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Effects of feeding a high-fiber byproduct feedstuff as a substitute for barley grain in the diets of dairy cows in early lactation

by

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DEDICATION

This thesis is dedicated to my family and my friends for their love and support.

ABSTRACT

The objective of this study was to evaluate effects of using wheat dried distillers' grains with solubles (DDGS) to replace barley grain in the diet on dry matter intake (DMI), milk production and rumen fermentation of early lactation dairy cows. Sixty-one Holstein cows including thirteen ruminally-cannulated cows were fed diets containing either barley grain or wheat DDGS at 17% of dietary dry matter for 12 weeks after calving. The hypothesis was that reducing dietary starch content by using DDGS would increase rumen pH, DMI, and milk production of early lactation cows. However, cows fed DDGS did not have higher rumen pH, DMI, or milk production, and tended to have higher plasma non-esterified fatty acid concentration. Wheat DDGS can be used as a partial substitute for grain in the diets of early lactation cows without affecting milk production, but it may be associated with the risk of exacerbating their energy balance.

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LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BCS body condition score

BW body weight

CON control

CP crude protein

DDGS dried distillers grains with solubles

DM dry matter

DMI dry matter intake

ECM energy corrected milk

LDA left displacement of abomasum

MP mutliparous

MUN milk urea nitrogen

NEB negative energy balance

NDF neutral detergent fiber

NFC non fiber carbohydrate

NE_L net energy for lactation

NE_m net energy for maintenance

OM organic matter

PEF physically effective factor

PP primiparous

PSPS Penn State Particle Separator

TCT total chewing time

TDN Total digestible nutrients

TG triglyceride

TMR total mixed ration

SARA subacute rumen acidosis

SEM standard error of the mean

SH Soybean hulls

Literature review

1.1 Introduction

During the first 3 weeks after calving, cows experience a lot of stress caused by delivery and milk production, which lead to metabolic disorders and reproductive inefficiency (Drackley, 1999; Grummer, 1993). During this period, most researchers agree that the negative energy balance (NEB) is the major cause of health disorders (Wall et al., 2007). With the start of milk production, the demand of energy for milk production increases; however the energy supplied to the cows from feedstuffs cannot meet the requirement, which will lead to a sharp reduction in body weight (BW) and suboptimal milk production.

Energy intake of dairy cows is determined by dry matter intake (DMI) and the energy density of the diet. Researchers try to feed high concentrate diets such as high fat and high starch diets to increase energy intake. Diets containing highly fermentable carbohydrate likely put cows at high risk to acidosis (Nocek, 1997). Rumen acidosis may have negative effects on DMI, which affects the efficiency of milk production, reduces milk fat, and even causes diarrhea and poor body condition (Nocek, 1997). Therefore, the challenge in nutritional management for cows in early lactation is to maximize energy intake while avoiding the incidence of acidosis.

The objective of this study was to evaluate the effects of replacing barley grain with wheat dried distillers' grains with solubles (DDGS) to increase energy intake and minimize the incidence of rumen acidosis in early-lactating dairy cows. This review focuses on the challenges of early lactation cows and how NEB and rumen acidosis affect the performance of dairy cows. The effects of feeding high fiber byproducts will be also discussed in this review.

1.2 Nutritional management of early lactating cows

1.2.1 Physiological challenges of early lactation cows

The transition period is defined as the period between late pregnancy and early lactation (Drackley, 1999), which is considered the most important stage of the lactation cycle. The transition period is the last 3 wk before parturition and 3 wk after parturition (Grummer, 1995). It is a critical period for dairy cows because most severe nutritional imbalances occur during this period, affecting health, production, and profitability of dairy cows (Grummer, 1995). Most infectious diseases such as mastitis and some metabolic disorders such as fatty liver, ketosis (Drackley, 1999; Grummer, 1993), ruminal acidosis (Owens et al., 1998), milk fever and displaced abomasum occur after calving. The activity of the immune system is depressed during the week before and the week after calving (Kehrli, 1989), and the immunosuppression during the periparturient period increases susceptibility to mastitis (Mallard, 1998).

During the dry period, the energy requirement of cows is low, so they are fed low energy diets containing high neutral detergent fiber. There are also some physiological changes in ruminal epithelial cells during the transition period. The papillae are short in dry cows fed low energy, high fiber diets. Therefore, the absorptive capacity of the ruminal mucosa is depressed and almost 50% of the absorptive area may be lost during the first 7 wk of the dry period (Dirksen, et al., 1985). High energy diets containing a lot of grains are fed to the cows immediately after calving to meet their increasing energy requirement for milk production. After calving, when cows switch from a low energy diet to a high starch diet, cows are very susceptible to rumen acidosis. When cows are fed a high starch diet, rumen pH decreases with a significant increase of lactate and VFA production in the rumen. The protozoa and many bacteria are killed or become inactive at low rumen pH. Rumen acidosis is defined as rumen pH lower than 5.8 (Nocek, 1997), and it affects milk production and health performance.

Displacement of abomasum is a common problem for early lactation cows. This disorder occurs during the late stage of gestation or within 2 wk postpartum (Moore et al., 1954). The growing uterus of pregnant cows occupies the abdominal space gradually, and the abomasum is forced to move forward and slightly to the left side of the cow, and the pylorus continues to extend across the abdomen to the right side of the cow (Habel, 1981). After calving, the uterus and abomasum return to their original position. The left displacement of abomasum (LDA) occurs when the abomasum is enlarged with fluid or gas, and it cannot move from the left side back to the original position (Habel, 1981). Cows with LDA were nearly as twice as likely to have another disease than cows without LDA (Detilleux et al., 1997). Cows with LDA have lower milk production (Detilleux et al., 1997; Raizman and Santos, 2002) and a higher culling rate

(Geishauser et al., 1998; Gröhn et al., 1998; Raizman and Santos, 2002). Also the loss from treatment costs, decreased milk production, and greater culling rate make LDA an economical problem for dairy producers. The success of this period is essential to improve milk production and health status of dairy cows. Therefore, the nutritional management of early lactation is important and has significant economic implication.

1.2.2 Negative energy balance

1.2.2.1 Causes for negative energy balance

Energy balance is the difference between the energy that a cow gains from feedstuffs and the energy the cow uses for milk production, growth, reproduction and maintenance (Forbes, 1983). When the energy expenditure is greater than the energy obtained from diet, it is called NEB. Cows in this state may reduce energy expenditure or use body fat as a source of energy to make up for NEB. Cows undergoing NEB often show reductions in milk production and body weight (BW) or body condition score (BCS), which lead to economic concerns.

Nutritional demand increases with the fast growth of the fetus and uterus during pregnancy. However, intake is often reduced by the diet or physiological changes that induce parturition or by parturition itself (Ingvarsten and Andersen, 2000). After calving, nutrient requirements suddenly increase with the initiation of milk production. At the same time, hypertrophy of visceral tissues increases nutrient demand of animals (Bell, 1995). Bell (1995) showed that the actual intake of NE_L and metabolizable protein at 4 d postpartum are 26% and 25%

lower than the requirements of dairy cows, respectively. The utilization of NE_L and metabolizable protein by the mammary gland for milk production is 97 and 83% of feed intake, leaving only 3% and 17% for maintenance and other needs (Bell, 1995). Cows most likely use own body reserves to make up for the insufficient energy supply, which results in BW and BCS reductions.

1.2.2.2 Impacts on animal health

Most of the metabolic disorders such as milk fever, ketosis, retained placenta, and LDA occur within the first 2 wk of lactation (Drackly, 1999; Grummer, 1993; Wall et al., 2007, Jordan and Fourdraine, 1993). The NEB coupled with other stressors associated with parturition likely causes high incidence of these health disorders. Some of those metabolic disorders are not clinically apparent, but they can be traced back to the NEB in early lactation (Goff, 1997). The NEB makes cows transfer their own energy like body fat to produce milk, leading to poor health and fertility and eventually to involuntary culling (Wall et al., 2007). Jordan and Fourdraine (1993) conducted a survey of 61 high producing dairy herds in the United States in 1991, and they reported that the average incidence rates of milk fever, displaced abomasums, ketosis and retained fetal membranes were 7.2%, 3.3%, 3.7%, 9%, and 12.8%, respectively. The incidence ranges of parturient paresis, displaced abomasum, and ketosis were 0 to 44.1 %, 0 to 14%), and 0 to 20%, respectively. The mean incidence rates of these disorders may not appear to be high, but the range of the incidences is quite wide. Therefore, metabolic disorders caused by NEB require a lot of attention.

Lipid metabolism is a key area of biology and it is important in early lactation cows. Cows undergoing NEB in early lactation mobilize body fat from adipose tissue and deposit it in the liver (Roberts et al., 1981). Excessive lipid mobilization from adipose tissue leads to greater incidence of periparturient health problems. The appearance of ketone bodies in blood, milk, and urine is the sign for diagnosis of ketosis and usually becomes clinically evident from 10 d to 3 wk after calving (Grummer, 1995).

Dairy cows in the transition period experience many metabolic changes. Plasma insulin concentration decreases and plasma growth hormone concentration increases suddenly at parturition (Kunz et al., 1985). Plasma glucose concentration remains stable or increases slightly during the prepartum transition period, but increases dramatically at calving and then decreases immediately (Kunz et al., 1985; Vazquez-Anon et al., 1994). Plasma NEFA concentration decreases gradually before calving, however, it increases suddenly after calving (Grummer, 1993). The liver plays an important role in fatty acid removal from blood (Bell, 1980). When lipid mobilization increases, uptake of NEFA by the liver also increases which results in greater triglyceride (TG) accumulation in the liver. When TG synthesis exceeds the rate of TG disappearance, it leads to hepatic lipidosis or fatty liver (Herdt, 1988). Increasing lipid accumulation and decreasing glycogen in the liver are associated with an increased susceptibility to ketosis (Drackley et al., 1992).

Cows are likely to have fatty liver the day after parturition (Grummer, 1993) and cows with fatty liver are at a high risk of ketosis (Veenhuizen et al., 1991). The concentration of plasma ketones reflects hepatic triglyceride concentration and it increases during the postpartum transition period. Liver triglyceride-to-glycogen ratio at parturition may be an indicator of susceptibility of cows to ketosis (Veenhuizen et al., 1991). More than 60 years ago, fatty liver was found in ketotic cows (Saarinen and Shaw, 1950). Cows with subclinical ketosis had eight fold greater risks to experience displaced abomasum (LeBlanc et al., 2005). As the displaced abomasum is related to ruminal fill, DMI is an important factor to determine the risk of displaced abomasum. Dyk et al. (1995) found a greater incidence of ketosis, displaced abomasum, and retained placenta for animals with a higher concentration of NEFA during the last 7 d before calving. Stressors increase the release of NEFA from adipose tissue, and it is recommended to minimize the stress by the appropriate management of transition cows. In addition, milk fever occurs at or just after parturition (Horst et al., 1997), so the metabolic change is a big threat to high producing dairy cows.

