silage. J. Dairy Sci. **83**: 756–764. American Dairy Science Association. doi:10.3168/jds.S0022-0302(00)74938-1.

Mustafa, A.F., Christensen, D.A., and McKinnon, J.J. 2000. Effects of pea, barley, and alfalfa silage on ruminal nutrient degradability and performance of dairy cows. J. Dairy Sci. **83**: 2859–2865. doi:10.3168/jds.S0022-0302(00)75186-1.

Mustafa, A.F., McKinnon, J.J., Christensen, D.A., and He, T. 2002. Effects of micronization of

flaxseed on nutrient disappearance in the gastrointestinal tract of steers. Anim. Feed Sci. Technol. **95**: 123–132. doi:10.1016/S0377-8401(01)00337-6.

Nair, J., Christensen, D., Yu, P., Beattie, A.D., McAllister, T., Damiran, D., Preston, N., Fuhr, L., and McKinnon, J.J. 2016. A nutritional evaluation of common barley varieties grown for silage by beef and dairy producers in western Canada. Can. J. Anim. Sci. **96**: 598–608. doi:10.1139/cjas-2016-0032.

Nair, J., Christensen, D., Yu, P., McAllister, T., Preston, N., Damiran, D., and McKinnon, J.J. 2017. Effect of variety and level of inclusion of barley varieties for silage selected to vary in neutral detergent fiber digestibility on performance and carcass characteristics of growing and finishing beef steers. Can. J. Anim. Sci. **97**: 383–394. doi:10.1139/cjas-2016-0109.

National Acadamies of Science Engineering and Medicine (NASEM) 2016. Nutrient Requirements of Beef Cattle, 8th Revised Edition. National Academies Press, Washington, D.C. doi:10.17226/19014.

National Research Council 2001. Nutrient Requirements of Dairy Cattle. Nutrient Requirements of Dairy Cattle, 7th Revise. National Academies Press, Washington, D.C. doi:10.17226/9825.

O'Donovan, J.T., Turkington, T.K., Edney, M.J., Clayton, G.W., McKenzie, R.H., Juskiw, P.E., Lafond, G.P., Grant, C.A., Brandt, S., Harker, K.N., Johnson, E.N., and May, W.E. 2011. Seeding rate, nitrogen rate, and cultivar effects on malting barley production. Agron. J. **103**: 709–716. doi:10.2134/agronj2010.0490.

Oba, M., and Allen, M.S. 2003. Effects of corn grain conservation method on feeding behavior and productivity of lactating dairy cows at two dietary starch concentrations. J. Dairy Sci. **86**: 174–183. doi:10.3168/jds.S0022-0302(03)73598-X.

Odle, J., and Schaefer, D.M. 1987. Influence of rumen ammonia concentration on the rumen degradation rates of barley and maize. Br. J. Nutr. **57**: 127–138. doi:10.1079/bjn19870016.

Ørskov, E.R. 1986. Starch digestion and utilization in ruminants. J Anim Sci **63**: 1624–1633. doi:10.2527/jas1986.6351624x.

Ørskov, E.R., and Mcdonald, I. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci. **92**: 499–503. doi:10.1017/S0021859600063048.

Oude Elferink, S.J.W.H., Driehuis, F., Gottschal, J.C., and Spoelstra, S.F. 2000. Silage fermentation processes and their manipulation. FAO Plant Production and Protection Papers.

Owens, F.N., Secrist, D.S., Hill, W.J., and Gill, D.R. 1997. The effect of grain source and grain processing on performance of feedlot cattle: a review. J. Anim. Sci. **75**: 868–879. doi:10.2527/1997.753868x.

Pelletier, N., Pirog, R., and Rasmussen, R. 2010. Comparative life cycle environmental impacts of three beef production strategies in the upper midwestern United States. Agric. Syst. **103**: 380–389. doi:10.1016/j.agsy.2010.03.009.

Penner, G.B., Aschenbach, J.R., and Gäbel, G. 2009. Technical note: Evaluation of a continuous ruminal pH measurement system for use in noncannulated small ruminants. Artic. J. Anim. Sci. **87**: 2363–2366. doi:10.2527/jas.2008-1665.

Penner, G.B., Beauchemin, K.A., and Mutsvangwa, T. 2006. An evaluation of the accuracy and precision of a stand-alone submersible continuous ruminal pH measurement system. J. Dairy Sci. **89**: 2132–2140. doi:10.3168/jds.S0022-0302(06)72284-6.

Penner, G.B., Beauchemin, K.A., and Mutsvangwa, T. 2007. Severity of ruminai acidosis in

primiparous holstein cows during the periparturient period. J. Dairy Sci. **90**: 365–375. doi:10.3168/jds.S0022-0302(07)72638-3.