Clinical mastitis, especially coliform mastitis, is most likely to occur during the first month of lactation and results from infection established during the dry period or early lactation (Erskine et al., 1988; Smith, 1985). When cows are fed a diet high in ruminally available carbohydrates to increase energy intake, more VFA are produced, but papillae and mucosa in the rumen have limited capacity for absorption of these metabolites; therefore rumen pH decreases. As rumen pH decreases, histamine and other endotoxins are released into the blood, and affect the microvasculature of the growing hoof wall, which will lead to vasodilation and ultimately damages the network of blood vessels in the hoof (Radostits et al., 1994). Claw tissue is disrupted, which increases the incidence of other type of lameness problems such as sole ulcers and heel erosion. The pain caused by laminitis might make the NEB even worse because the discomfort caused by laminitis may make cows spend more time lying down instead of eating. Several studies reported associations between NEB and lameness. Boettcher et al. (1998) evaluated clinical lameness in 24 herds in Minnesota, Wisconsin, and Virginia, and reported that lameness was most common during the first 50 d of lactation. Manson and Leaver (1989) and Wells et al. (1993) reported that the cows are more likely to experience lameness as their BCS decreases. The reduction in BCS means that body reserves are used by the cows to meet the energy requirement. Results reported by Treacher et al. (1986) suggested that significantly more cases of disease (mastitis, retained placenta, ketosis, milk fever, and lameness) occur after calving in cows with inadequate feed intake in early lactation. It is important to minimize transition stresses and maximize energy intake during the early lactation period, which will reduce fatty acid mobilization from adipose, and prevent excessive depletion of hepatic glycogen (Grummer, 1995).

1.2.2.3 Impact on milk production

It is more likely cows decrease milk production when they suffer from NEB. (NRC, 2001). Health disorders caused by NEB during the transition period decreases milk production. For example, Rajala-Schultz et al. (1999) found that cows with ketosis decreased milk yield by 25% or greater

1.2.3 Strategies to maximize energy intake in early lactation

1.2.3.1 Feed high starch diet

During the transition period, cows experiencing NEB exhibit a series of homeorhetic responses such as mobilization of energy from muscle and adipose tissue (Chibisa et al., 2008) to support lactation (Bauman and Currie, 1980). Maximizing energy intake is important to maintain the health and welfare of cows. Some studies evaluated the effects of the prepartum diet on postpartum performance (Dann et al., 1999; Rabelo et al., 2003). Grummer and Carroll (1988) mentioned that greater energy intake is essential to minimize NEB and the related metabolic disorders. Increasing energy intake is normally done by increasing dry matter intake (DMI) or energy density of diet. As the gut fill of animals limits DMI, increasing dietary energy density is the most important strategy to maximize energy intake.

Starch is a good dietary energy source to increase energy intake of cows in early lactation. Carbohydrates fermented in the rumen increase microbial protein yield (Nocek and Tamminga, 1991), but excess carbohydrate fermentation may decrease DMI and subsequent performance of early lactation cows. Milk yield, fat-corrected milk (FCM) and DMI have been improved with diets that replaced sources of rapidly available carbohydrates with more slowly available carbohydrate sources (Nocek and Tamminga, 1991). However, Oba and Allen (2003) showed that high-starch diets increase DMI compared with low-starch diets (21.7 vs. 19.7 kg/d). Cows had duodenal infusions of starch increased milk yield and 4% Fat corrected milk but decreased milk fat concentration and yield compared with the control cows, but there were no differences in BW or DMI (Reynolds et al., 2001). In another study, DMI decreased, but milk and milk lactose yields tended to increase when partially hydrolyzed starch was infused into the rumen or abomasum at 1,500 g/d (Knowlton et al., 1998). Feeding diets containing high starch or infusing starch did not show consistent effects on DMI and milk yield. Therefore, feeding high starch diets may not necessarily supply more energy to dairy cows in early lactation.

1.2.3.2 Feed high fat diet

Feeding supplemental fat is a common approach to increase energy density of diets and energy intake of dairy cattle (Coppock and Wilks, 1991; Palmquist and Jenkins, 1980). However, dietary fat supplementation often affects DMI (NRC, 2001). Numerous trials have indicated that diets supplemented with fat increase milk yield slightly or decrease BW loss during the first 5 wk postpartum (Chilliard, 1993; Grummer, 1995; Hoffman etal., 1991; Jerred et al., 1990; Ruegsegger and Schultz, 1985; Schingoethe and Casper, 1991). Cows respond best to fat supplementation approximately at the time they reach positive energy balance (Grummer and Carroll, 1991). Seymour et al. (1994) found that a diet containing 5.5% dietary fat was optimal for cows in d 1 to 49 of lactation and a diet containing 7% dietary fat was best during d 50 to 100 of lactation. Some studies showed that milk yield increased with increased dietary fat concentration. Knapp et al. (1991) used a diet containing whole roasted soybeans and reported that dietary fat concentration increased from 2.8 to 6.8% and the milk yield of cows in early lactation increased. Kronfeld (1982) found that feeding fat as an energy supplement would reduce fatty acid mobilization from adipose tissue, and may decrease the incidence of ketosis. However, Chilliard (1993) indicated that feeding supplemental fat did not reduce the loss of BW or BCS during early lactation. High fat diets may increase NEFA release from adipose tissue, so plasma NEFA concentrations increased when supplemental fat was fed (Van Knegsel et al., 2007). This may be due to increased basal lipolysis, decreased re-esterification of fatty acids, or both (Grummer and Carroll, 1991). Sometimes, DMI decreased when cows were fed high fat diets, offsetting the advantage of increased energy density of high-fat diets (Seymour et al., 1994). Previous research clearly indicates that feeding supplemental fat does not necessarily increase energy intake during the postpartum transition period.

1.2.3.3 Strategies to increase dry matter intake

Dietary factors such as the concentrations of starch, fat and physically effective fiber have a strong effect on DMI of lactating cows. Energy intake is determined by DMI and net energy content of the diet. The interaction of diet characteristics, physiological state of animals, and environmental stressors affect feed intake of dairy cows (Allen, 2000)

Chemical composition of the diet is a factor affecting DMI. Dietary NDF content is highly related to DMI (Van Soest, 1965), and it can be used as a predictor of DMI for dairy cows (Waldo, 1986). When NDF content exceeds 25%, DMI decreases as dietary NDF increases (Allen, 2000). When grain is substituted by forage in diets, DMI of dairy cows often decreases, resulting in a decrease in energy intake.

Particle size of diet also affects DMI. Beauchemin et al. (1994) found an interaction between forage particle length (alfalfa silage chopped at 0.5 or 1.0 cm) and the percentage of forage in the diet (35 or 65%). They found when diet contained long chopped alfalfa silage, DMI of cows was reduced by nearly 3 kg/d. Non-forage fiber sources (NFFS; e.g., linted cottonseeds, soy hulls, and beet pulp) have smaller particle length than forages, but similar NDF content (Allen, 2000). Feeding those non-forage fiber sources may increase DMI of dairy cows.

1.3 Rumen acidosis

Feeding diets high in grain and highly fermentable carbohydrates may increase milk production; however it will also increase the risk of rumen acidosis. Rumen acidosis is associated with a high culling rate and depression of milk production (Nocek, 1997), and it is a concern not only for economic reasons but also for animal welfare.

1.3.1 Types of rumen acidosis

"Rumen acidosis" is the term used for digestive disturbances of the rumen (Owens et al., 1998), and it affects health and productivity of dairy cattle (Nocek, 1997). There are normally two distinct syndromes: acute acidosis and sub acute rumen acidosis (**SARA**) (Owens et al., 1998).

Acute acidosis is defined as low rumen pH associated with clinical signs of illness. Cows are more likely to get acute rumen acidosis when suddenly fed a high grain diet. If the diet contains highly fermentable carbohydrates, it decreases rumen pH dramatically. When rumen pH decreases to 5.2 or less, the production of lactic acid is increased by the lactic acid-producing bacteria (Nocek, 1997; Owens et al., 1998). When pH decreases to 5.0, lactate production becomes the main reason for increased hydrogen ion concentration in the rumen (Owen et al., 1997). A low pH enhances activity of pyruvate hydrogenase and the conversion from pyruvate to lactate (Russell and Hino, 1985). As such, a dramatic drop of ruminal pH is difficult for cows to recover by themselves (Owen et al., 1997).

For SARA, rumen pH ranges from 5.2 to 5.6 (Cooper and Klopfenstein, 1996), and the reduction in rumen pH is primarily caused by production of VFA rather than lactic acid. Sub acute rumen acidosis causes decreased DMI and milk production of dairy cows (Nocek, 1997), but cows with SARA may not appear to be sick (Cooper and Klopfenstein, 1996). It is not easy to detect chronic acidosis or SARA because the clinical symptoms, like decreased DMI, decreased milk production, diarrhea, and poor body condition (Nocek, 1997).

1.3.2 Factors affecting rumen pH

1.3.2.1 Physiology of rumen pH

Rumen pH is determined by the amount of acid produced in the rumen and the amount of acid removed from the rumen. Volatile fatty acids are end-products of organic matter (OM) fermentation (Allen, 1997). Rumen pH decreases when lactic acid concentration increases (Allen, 1997). Ruminal pH between 6.0 and 6.4 is considered as normal rumen pH (Lewis and Emery, 1962). At normal ruminal pH, lactic acid is slowly absorbed from the rumen, but is rapidly metabolized in the rumen to form acetic (61%), propionic (34 %), and butyric (5%) acids (Gill, 1986). Lactic acid plays an important role in determining ruminal pH during adaptation to dietary changes (Allen 1997). Although lactic acid could exert major impacts on ruminal pH, it is normally a minor intermediate in ruminal metabolism (Counotte and Prins, 1981). To maintain normal rumen pH, the hydrogen ions are removed through VFA absorption and passage. When ruminal pH is normal, less VFA exist in the associated form and the fractional rate of absorption is reduced (Ash and Dobson, 1963). Absorption rate varies by the type of VFA. At neutral pH, the absorption rate of acetic, propionic, and butyric acids are similar, but when pH decreases, absorption rates increase at a greater rate compared with that of neutral pH (Danielli et al., 1945; Thorlacius and Lodge, 1973; Weigand, 1972). Ruminal papillae surface area is another factor determining the rate of absorption of VFA from the rumen (Dirksen et al., 1985). The majority of hydrogen ions and VFA are removed by absorption from the rumen. As such, increasing acid neutralization is another way to maintain normal rumen pH (Allen, 1997).

1.3.2.2 **Sorting behavior affecting rumen pH**

Dairy cows usually sort for the palatable part of a diet. De Vries et al. (2007) found that dairy cows prefer consuming shorter particles rather than longer particles when fed a high forage diet. Nocek and Braund (1985) suggested an optimal way to provide well-balanced nutrients is feeding a diet as a homogenous mixture such as a total mixed ration (TMR). However, dairy cattle still sort and consume more palatable feedstuffs when fed a TMR (De Vries et al., 2007). Sorting behavior affects rumen pH. Eating and chewing activities stimulate the secretion of saliva (Maekawa et al., 2002), and the secretion of saliva increases rumen pH and decreases the risk of ruminal acidosis (Krause et al., 2002; Yang et al., 2001). Fermentation acids in the rumen are mainly removed by absorption through the ruminal wall (Ash and Dobson, 1963) or neutralized by salivary buffer (Allen, 1997). Saliva contains bicarbonate and phosphate buffers, which neutralize about 30 to 40% of fermentation acids in the rumen (Allen, 1997). As such, sorting behavior of animals increases the risk of SARA (Stone, 2004).

1.3.2.3 Dietary factors affecting rumen pH

Ruminal pH is affected by particle size of diets. The Penn State Particle Separator (PSPS) is an effective tool to determine the particle size distribution of forages and TMR (Lammers et al., 1996). Particle size is positively related to chewing time (Allen, 1997). The typical rate of acid production from fermentation of OM in the rumen (74,000 meq/d) is nearly twice as fast as the rate of salivary buffer secretion (41,000 meq/d) (Allen, 1997). Previous studies showed that the intake and the dietary concentration of fiber were positively related to total chewing time (TCT) (Allen, 1997). Hence, it is usually accepted that increasing dietary particle size increases chewing time and ruminal pH, potentially reducing the risk of ruminal acidosis (Krause et al., 2002; Yang et al. 2002).

Ruminal pH is affected by dietary NDF and starch concentrations, and ruminal pH decreases when starch concentration increases and dietary NDF concentration decreases (Dado and Allen, 1993). Diets that are high in fermentable carbohydrates are fed to cows in order to maximize milk production; however, high starch diets may decrease ruminal pH because they increase the accumulation of VFA in the rumen. Diets with high starch concentration are sometimes associated with sharp reductions in DMI (NRC 2001), which also increases the incidence of bloat, acidosis, and laminitis.

Providing sufficient physically effective fiber (PEF) in diets to high-producing dairy cows is necessary to prevent SARA (NRC, 2001). The concept of PEF was proposed by Mertens (1997). The PEF reflects the physical characteristics of fiber, chemical NDF content, particle size, the ability to stimulate chewing and saliva secretion, and buffering in the rumen, which is closely related to ruminal pH. The PEF intake is recommended to be at least 20% of the ration DM for lactating dairy cows (NRC, 2001). Greater PEF intake increases ruminal pH by increasing chewing activity, which stimulates salivary secretion and helps minimize the risk of ruminal acidosis in dairy cows (Krause et al., 2002).

1.3.3 Pathophysiology of ruminal acidosis

When cows experience acute rumen acidosis, the rumen does not only have a high concentration of lactic acid, but also has rumenitis, ruminal hyperosmolality, dehydration and systemic damage (Owens et al., 1998; Radostits et al., 1994). Clinical signs of acute rumen acidosis include complete anorexia, abdominal pain, tachycardia, tachypnea, diarrhea, lethargy, and staggering (Radostits et al., 1994). Sub acute rumen acidosis reduces fiber digestion and causes inconsistent feed intake, diarrhea, low milk fat, laminitis, and other health disorders (Nocek, 1997). Ruminal epithelial cells are not protected by mucus, and they are easily damaged by acids in the rumen. Once the epithelia is inflamed, bacteria may occupy the papillae, and get into the systemic circulation causing liver abscesses or colonizing the lungs, heart valves, kidneys or joints (Nocek, 1997).

1.3.4 Economic importance of rumen acidosis

Rumen acidosis is also an economic issue. Gröhn and Bruss (1990) reported that incidence rate of acute acidosis through lactation is 0.3%, but the highest incidence rate is observed during the first 4 weeks after calving. Sub acute rumen acidosis is estimated to cost the U.S. dairy industry between US$ 500 million to 1 billion per year (Donovan, 1997). The economic losses from SARA are also attributed to health problems such as lameness and some reproductive disorders. The cost of poor reproduction and other disorders is not clear, but these costs are expected to be greater than the cost of milk production loss.

Lameness is one of the most important animal welfare issues in the dairy industry today and ruminal acidosis has been recognized as a risk factor for laminitis (Nocek, 1997; NRC, 2001). Lameness is associated with infertility and the depression of milk production, and can be an important cause of premature and involuntary culling in a dairy herd (Krause and Oetzel, 2006).

1.4 Use of high-fiber byproducts as a substitute for grain: nutritional management to prevent rumen acidosis

High-grain diets that are low in dietary NDF concentration usually increase DMI by reducing the filling effect (Allen, 2000) but also reduce chewing. However, increasing the percentage of grain in the diets often negatively affects DMI and milk production, ruminal pH, fiber digestion, and milk fat concentration (Allen, 1997). In general, adding non-forage NDF in place of grains reduces the negative effects of increased starch fermentation from feeding high-grain diets.

1.4.1 Soy hulls

After being graded and cleaned, whole-raw soybean seeds are dried to about 10% moisture for soybean oil extraction. Then, soybean seeds are cracked, and separated into defatted-high-protein meal (SBM) and hulls (Rhee, 2000). Soybean hulls (SH) are the skins taken off from soybean, and normally ground or pelleted. According to NRC (2001), SH contains 11.8% CP, 60.3% NDF, and 44.6% ADF on a DM basis. The starch content ranges from 0 (Hsu et al., 1987) to 9.4% (Batajoo and Shaver, 1998). Soy hulls are considered as good feedstuffs for dairy cows because they are high in energy and digestible fiber. Stone (1996) reported that multiparous cows increased DMI by 2 kg/d when high-moisture corn was replaced with SH at 14% of dietary DM, but there was no treatment effect on DMI of primiparous cows. Ipharraguerre et al. (2002) used SH to replace corn grain incrementally at 0, 10, 20, 30, and 40% of DM in the diets of lactating dairy cows, and found that DMI tended to decrease ($P < 0.06$) linearly with increasing usage of SH. When SH supplied more than 30% of the dietary DM, DMI decreased by 1 kg/d compared with corn (Ipharraguerre et al., 2002). Sarwar et al. (1992) found that using SH as a substitute for corn grain at 19 to 34% in the diets linearly increased milk yield of dairy cows. Nakamura and Owen (1989) used concentrate mixtures containing SH at 0, 50, and 95%, and observed a decrease in milk yield by about 2.5 kg/d and a slight increase in milk fat concentration with increased usage of SH. They speculated that the reduction in milk yield can be attributed to low starch content of the diet. Replacing grains with SH in the diets of dairy cows decreased protein content of milk (Ipharraguerre et al., 2002; Sarwar et al., 1992). The results of using SH were inconsistent, but the price of SH is competitive, so SH are important for dairy producers to minimize feed costs to maximize net income.

1.4.2 Beet pulp

Beet pulp is the residue left after sugar is extracted from sugar beets. Beet pulp contains approximately 40% NDF. The NDF in beet pulp can be digested faster than forage NDF (Bhatti and Firkins, 1995). The responses in DMI are not consistent when dried beet pulp is used as a substitute for corn grain in TMR. Clark and Armentano (1997) showed that beet pulp increased DMI but did not affect milk yield compared with the diet containing corn grain. O'Mara, et al. (1997) used beet pulp as a substitute for corn grain and increased DMI but decreased milk yield. Mansfied et al. (1994) found that using beet pulp in diet instead of soybean meal decreased DMI but had no effect on milk yield. Substituting beet pulp for high-moisture corn grain in a diet dilutes dietary starch and is expected to produce less propionate in the rumen (Voelker and Allen, 2003). Therefore, beet pulp is considered as another option of high fiber feedstuff that can be used as a substitute for grain.

1.4.3 Other feeds

Dried distillers grains plus solubles (DDGS) is another high-fiber byproduct can be used as a feedstuff in diet. It is a by-product of ethanol production and high in crude protein (CP), crude fat, and highly digestible NDF but low in starch content (Widyaratne and Zijstra, 2006). The fat concentration of wheat DDGS ranges from 2.9 (Widyaratne and Zijlstra, 2006) to 9.9% (Penner et al., 2009). The NDF concentration of wheat DDGS ranges from 25.9 (Dong et al., 1987) to 54.1% (McKinnon and Walker, 2008). The CP concentration of wheat DDGS ranges from 34.0 (Emiola et al., 2009) to 45.8% (Gibb et al., 2008). Brewers grain is the byproduct of the beer industry, and is relatively high in digestible fiber (40% NDF) and middle-ranged in CP (23%) contents. Cotton seed is commonly used as a feed for dairy cattle. It is high in fiber (51.5%), fat (15.7%), and protein (24%) (Bertrand et al., 2005).

Dried distillers grains with solubles can be fed up to 20% of DM in the diets of lactating dairy cows. A diet containing DDGS at 20% of DM maintained high milk production without affecting DMI (Anderson et al., 2006; Kleinschmit et al., 2006; Schingoethe et al., 2009). Zhang et al. (2010) found using DDGS to replace 20% of barley grain in the diets maintained DMI and milk yield and tended to increase rumen pH for cows in mid to late lactation. The previous study indicated that DDGS can be used as an alternative feedstuff to increase energy intake for early lactation cows without the risk of rumen acidosis.

1.6 Conclusion

The early lactation period is a big challenge for dairy cows. The NEB affects milk production and animal health. Feeding high energy diets is an approach to decrease the extent of NEB for cows in early lactation. Cows are often fed high starch or high fat diets. High fat diets increase the dietary energy density, but often decrease DMI; thus the total energy intake might not increase. High starch diets increase the dietary energy density, but also increase the incidence of rumen acidosis. DDGS is a high fiber byproduct which is widely used in diets of dairy cows. Because DDGS contains high CP and RUP, it can be used as a protein supplement. However, DDGS also can be used as an energy source and as a partial replacement of grain in diets for dairy cows. One study reported that using DDGS to replace barley grain at 20% of dietary DM maintained DMI and milk yield in mid and late lactation cows (Zhang et al., 2010), but the effects of using DDGS as an alternative energy source in the diets of early lactating dairy cows are not known, and warrant investigation.