Plascencia, A., and Zinn, R.A. 1996. Influence of flake density on the feeding value of steam-processed corn in diets for lactating cows. J. Anim. Sci. **74**: 310–316. doi:10.2527/1996.742310x.

Vander Pol, K.J., Luebbe, M.K., Crawford, G.I., Erickson, G.E., and Klopfenstein, T.J. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. J. Anim. Sci. **87**: 639–652. doi:10.2527/jas.2008-1036.

Randby, T., Nadeau, E., Karlsson, L., and Johansen, A. 2019. Effect of maturity stage at harvest and kernel processing of whole crop wheat silage on digestibility by dairy cows. Anim. Feed Sci. Technol. **253**: 141–152. doi:10.1016/j.anifeedsci.2019.04.016.

Rosser, C.L., Górka, P., Beattie, A.D., Block, H.C., McKinnon, J.J., Lardner, H.A., and Penner, G.B. 2013. Effect of maturity at harvest on yield, chemical composition, and in situ degradability for annual cereals used for swath grazing. J. Anim. Sci. **91**: 3815–3826. doi:10.2527/jas.2012-5677.

Sadri, H., Ghorbani, G.R., Alikhani, M., Babaei, M., and Nikkhah, A. 2007. Ground, dry-rolled and steam-processed barley grain for midlactation Holstein cows. Anim. Feed Sci. Technol. **138**: 195–204. doi:10.1016/j.anifeedsci.2007.06.025.

Safaei, K., Ghorbani, G.R., Alikhani, M., Sadeghi-Sefidmazgi, A., and Yang, W.Z. 2017. Response of lactating dairy cows to degree of steam-flaked barley grain in low-forage diets. J. Anim. Physiol. Anim. Nutr. (Berl). **101**: e87–e97. doi:10.1111/jpn.12565.

Safaei, K., and Yang, W. 2017. Effects of grain processing with focus on grinding and steam-flaking on dairy cow performance. Pages 117–131 *in* Herbivores. Vonnie D. C. Shields InTechOpen. doi:10.5772/67344.

SaskBarley Development Commission 2018. Alberta barley feed guide. [Online] Available: http://saskbarleycommission.com/priorities/communications [2020 Jan. 14].

Saunders, C.S., Yang, S.Y., Eun, J.-S., Feuz, D.M., and ZoBell, D.R. 2015. Feeding a brown midrib corn silage-based diet to growing beef steers improves growth performance and economic returns. Can. J. Anim. Sci. **95**: 625–631. doi:10.4141/cjas-2015-057.

Schroeder, J.W. 2013. Silage fermentation and preservation. revised edition. NDSU Ext. Serv. **1254**: 1–8.

Van Soest, P.J., Robertson, J.B., and Lewis, B.A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. **74**: 3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2.

Soita, H.W., Christensen, D.A., and McKinnon, J.J. 2000. Influence of particle size on the effectiveness of the fiber in barley silage. J. Dairy Sci. **83**: 2295–2300. doi:10.3168/jds.S0022-0302(00)75116-2.

Statistics Canada 2019.April. Estimated areas, yield, production, average farm price and total farm value of principal field crops, in metric and imperial units. [Online] Available: https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210035901 [2019 Jun. 28].

Steiner, E., Gastl, M., and Becker, T. 2011. Protein changes during malting and brewing with focus on haze and foam formation: A review. Eur. Food Res. Technol. **232**: 191–204. doi:10.1007/s00217-010-1412-6.

Stock, R.A., Brink, D.R., Brandt, R.T., Merrill, J.K., and Smith, K.K. 1987. Feeding combinations of high moisture corn and dry corn to finishing cattle. J. Anim. Sci. **65**: 282–

289. doi:10.2527/jas1987.651282x.

Sutherland, B.D., Johnson, J.A., McKinnon, J.J., McAllister, T.A., and Penner, G.B. 2020. Effects of barley and corn as sources of silage and grain on growth performance and apparent nutrient digestibility. Can. J. Anim. Sci **In review**.

Takeda, Y., Takeda, C., Mizukami, H., and Hanashiro, I. 1999. Structures of large, medium and small starch granules of barley grain. Carbohydr. Polym. **38**: 109–114. doi:10.1016/S0144-8617(98)00105-2.

Taylor, C.C., and Allen, M.S. 2005. Corn grain endosperm type and brown midrib 3 corn silage: site of digestion and ruminal digestion kinetics in lactating cows. J. Dairy Sci. **88**: 1413–1424. doi:10.3168/jds.S0022-0302(05)72809-5.

Theurer, C.B. 1986. Grain processing effects on starch utilization by ruminants. J. Anim. Sci. **63**: 1649–1662. doi:10.2527/jas1986.6351649x.