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CHAPTER 2 THE EFFECTS OF A FEEDING HIGH-FIBER BYPRODUCT FEEDSTUFF AS A SUBSTITUTE FOR BARLEY GRAIN IN THE DIET ON PRODUCTIVITY OF DAIRY COWS IN EARLY LACTATION

2.1 Introduction:

Early lactation is a critical period for lactating dairy cows because cows experience a variety of metabolic changes and severe negative energy balance (NEB) during this period (Grummer, 1995; NRC, 2001). Their energy requirement increases with the onset of milk production. However, energy intake from feedstuffs cannot meet the requirements of those cows, resulting in NEB (Grummer, 1995). Cows under NEB mobilize their body fat to produce milk, therefore the extent of NEB affects milk production and causes health problems such as ketosis (Grummer, 1995), infertility, which eventually result in involuntary culling (Wall et al., 2007). Therefore, it is important to mitigate the extent of NEB through sound nutritional management during the early lactation period.

One strategy to increase energy intake is increasing the energy density of the diet. Feeding supplemental fat is a common approach to increase energy density of diets, but it negatively affects DMI (NRC, 2001). In the study of Onetti et al. (2001), cows fed a high fat diet had lower DMI compared with cows fed a low fat diet in mid-lactation. The reduction in DMI offsets the advantage of feeding diets high in energy density. Some researchers increased the starch concentration of the diet to increase energy density, and some fed a high sugar diet to dairy cows to increase DMI. Penner and Oba (2009) found that a high sugar diet increased DMI of dairy cows in early lactation compared with a low sugar diet, but the high sugar diet increased adipose tissue mobilization. Based on previous studies, increasing grain and fat concentrations in the diet to increase energy density cannot eliminate problems associated with NEB.

Dried distillers' grains with solubles (DDGS) is a by-product of the ethanol industry. It has high concentrations of digestible NDF and fat (Schingoethe et al., 2009). Dried distillers grains with solubles can be fed up to 20% of DM in diets of lactating dairy cows without negatively affecting DMI and milk production (Anderson et al., 2006; Kleinschmit et al., 2006; Schingoethe et al., 2009). However, Ranathunga et al. (2010) found that DMI decreased when non-forage fiber from DDGS and soy hulls replaced dietary starch from corn. Zhang et al. (2010) found that feeding DDGS to replace barley grain maintained DMI and milk yield. However, there were only 6 cows fed experimental diets for 21 days in mid and late lactation (Zhang et al, 2010). Although many studies evaluated nutritional strategies to increase energy intake, no study evaluated wheat DDGS as a substitute for barley grain in the diet of cows in early lactation. The objective of the study was to evaluate effects of a partial substitution of dietary grain with wheat DDGS on DMI, sorting behavior, plasma metabolites and milk production of early-lactating dairy cows

2.2 Material and Methods

2.2.1 Animals, diets and experimental design

This experiment was conducted from January 2010 to August 2010 at the Dairy Research and Technology Center at the University of Alberta (Edmonton, Alberta, Canada). All procedures were pre-approved by the Animal Care and Use Committee for Livestock at the University of Alberta and conducted according to the guidelines of the Canadian Council of Animal Care (Ottawa, Ontario, Canada).

Two experimental diets were formulated for this study. The control (CON) diet contained 43% barley silage, 17.3% dry-rolled barley grain, and 39.3% concentrate mix on a DM basis while the DDGS diet contained the same ingredients except wheat DDGS replaced dry-rolled barley grain (Table 2.1). Both diets were formulated according to dairy NRC (2001) to meet or exceed the nutritional requirements for early lactating cows (650 kg BW at 25kg/d DMI) producing 45.0 kg of milk/d with 3.50% milk fat and 3.00% milk protein. As wheat DDGS contained more CP and fat compared with barley grain, corn gluten meal, urea, and vegetable oil were used to increase the dietary CP and fat concentrations of the CON diet. Particle size distribution of feed ingredients was determined by using the Penn State Particle Separator (Leonardi and Armentano, 2003). Both diets had similar physical effective fiber (PEF), but DDGS diet had more fine particles collected in the pan (28.0 vs. 10.8%). The DM concentration of barley silage and concentrate mixes were determined weekly and diet formulations were adjusted if necessary.

Sixty-one Holstein cows (22 primiparous (PP) and 39 mutliparous (MP) cows) were blocked by parity and calving date and assigned to one of two experimental diets immediately after calving until 12 wk in lactation. Additional 7 cows had been originally assigned to the treatments, but 6 of them were removed from the experiment due to displaced abomasum. One cow was removed from the study because blood samples could not be collected due to bad temperament. In addition, data from any week when cows had health problems and were treated with antibiotics were removed. Cows were housed individually in tie stalls and allowed to exercise outside for 2 h daily except weekends. All cows were fed experimental diets as TMR and had free access to water. Cows were fed once daily at 105% to 110% of expected intake. Cows were milked in their stalls twice daily at 0400 and 1600 h.

2.2.2 Data and sample collection

Data and samples were collected on Tuesday, Wednesday, and Thursday every week, and the amount of feed offered was recorded daily. Samples of diet ingredients were collected daily during the sample collection periods. At the end of the sample collection period, daily samples were composited to obtain a representative sample for each week. Orts were collected from each cow daily (Wednesday, Thursday and Friday before feeding) and daily samples were composited to obtain a representative sample for each cow each week. The composited orts samples were separated into two parts; one to determine chemical composition and another to determine particle size distribution. The Penn State Particle Separator was used to measure particle size distribution of feed ingredients and orts, and the sorting index was determined for each particle category according to Leonardi and Armentano (2003; Sorting index = Actual DMI / Expected DMI ×100).

Body weight and BCS were measured one week prior to calving. After calving, BW was measured twice per week at 0700 h, after milking but before feeding on Tuesday and Thursday. The average of the two BW measurements was used as the data for each week. Body condition score was determined for each collection period using a five-point scale (1= thin and 5= fat; Wildman, et al., 1982).

Milk yield was recorded daily and milk samples were collected 6 times during the sample collection period consecutively from Tuesday pm to Friday am. The weekly average of daily milk yield was used as the data of each week.

Blood samples were collected from the coccygeal vessels every 18 h over 3 d (Tuesday 1300 h, Wednesday 0700 h, Thursday 0100 h, and Thursday 1900 h) using vacutainer tubes (Fisher Scientific Company; Franklin Lakes, NJ, USA) containing Na heparin. Blood samples were immediately centrifuged at 4 ℃ at 3,000 *g* for 20 min. Four plasma samples collected during the collection period were composited to yield one sample per cow per week, and stored at -20 ℃ until analysis.

2.2.3 Sample analysis

Samples of feed ingredients, orts, and feces were dried in a forced air oven at 55 ℃ for 48 h to determine DM, then samples were ground through a 1-mm screen using a Wiley mill (Thomas-Wiley, Philadelphia, PA). The ground samples were used for chemical analysis. The samples were further dried at 135 ℃ for 2 h to determine analytical DM. Dried samples were oxidized in a muffle furnace for 2 h at 600 ℃ (AOAC, 2002; method 942.05) to determine OM concentration. The CP concentration was determined using Leco (Leco FP-2000 N Analyzer; Leco instrument Inc., St. Joseph, MI, USA. Rhee 2005). The neutral detergent fiber (NDF) concentration was determined using heat stable amylase and sodium sulfite (Van Soest et al., 1991). Starch concentration was measured by the method described by Karkalas (1985). Goldfisch extraction apparatus (Labconco, Kansas City, MO) with petroleum ether was used to measure ether extract concentration. To determine indigestible NDF, samples were placed in nitrogen free polyester bags (5 × 10 cm, pore size = 50 μm; R510, Ankom Technology, Macedon, NY) and incubated in the rumen for 120 h. Indigestible NDF was used as an internal marker to calculate apparent total tract digestibility (Cochran et al., 1986).

Plasma samples were analyzed for glucose, BHBA, (NEFA), and urea N concentrations. Plasma glucose concentration was measured using a glucose oxidase-peroxidase enzyme (No. P7119; Sigma) and dianisidine dihydrochloride (No. F5803; Sigma). Absorbance was determined by a plate reader (SpectraMax 190, Molecular Devices Corp., Sunnyvale, CA). Enzymatic oxidation to acetoacetate with 3-hydroxybutrate dehydrogenase (No. H6501; Roche, Mississauga, Ontario, Canada) was used to measure plasma BHBA concentration. Concentration of NEFA was determined using a commercial kit (NEFA C kit, Wako Pure Chemical Industries Ltd., Richmond, VA) as described by Johnson and Peter (1993). The concentration of plasma urea N was determined according to Fawcett and Scott (1960).

Milk samples were analyzed at the Alberta Central Milk Testing Laboratory (Edmonton, Alberta, Canada) for milk fat, CP, lactose, MUN, and SCC contents (AOAC, 2002).

2.2.4 Statistical analysis

The energy corrected milk (ECM) yield was calculated according to the equation described by Tyrrell and Reid (Tyrrell and Reid, 1965):

ECM = [0.327 × milk yield (kg) + 12.95 × fat yield (kg) + 7.2 × protein yield]

Data were analyzed using the Proc Mixed procedure of SAS (version 9.2, Cary, NC) according to the following model:

$$Y_{ijk} = \mu + T_i + W_j + P_k + TW_{ij} + WP_{jk} + TWP_{ijk} + Cov + e_{ijk},$$

where μ is the overall mean, T_i is the fixed effect of treatment, W_j is the fixed effect of week used as a repeated measure, P_k is the fixed effect of parity, Cov is the BCS prior to calving used as a covariate, e_{ijk} is the residual. Treatment effects were declared significant at $P \leq 0.05$ and tendencies were declared at $0.05 < P \leq 0.10$.

2.3 Results and Discussion

2.3.1 DMI

A treatment by parity interaction was observed for DMI ($P < 0.0001$; Table 2.2). There were no treatment effects on DMI for PP cows; (Figure 2.1). However, MP cows fed barley grain had higher DMI compared with cows fed DDGS in early lactation (Figure 2.2). The PP cows fed either diet had similar rates of DMI increase as MP cows fed the CON diet, which indicated that MP cows fed DDGS showed a slower rate of increasing DMI in early lactation. There are several factors affecting DMI. First of all, DMI generally declined with increasing concentration of dietary NDF (Allen, 2000). The NDF concentrations of both diets were similar (27.2 vs. 30.5, % of DM), so the different concentrations of NDF did not explain the different DMI responses. Particles retained on the screen with 8-mm aperture or greater are considered to be physically effective fiber (PEF) (Lammers et al., 1996). Zebeli et al (2006) indicated that dietary PEF is a good indicator to assess the adequacy of effective fiber in dairy cow rations compared with dietary NDF or forage NDF. In the current study, both diets had similar PEF contribution (44.0 and 44.8, % as fed), so the dietary PEF was not the factor affecting DMI for MP cows.

High fat diets often decrease DMI (NRC 2001). In the study of Onetti et al. (2001), cows fed a high fat diet had lower DMI compared with cows fed a low fat diet in mid-lactation. The diet containing DDGS had higher fat concentration than the control diet (4.38 vs. 3.67%), and the higher fat concentration of the DDGS diet might be a reason why MP cows on the DDGS diet had lower DMI compared with MP cows fed the control diet. However, both experimental diets were formulated as low fat diets (3.7% vs. 4.4%), therefore, the concentration of fat in the diets may not explain why DMI was lower for MP cows fed DDGS. Hoffman et al. (1991) found no difference in DMI for cows fed 0% or 2.8% supplemental fat in early lactation. Also, Schingoethe and Casper (1991) fed diets with two different fat concentrations (2.6% vs. 5.3%) to early lactation cows, and no treatment effect on DMI was observed from week 4 to week 16.

Another possible factor affecting DMI is BCS. Bines et al. (1979) and Bines and Morant (1983) found that fat cows had approximately 23% lower daily intake of hay and concentrate compared with thin cows. Cows fed the DDGS diet had a higher BCS than the CON group (3.68 vs. 3.5) before calving, and this might be a reason for the difference in DMI. However, the statistical model included BCS as a covariate. As such, different BCS may not be the reason for the lower DMI for cows fed the DDGS diet in early lactation in current study.

In some studies, a high starch diet was fed to early lactation dairy cows. Van Knegsel et al. (2007) fed glucogenic, lipogenic and mixed diets to high-producing dairy cows in early lactation, and found an increase in glucogenic nutrients in the diet for MP cows did not affect DMI during the transition period and early lactation. Nelson et al. (2011) used soy hulls to replace corn meal to alter dietary starch concentration (21, 23, and 26%). They found that DMI was not affected by treatment during the first 21d of lactation, but the high starch diet (26%) improved DMI for 91 d period. The effects of feeding high starch diets to early lactation cows were inconsistent.

2.3.2 Sorting behavior

There were no treatment effects on sorting for particle size on 19 mm (P = 0.24; Table 2.2). Cows in the DDGS group consumed more 8 mm particle size compared with cows fed the CON diet (98.0% vs. 93.8%, P = 0.0004). Cows fed the DDGS diet sorted for particle size smaller than 1.18 mm to a lesser extent than cows in the CON group (107 vs. 110 %, P = 0.002). These results showed that cows fed the DDGS diet consumed more PEF than CON cows, and consumed less short particles.

Feeding a TMR is the optimal way to provide balanced nutrients (Nocek and Braund, 1985), but cows sorting TMR will lead cows to consume nutrients that are different from those intended (Stone, 2004). In the current experiment, CON and DDGS diets had similar particle size distribution and both diets contained similar PEF. Cows in both treatments sorted against particle size on 8mm, but cows in the CON diet consumed less of the 8 mm particle size compared with cows fed the DDGS diet. DeVries et al., (2008) found that cows sorted against long particles when they were fed diets high in starch. Cows in the CON group consumed less PEF and more smaller particles, and this sorting behavior might be attributed to the 10% higher starch content of the CON diet compared with the DDGS diet. Ruminants sometimes select feeds to help meet their nutrient requirements if diets are not well balanced or they are deprived of some nutrients (Tolkamp et al., 1998). When gut fill limits DMI, sorting for shorter particle size might be an approach to increase energy intake. Cows fed both diets sorted for smaller particle size, and this behavior might be caused by cows in early lactation experiencing NEB trying to increase energy intake to meet their nutrient requirements. Previous studies showed that cows sorted against the longest ration particles and sorted for fine ration particles, but did not sort the medium ration particles (Leonardi and Armentano, 2003; DeVries et al., 2007). Zhang et al., (2010) found that cows fed DDGS tended to consume less PEF compared with cows in control group and cows fed DDGS spent less time chewing compared with cows fed with barley grain. Greater sorting against the longest ration particles was associated with greater efficiency of milk production

(Yang and Beauchemin, 2006), but there were no treatment effects on milk production in the current study.

In the current study, cows in different parities showed different sorting behavior. All cows sorted against particles on the 8-mm screen, but MP cows sorted to a greater extent than PP cows (Figure 2.5; Figure 2.6), and both PP and MP cows sorted for small particles on the bottom pan, but the intake of particles on the pan was greater for PP cows compared with MP cows (Figure 2.7). DeVries et al. (2011) and Leonardi et al. (2005) found PP cows sorted to a greater extent for short particles and sorted against longer particles than MP cows. DeVries et al. (2011) found sorting behavior was not affected by stage of lactation, but in the current study, we found that sorting for small particles on the pan was affected by the week of lactation ($P = 0.04$) (Figure 2.7).

2.3.3 Milk production

The DDGS diet was 10% unit lower in starch content than the CON diet, but there were no treatment effects on milk production. Ranathunga et al. (2010) used DDGS and SH to replaced corn to decrease starch content in experimental diets, and the diets contained a decreasing concentration of starch (29, 26 23 and 20% of dietary DM). They found that the dietary starch concentration did not affect milk production or composition (Ranathunga et al., 2010). In another study, diets ranging in the percentage of nonstructural carbohydrates from 24 to

42% did not affect milk yield and milk fat concentration (Beauchemin et al., 1997). Nelson et al. (2011) used SH to replace corn meal to get different starch concentrations in the diet (21, 23, and 26%). They found no treatment effects on milk production when cows were fed different starch concentration diets in early lactation. Zhang et al. (2010) used DDGS as a substitute for barley grain to decrease dietary starch in diets for mid-lactation cows, and they did not find treatment effects on DMI and milk yield. These studies reported that milk production was not affected by dietary starch content, and the results of the current study were consistent with past similar studies.

2.3.4 Plasma Metabolites and Hormones

There were no treatment effects on concentrations of plasma glucose and BHBA. Cows fed the DDGS diet tended to have higher NEFA concentrations compared with cows fed the CON diet (173 vs.142 mEq/L, $P = 0.08$). Interestingly, there was an interaction among treatment, parity, and week ($P = 0.02$). For PP cows, plasma concentration of NEFA of cows on DDGS diet was higher at week 2, week 6 and week 8 compared with the CON diet (Figure 2.3). For MP cows, the DDGS diet had significantly higher NEFA concentration than CON diet at week 3 ($P = 0.04$) and week 4 ($P = 0.02$) (Figure 2.4), which are consistent with lower DMI for the DDGS treatment at week 3 and week 4. The plasma concentration of NEFA is related to how much energy cows mobilize from body reserves, and is an indicator for the risk of ketosis (Grummer, 1993). Cows fed the CON diet had lower NEFA concentration, indicating that they mobilized less energy from body reserves. These results may suggest that DDGS diet supplied less energy to cows in early lactation compared with the CON diet. Current results indicated that barley grain might be a better energy source to increase energy intake. Van Knegsel et al. (2007) fed glucogenic and lipogenic diets to high-producing dairy cows in early lactation, and found plasma NEFA concentration tended to be lower for cows fed the glucogenic diet compared with cows fed the lipogenic diet. Although treatment did not affect DMI and milk production, their finding indicated that feeding a diet high in glucogenic nutrients resulted in a less negative NEB. Nelson et al. (2011) used SH to replace corn meal to make diets varied in starch concentration (21, 23, and 26%). They found cows fed a high starch diet (26%) had a lower NEFA concentration than the cows fed a medium starch diet (23%) or a low starch diet (21%). Current results suggest that cows fed the high starch diet had a lower risk for metabolic disorders such as ketosis and fatty liver.

Some might think that the number of cows used in current study was not sufficient to detect treatment effects. However, power analysis conducted with SAS (Cary, NC) showed that the risk of making a Type II error was less than 1% for primary response variables; a sample size of 28 cows per treatment was required to detect treatment effects while there were 31 cows used in CON group and 30 cows used in the DDGS group, which means that the current study had sufficient statistical power to detect treatment effects if there was any.

2.4 Conclusion

A partial replacement of barley grain with DDGS did not affect DMI and milk yield indicating that wheat DDGS can be used as a substitute for barley grain in the diets of dairy cows in early lactation. However, the postpartum DMI increase for MP cows fed DDGS diet was slower compared with those fed CON diet, and plasma NEFA concentration tended to be higher for cows fed the DDGS diet. These results suggested that feeding wheat DDGS in place of grain may be associated with the risk of decreasing energy intake of dairy cows in early lactation.

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Table 2.1 Ingredients, nutrient composition, and particle size distribution of experimental diets.

Item	CON[1]	DDGS[2]
Ingredients, % of DM		
Barley silage	43.1	43.1
Corn grain, rolled	21.6	21.6
Barley grain, rolled	17.3	…
Wheat DDGS	…	17.2
Corn gluten meal	8.3	…
Urea	0.3	…
Beet pulp	3.2	12.3
Vegetable oil	2.4	1.9
Mineral and vitamin mix[3]	3.9	3.9
Nutrient composition		
DM, %	50.1	50.0
OM, % DM	89.1	89.1
CP, % DM	17.3	19.4
NDF, % DM	27.2	30.5
Starch, % DM	29.2	19.1
Ether extract, % DM	3.7	4.4
NFC, % DM	33.9	38.3
Particle size distribution, % as fed		
19 mm	16.5	16.5
8 mm	27.5	28.3
1.18 mm	45.2	27.2
Pan	10.8	28.0
PEF[4]	44.0	44.8

[1] CON: control diet

[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM

[3] Mineral and vitamin mix including: Contained 1.73% Ca; 0.47% P; 1.14% Na; 0.50% Mg; 2.14% Cl; 1.66% K; 0.75 mg/kg Co; 16.6 mg/kg Cu; 0.63 mg/kg I; 396 mg/kg Fe; 56.3 mg/kg Mn; 0.31 mg/kg Se; 55.7 mg/kg Zn; 22.6 KIU/kg vitamin A; 2.3 KIU/kg vitamin D; 74.7 IU/kg vitamin E

[4] PEF = physically effective fiber determined as the proportion of particles retained on 19- and 8-mm sieves (Lammers et al., 1996).

Table 2.2 Effects of replacing barley grain with wheat DDGS in diets for early lactating cows on DMI, body weight, body condition score, and sorting behavior.

					P values						
Variables	CON[1]	SE	DDGS[2]	SE	T[3]	P[4]	Wk[5]	T*P	T*Wk	P*Wk	INT[6]
DMI, kg/d	18.1	0.44	18.4	0.45	0.62	0.06	<.0001	<.0001	0.03	0.32	0.74
BW, kg	573	11.7	567	11.9	0.73	0.50	<.0001	<.0001	0.19	0.02	0.50
BCS,(0~5)	2.75	0.06	2.95	0.06	0.04	0.99	0.82	<0.0001	0.03	0.97	0.11
Sorting index[7]											
19 mm	102	1.02	104	1.04	0.24	0.57	0.09	0.83	0.56	0.43	0.11
8 mm	93.8	0.78	98.0	0.79	0.004	0.10	0.03	0.0008	0.70	0.14	0.74
1.18 mm	94.9	0.64	95.0	0.65	0.42	0.88	0.01	0.30	0.40	0.90	0.17
Pan	110	0.63	107	0.64	0.002	0.02	0.02	0.04	0.37	0.06	0.08

[1] CON: control diet
[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM
[3] T: effects of treatment
[4] P: effects of parities
[5] Wk: effects of week
[6] INT: effects of treatment by week by parity interaction
[7] Sorting index above 100 indicates sorting for particles and that below 100 indicates sorting against particles (Leonardi and Armentano, 2003).