Tothi, R., Lund, P., Weisbjerg, M.R., and Hvelplund, T. 2003. Effect of expander processing on fractional rate of maize and barley starch degradation in the rumen of dairy cows estimated using rumen evacuation and in situ techniques. Anim. Feed Sci. Technol. **104**: 71–94. doi:10.1016/S0377-8401(02)00292-4.

Wang, Y., Greer, D., and McAllister, T.A. 2003. Effects of moisture, roller setting, and saponin-based surfactant on barley processing, ruminal degradation of barley, and growth performance by feedlot steers1. J. Anim. Sci. **81**: 2145–2154. doi:10.2527/2003.8192145x.

Ward, R.T., and de Ondarza, M.B. 2008. Effect of month of sample submittal on corn silage nutrient fractions, starch availability, NDF digestibility, and fermentation profiles measured at commercial forage-testing laboratory. J. Dairy Sci. **91**: 1–30. [Online] Available: https://www.foragelab.com/Media/ADSA-Corn-Silage-Poster-July-2008.pdf.

Wardynski, F.A., Rust, S.R., and Yokoyama, M.T. 1993. Effect of microbial inoculation of high-moisture corn on fermentation characteristics, aerobic stability, and cattle performance. J. Anim. Sci. **71**: 2246–2252. doi:10.2527/1993.7182246x.

Webster, F., and Wood, P. 2011. Oats: Chemistry and Technology. 2nd editio. AACC International. [Online] Available: https://books.google.ca/books?hl=en&lr=&id=HhIvDAAAQBAJ&oi=fnd&pg=PA1&dq=feed+oat+production+usda&ots=B4Zgp9SCwx&sig=GF3bpemNOzrL41A2LkR_OYmLwqg#v=onepage&q=feed oat production usda&f=false [2020 Jan. 15].

Weiss, C.P., Gentry, W.W., Meredith, C.M., Meyer, B.E., Cole, N.A., Tedeschi, L.O., McCollum, F.T., and Jennings, J.S. 2017. Effects of roughage inclusion and particle size on digestion and ruminal fermentation characteristics of beef steers. J. Anim. Sci. **95**: 1707–1714. doi:10.2527/jas2016.1330.

Wiersma, D.W., Carter, P.R., Albrecht, K.A., and Coors, J.G. 1993. Kernel milkline stage and corn forage yield, quality, and dry matter content. Jounal Prod. Agric. **6**: 94. doi:10.2134/jpa1993.0094.

Yang, W.Z., and Beauchemin, K.A. 2006. Effects of physically effective fiber on chewing activity and ruminal pH of dairy cows fed diets based on barley silage. J. Dairy Sci. **89**: 217–228. doi:10.3168/jds.S0022-0302(06)72086-0.

Yang, W.Z., Beauchemin, K.A., and Rode, L.M. 2001a. Barley processing, forage:concentrate, and forage length effects on chewing and digesta passage in lactating cows. J. Dairy Sci. **84**: 2709–2720. doi:10.3168/jds.S0022-0302(01)74725-X.

Yang, W.Z., Beauchemin, K.A., and Rode, L.M. 2001b. Effects of grain processing, forage to concentrate ratio, and forage particle size on rumen pH and digestion by dairy cows. J.

Dairy Sci. **84**: 2203–2216. doi:10.3168/jds.S0022-0302(01)74667-X.

Yu, P., Huber, J.T., Santos, F.A.P., Simas, J.M., and Theurer, C.B. 1998. Effects of ground, steam-flaked, and steam-rolled corn grains on performance of lactating cows. J. Dairy Sci. **81**: 777–783. doi:10.3168/jds.S0022-0302(98)75634-6.

Zinn, R.A. 1993. Influence of processing on the feeding value of oats for feedlot cattle. J. Anim. Sci. **71**: 2303–2309. doi:10.2527/1993.7192303x.

Zinn, R.A., Alvarez, E.G., Montaño, M.F., Plascencia, A., and Ramirez, J.E. 1998. Influence of tempering on the feeding value of rolled corn in finishing diets for feedlot cattle. J Anim Sci **76**: 2239–2246. doi:10.2527/1998.7692239x.

Zinn, R.A., and Barajas, R. 1997. Influence of flake density on the comparative feeding value of a barley-corn blend for feedlot cattle. J. Anim. Sci. **75**: 904–909. doi:10.2527/1997.754904x.

Zinn, R.A., Owens, F.N., and Ware, R.A. 2002. Flaking corn: processing mechanics, quality standards, and impacts on energy availability and performance of feedlot cattle. J. Anim. Sci. **80**: 1145–1156.

Zinn, R.A., and Shen, Y. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. J Anim Sci **76**: 1280–1289. doi:10.2527/1998.7651280x.