Table 2.3 Effects of replacing barley grain with DDGS in diets for early lactating cows on plasma metabolite concentrations.

[1] CON: control diet

					P-value						
Variables	CON[1]	SE	DDGS[2]	SE	T[3]	P[4]	Wk[5]	T*P	T*Wk	P*Wk	INT[6]
Glucose, mg/dL	53.4	1.09	53.6	1.11	0.67	0.09	< 0.001	0.42	0.12	0.14	0.91
BHBA,mg/dL	7.25	0.57	8.34	0.58	0.19	0.09	0.39	0.93	0.61	0.59	0.81
NEFA,mEq/L	143	11.4	173	11.7	0.08	0.15	< 0.001	0.82	0.79	0.48	0.02
Urea-N,mg/dL	5.46	0.40	6.58	0.40	0.81	0.39	0.07	0.57	0.84	0.16	0.91

[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM

[3] T: effects of treatment

[4] P: effects of parities

[5] Wk: effects of week

[6] INT: effects of treatment by week by parity interaction

Table 2.4 Effects of replacing barley grain with DDGS in diets for early lactating cows on body weight and lactation performance during the first 4 wk of lactation

					P – value						
Variables	CON[1]	SE	DDGS[2]	SE	T[3]	P[4]	Wk[5]	T*P	T*Wk	P*Wk	INT[6]
Yield, kg/d											
Milk	35.3	1.02	34.9	1.03	0.83	<.0001	<.0001	0.97	0.97	0.03	0.90
Fat	1.33	0.04	1.31	0.05	0.85	<.0001	<.0001	0.28	0.28	0.008	0.91
CP	0.97	0.03	0.97	0.03	1.00	<.0001	0.94	0.83	0.83	0.0002	0.69
Lactose	1.67	0.05	1.63	0.05	0.57	<.0001	<.0001	0.84	0.84	0.08	0.92
ECM[7]	35.6	1.02	35.4	1.04	0.88	<.0001	0.001	0.61	0.61	0.001	0.93
Milk composition, %											
Fat	3.84	0.09	3.79	0.10	0.75	0.63	<.0001	0.20	0.20	0.82	0.59
CP	2.77	0.03	2.80	0.03	0.56	0.38	<.0001	0.37	0.37	0.36	0.39
Lactose	4.73	0.04	4.64	0.04	0.01	0.03	<.0001	0.23	0.23	0.02	0.77
MUN, mg/dL	10.5	0.29	10.2	0.29	0.69	0.61	0.20	0.30	0.30	0.47	0.99
SCC, cells/mL	100	52.5	213	53.3	0.15	0.96	0.50	0.71	0.71	0.62	0.67

[1] CON: control diet
[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM
[3] T: effects of treatment
[4] P: effects of parities
[5] Wk: effects of week
[6] INT: effects of treatment by week by parity interaction
[7] ECM = [0.327 × milk yield (kg) + 12.95 × fat yield (kg) + 7.2 × protein yield]; (Tyrrell and Reid, 1965).

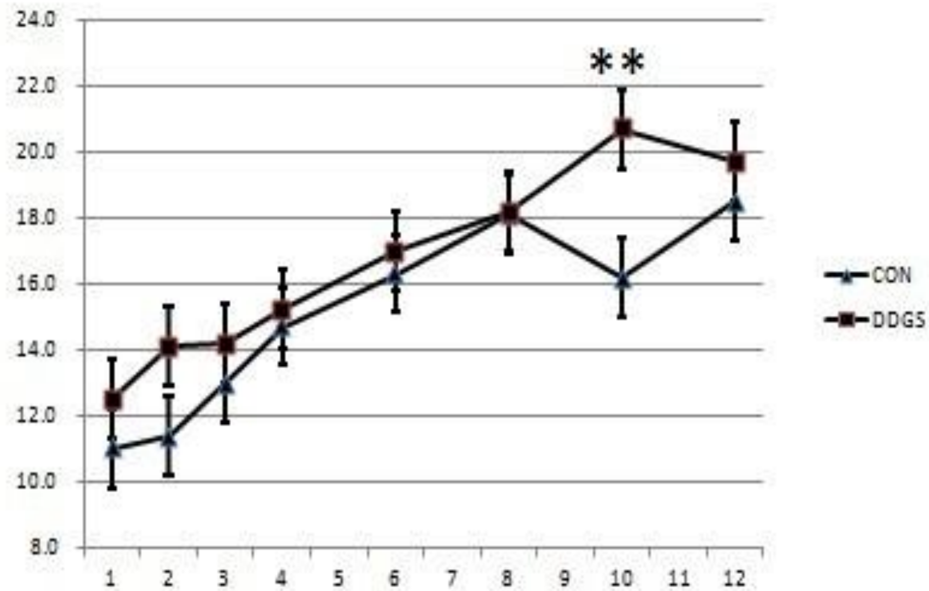

Figure 2.2 Effects of replacing barley grain with DDGS in diets for early lactating cows on DMI of PP cows

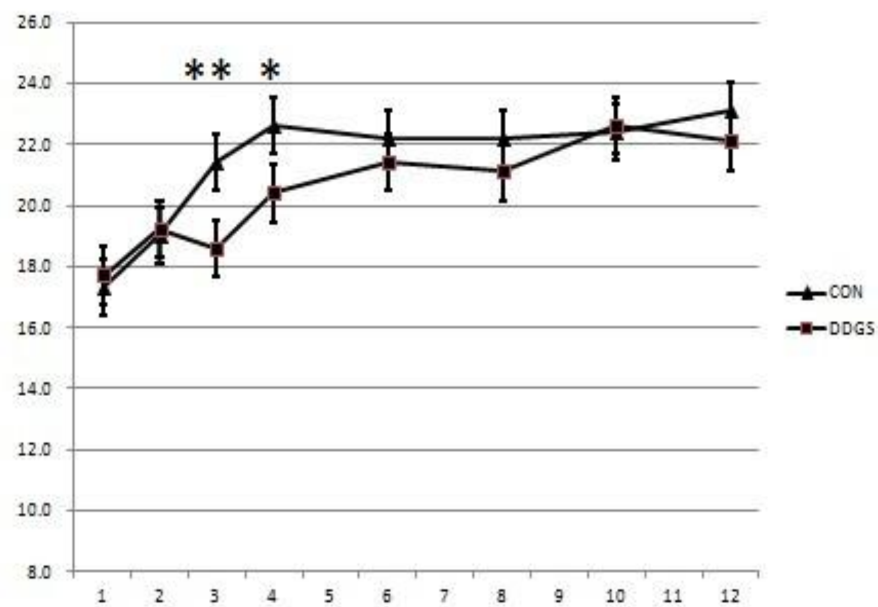

Figure 2.2 Effects of replacing barley grain with DDGS in diets for early lactating cows on DMI of MP cows

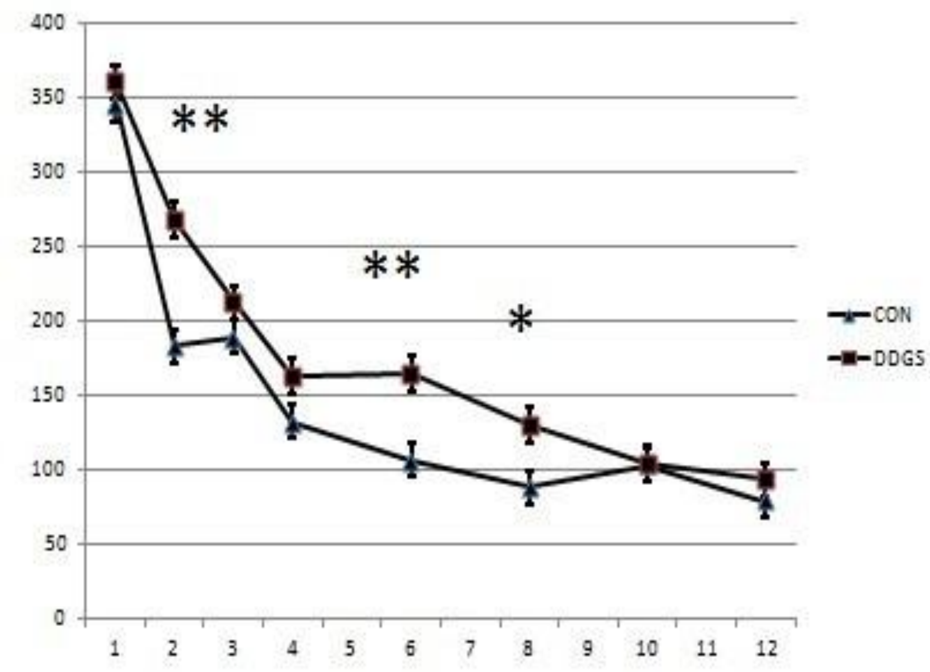

Figure 2.3 Effects of replacing barley grain with DDGS in diets for early lactating cows on NEFA concentration of PP cows

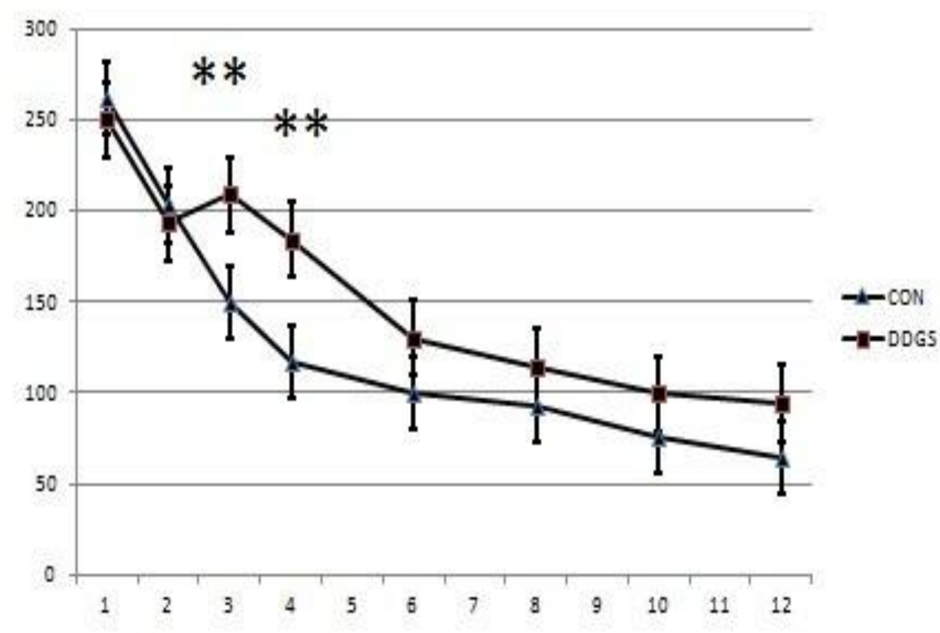

Figure 2.4 Effects of replacing barley grain with DDGS in diets for early lactating cows on NEFA concentration of MP cow

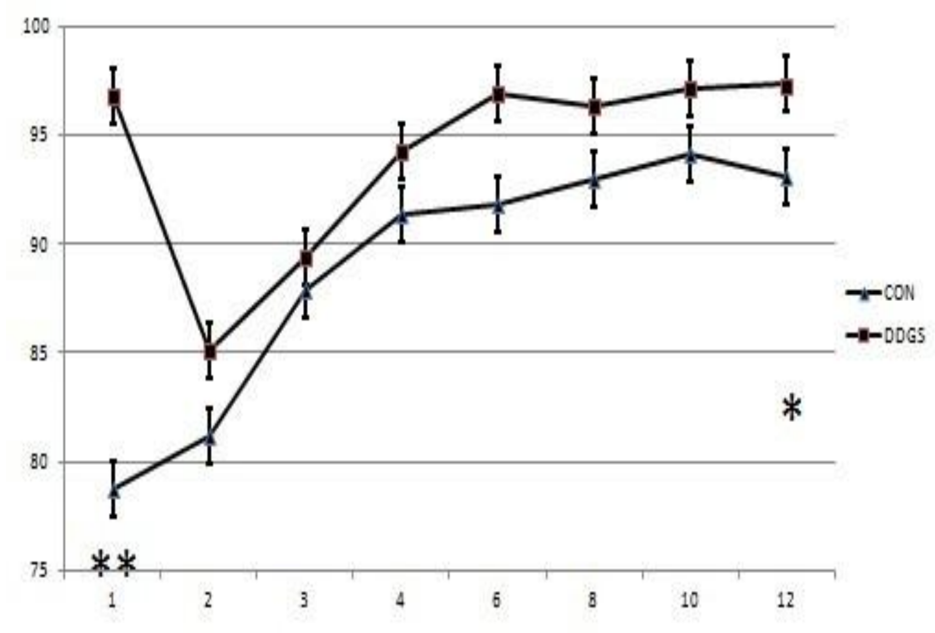

Figure 2.5 Effects of replacing barley lactating cows on sorting on particle size of 8 mm of PP cows

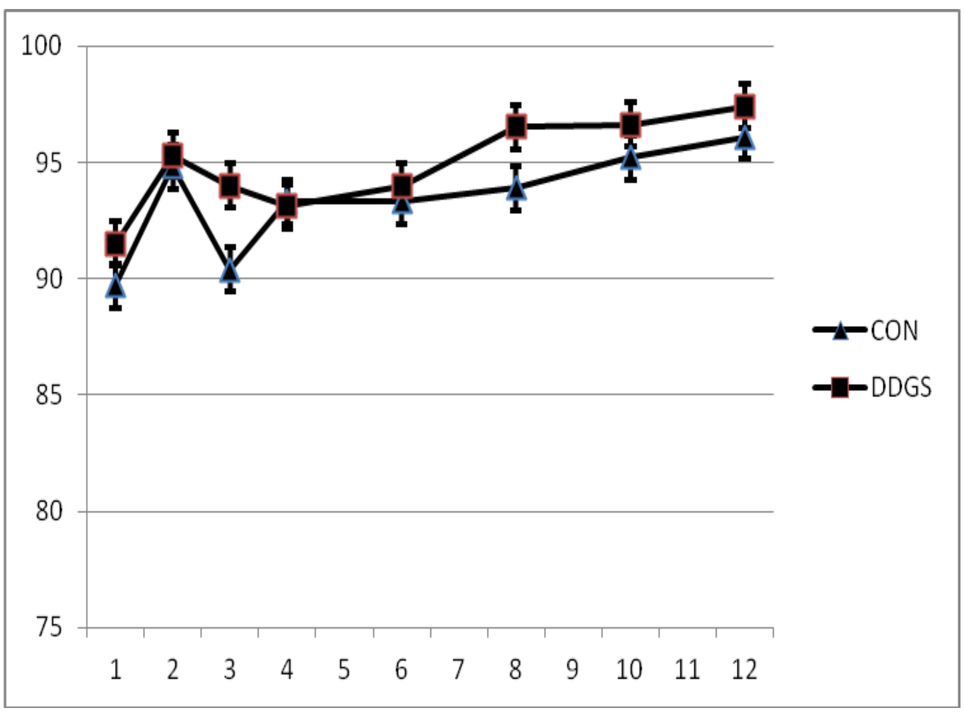

Figure 2.6 Effects of replacing barley grain with DDGS in diets for early lactating cows on sorting on particle size of 8 mm of MP cow

CHAPTER3. EFFECTS OF FEEDING A HIGH FIBER BYPRODUCT FEEDSTUFF AS SUBSTITUTE FOR BARLEY GRAIN IN DIET ON RUMEN FERMENTATION AND PRODUCTIVITY OF DAIRY COWS IN EARLY LACTATION

3.1 Introduction:

High producing dairy cows often experience negative energy balance (NEB) after calving (Grummer, 1995; NRC, 2001). High grain diets are usually fed to cows in early lactation to increase their energy intake, but that often increases the incidence of acidosis and laminitis (Nocek, 1997) and decreases milk production (Krause and Oetzel, 2006). Most high-producing dairy cows are at the risk of subacute rumen acidosis (SARA) which is a common digestive disorder (Nocek, 1997). Rumen acidosis affects milk production and animal health. Rumen pH below 5.2 is considered acute rumen acidosis (Owens et al., 1998) while SARA is defined as rumen pH below 5.8 (Beauchemin and Yang, 2005) and usually caused by feeding diet containing highly fermentable carbohydrates with insufficient physically effective fiber (NRC, 2001).

Early-lactating dairy cows have greater risk of rumen acidosis because their diets change from a high-forage to a high-starch diet immediately after calving. When cows are fed rapidly fermentable grain, their DMI often decreases because of excess acid production in the rumen (Fulton et al., 1979a, b). The reduction in DMI caused by subclinical acidosis decreases energy intake, and may worsen negative energy balance. Therefore, it is challenging to maximize energy intake of dairy cows in early lactation without causing rumen acidosis.

Wheat dried distillers' grains with solubles (DDGS) is a byproduct of the ethanol industry. It contains high CP and high NDF (Dong et al., 1987; McKinnon and Walker, 2008) and is widely accepted as a dietary protein source. Milk production was higher when DDGS replaced soybean meal in nutritionally balanced diets fed to dairy cattle (Kleinschmit, 2006). Some researchers used DDGS to replace grain in the diet fed to dairy cows. Janicek et al (2008) used DDGS to replace both forage and concentrate and found DMI and milk production increased linearly with increasing dietary allocations of DDGS (0, 10, 20 and 30%), indicating that DDGS might be an option as a substitute for grain to increase DMI and energy intake. However, Ranathunga et al. (2010) used soy hulls and DDGS to replace corn grain, and they found that DMI decreased linearly as dietary NDF content increased, but milk production was not affected, and causes for the discrepancy are not known. Feeding DDGS to replace grain in dairy diets would reduce dietary starch concentration and increase NDF concentration, and rumen pH would be expected to increase. Zhang et al. (2010) found that rumen pH tended to increase when DDGS was used to replace barley grain at 20% of dietary DM in the diets for mid–lactation dairy cows. It is well known that the early lactation period is a big challenge for dairy cows; however the effects of using DDGS as a substitute for grain on productivity of dairy cows in early lactation have not been extensively studied. Based on previous research using cows in mid-lactation, we hypothesized that reducing dietary starch content by replacement of barley grain with DDGS would increase rumen pH, DMI and milk production of dairy cows in early lactation. The objective of the current study was to evaluate the effects of using wheat DDGS as a substitute for barley grain on DMI, rumen fermentation, apparent total tract nutrient digestibility, and milk production of dairy cows in early lactation.

3.2 Material and Methods

3.2.1 Animals, diets and experimental design

This experiment was a part of a larger study, conducted from January 2010 to August 2010 at the Dairy Research and Technology Center at the University of Alberta (Edmonton, Alberta, Canada), to evaluate the effects of feeding a high-fiber byproduct feedstuff on productivity of dairy cows in early lactation (Chapter 2). This chapter focuses treatment effects on rumen pH, rumen fermentation, and total tract nutrient digestibility as well as DMI and milk production of dairy cows in early lactation. All procedures were pre-approved by the Animal Care and Use Committee for Livestock at the University of Alberta and conducted according to the guidelines of the Canadian Council of Animal Care (Ottawa, Ontario, Canada).

Two experimental diets were formulated for this study. The control (CON) diet contained 43% barley silage, 17.3% dry-rolled barley grain, and 39.3% concentrate mix on a DM basis while the DDGS diet contained the same ingredients except wheat DDGS replaced dry-rolled barley grain (Table 2.1). Both diets were formulated according to dairy NRC (2001) to meet or exceed the nutritional requirements for early lactating cows (650 kg BW at 25kg/d DMI) producing 45.0 kg of milk/d with 3.50% milk fat and 3.00% milk protein. Corn gluten meal, urea, and vegetable oil were used to increase the dietary CP and fat concentrations of the CON diet as wheat DDGS contained higher CP and fat compared with barley grain. Particle size distribution of feed ingredients was determined by using the Penn State Particle Separator (Leonardi and Armentano, 2003) (Table 2.1). Both diets had similar physical effective fiber (PEF), but DDGS diet had more fine particles collected in the pan (28.0 vs. 10.8%). The DM concentration of barley silage and concentrate mixes were determined weekly and diet formulations were adjusted if necessary.

Thirteen multiparous ruminally cannulated Holstein cows) were assigned to one of two experimental diets (CON, n=6; DDG, n=7) immediately after calving. Data collected from the week when cows had left displacement of abomasum or cows were treated with antibiotics were removed. Cows were housed individually in tie stalls and allowed to exercise outdoor for 2 h daily except weekends. All cows were fed experimental diets as TMR and had free access to water. Cows were fed once daily at 105% to 110% of expected intake. Cows were milked in their stalls twice daily at 0400 and 1600 h.

3.2.2 Data and sample collection

Data and samples were collected on Tuesday, Wednesday, and Thursday every week, and the amounts of feed offered were recorded daily. The samples of diet ingredients were collected daily during the sample collection periods. At the end of the sample collection period, daily samples were composited to obtain a representative sample for each week. Orts were collected from each cow daily (Wednesday, Thursday and Friday before feeding) and daily samples were composited to obtain a representative sample for each cow each week. The composited orts samples were separated into two parts; one to determine chemical composition and another to determine particle size distribution. The Penn State Particle Separator was used to measure particle size distribution of feed ingredients and orts, and sorting index was determined according to Leonardi and Armentano (2003; Sorting index = Actual DMI / Expected DMI $\times$100).

Body weight and BCS were measured one week prior to calving. The BW of cows in the CON group was 704 $\pm$ 65 kg, and their BCS and parity were 3.5 $\pm$ 0.5 and 3.2 $\pm$ 1.6, respectively. The BW of cows in the DDGS group was 701 $\pm$ 28 kg, and their BCS and parity were 3.7 $\pm$ 0.4 and 3.0 $\pm$ 2.0, respectively. After calving, BW was measured twice per week at 0700 h, after milking but before feeding, on Tuesday and Thursday. The average of two BW measurements was used as the data for each week. Body condition score with five-point scale (Wildman, et al., 1982) was determined for each collection period.

Milk samples were collected and milk yield was recorded 6 times during the sample collection period, consecutively from Tuesday pm to Friday am. The average of daily milk yield was used as the data for each week.

Rumen pH was measured every 30 s for 72 h using LRC rumen pH data logger system (Penner et al., 2006). Rumen fluid was collected every 9 h over a 72-h period of each experimental period (1300 and 2200 h on Tuesday, 0700 and 1600 h on Wednesday, 0100, 1000, and 1900 h on Thursday, and 0400 h on Friday). Each rumen fluid sample was collected from the cranial, ventral, and caudal regions, and filtered through a double layer of perforated nylon screen. Filtered rumen fluid samples were placed on ice immediately after collection and centrifuged at 4 ℃ at 3,000 *g* for 20 min. Samples were stored at -20 ℃ until analysis. Immediately prior to analysis, eight rumen fluid samples collected from each cow were composited to yield one representative sample for each week. Fecal samples were collected from the rectum every 9 h over a 72-h period at the same time as rumen fluid collection, and the samples were composited to yield one sample per cow per week.

3.2.3 Sample analysis

Samples of feed ingredients, orts, and feces were dried in a forced air oven at 55 ℃ for 48 h to determine DM, then samples were ground through a 1-mm screen using a Wiley mill (Thomas-Wiley, Philadelphia, PA). The ground samples were used for chemical analysis. The samples were further dried at 135 ℃ for 2 h to determine analytical DM. Dried samples were oxidized in a muffle furnace for 2 h at 600 ℃ (AOAC, 2002; method 942.05) to determine the OM concentration. The CP concentration was determined using Leco (Leco FP-2000 N Analyzer; Leco instrument Inc., St. Joseph, MI, USA. Rhee 2005). The neutral detergent fiber (NDF) concentration was using heat stable amylase and sodium sulfite (Van Soest et al., 1991). Starch concentration was measured by the method described by Karkalas (1985). The Goldfisch extraction apparatus (Labconco, Kansas City, MO) with petroleum ether was used to measure ether extract concentration. To determine indigestible NDF, samples of feed ingredients, orts, and fecal were put in the nitrogen free polyester bags (5 × 10 cm, pore size = 50 μm; R510, Ankom Technology, Macedon, NY) and incubated in the rumen for 120 h. Indigestible NDF was used as an internal marker to calculate apparent total tract digestibility (Cochran et al., 1986).

Rumen fluid samples were analyzed for VFA concentration by gas chromatography (Khorasani et al., 1996). Rumen NH_3-N concentration was determined by the method described by Fawcett and Scott (1960).

Milk samples were analyzed at the Alberta Central Milk Testing Laboratory (Edmonton, Alberta, Canada) for milk fat, CP, lactose, MUN, and SCC contents (AOAC, 2002).

3.2.4 Calculations and statistical analysis

The energy corrected milk (ECM) yield was calculated according to the equation described by Tyrrell and Reid (Tyrrell and Reid, 1965):

ECM = [0.327 × milk yield (kg) + 12.95 × fat yield (kg) + 7.2 × protein yield]

Total digestible nutrients (TDN) was calculated from apparent total tract DM digestibility according to NRC (2001), with the modifications described by Penner and Oba (2009), and TDN was then used to calculate dietary NEL according to NRC (2001):

DE=0.04409 x TDN

ME = (DE x1.01-0.45) + 0.0046 x (EE-3)NE_L = 0.703 x ME – 0.19 + (0.097 x ME+0.19)/97 x (EE-3)

The net energy required for maintenance was calculated as NE_M (Mcal/d) = 0.08 Mcal/kg of $BW^{0.75}$, and NE_L was calculated according to NRC (NRC, 2001) with the observed milk yield and concentrations of milk fat, milk CP, and milk lactose according to NRC (2001): NEL (Mcal/d) = Milk yield × (0.0929 × milk fat + 0.0547 × milk protein + 0.0395 × milk lactose).

Data were analyzed using the Proc Mixed procedure of SAS (version 9.2, Cary, NC) using the following model:

$Y_{ij} = \mu + T_i + W_j + TW_{ij} + Cov + e_{ij}$

Where μ is the overall mean, T_i is the fixed effect of treatment, W_j is the fixed effect of week, Cov is the BCS prior to calving used as a covariate, e_{ij} is the residual. Week of lactation was used as a repeated measure. Treatment effects were declared significant at $P \leq 0.05$ and a tendency was declared at $0.05 < P \leq 0.10$.

3.3 Results

3.3.1 Effects of feeding treatment diets on intake, BW, BCS and sorting behavior

Cows fed the DDGS diet did not have higher DMI compared with cows fed the CON diet ($P = 0.66$; Table 3.2) and there were no treatment effects on BW ($P = 0.68$) and BCS ($P = 0.98$). Also there were no treatment effects on sorting behavior; cows on both dietary treatments consumed the same amount of each particle size; 19mm ($P = 0.47$), 8mm ($P = 0.15$), 1.18mm ($P = 0.60$), and pan ($P = 0.33$).

3.3.2 Effects of feeding treatment diets on rumen pH and fermentation

There were no treatment effects on mean rumen pH ($P = 0.78$), minimum pH ($P = 0.52$), maximum pH ($P = 0.82$) (Table 3.3). Also the area ($P = 0.53$) and the duration ($P = 0.80$) of rumen pH below 5.8 was not different between treatments. However, cows fed the DDGS diet tended to have higher total VFA concentration in rumen fluid compared with the cows fed the CON diet (107 vs. 116 m*M*, $P = 0.06$). The molar proportion of acetate (55.8 vs. 57.0 mol/100 mol, $P = 0.07$) and butyrate (12.8 vs. 13.1 mol/100 mol, $P = 0.08$) tended to be higher for the DDGS treatment. The molar proportion of isovalerate in DDGS diet was lower than the CON diet (1.70 vs. 1.20 mol/100 mol, $P = 0.05$). There were no treatment effects on other VFA variables or rumen NH_3-N concentration (P = 0.27)

3.3.3 Effects of feeding treatment diets on apparent total tract digestibility

Cows fed the DDGS diet tended to have higher total tract CP digestibility (56.9 vs. 46.4%, P = 0.06), but lower starch digestibility (81.9 vs. 91.2%, P = 0.05) compared with cows fed the CON diet (Table 3.4), but there were no treatment effects on the digestibility of DM (P = 0.67), OM (P = 0.82), and NDF (P = 0.36).

3.3.4 Effects of feeding treatment diets on energy balance

Cows fed either diet had the same NE_L intake (P = 0.69), NE_L output (P = 0.94), NE_M output (P = 0.88), total net energy output (P = 0.86). So energy balance was not affected by treatment (P = 0.62) (Table 3.5).

3.3.5 Effects of feeding treatment diets on milk Production

There were no treatment effects on milk yield (P = 0.57), milk fat (P = 0.95), milk CP (P = 0.80), and milk lactose (P = 0.62); (Table 3.6). The experiment diets did not affect milk composition; milk fat (P = 0.80), milk CP (P = 0.80), and milk lactose (P = 0.66). Cows fed the DDGS diet had the same milk yield / DMI (P = 0.57), ECM (P = 0.91), and ECM / DMI (P = 0.85) as cows fed the CON diet.

3.4 Discussion

3.4.1 Rumen pH

Cows in early lactation often experience severe ruminal acidosis (Fairfield et al., 2007; Penner et al., 2007; Penner and Oba, 2009). Ruminal pH decreases as the dietary starch concentration increases because of excess fermentation of starch to VFA in the rumen. Voelker and Allen (2003a) fed beet pulp to replace high-moisture corn at 0, 6.1, 12.1, or 24.3% dietary DM, and they found that substituting beet pulp for corn did not affect daily mean or minimum ruminal pH but tended to reduce pH range. Zhang et al. (2010) used DDGS to replace barley grain at 20% of dietary DM, and reported that cows fed the diet with DDGS tended to increase rumen pH. Based on the previous studies, cows fed diets with high-fiber byproducts in place of grain are expected to have a lower risk of rumen acidosis. In the current study, the starch concentration of the DDGS diet was 10% lower than that of the CON diet. As such we had hypothesized that cows on the DDGS diet would increase rumen pH.

However, in the current study, rumen pH was not affected by treatment although the DDGS diet was approximately 10% unit lower in starch concentration. DeVries et al. (2007) reported that dairy cows prefer sorting for shorter particles rather than longer particles when fed a low forage diet, which means that cows would consume more grain and less fiber. Cows sorted for short particles and against long particles, which may increase the risk of SARA (Cook et al., 2004; Stone, 2004). Consumption of sufficient physically effective fiber (PEF) is necessary to prevent SARA (NRC, 2001). However, both diets in the current study had similar particle size distributions and cows on both treatments had similar sorting behavior. Thus, cows on both treatments consumed similar PEF, and the lack of treatment effects on rumen pH might not be attributed to different PEF intake. Physically effective fiber stimulates chewing behavior, which increases the secretion of salivary buffers (Maekawa et al., 2002) that neutralizes approximately 30 to 40% of fermentation acids in the rumen (Allen, 1997). As such, salivary secretion increases rumen pH and decreases the risk of ruminal acidosis (Krause et al., 2002; Yang et al., 2001). In the current study, chewing behavior was not evaluated, but a previous study (Zhang et al., 2010) compared the chewing behavior between cows fed DDGS and those fed barley grain, and reported that chewing time of cows fed DDGS was significantly shorter than the cows fed barley grain (31.6 vs. 39.1 min/kg DMI, $P = 0.01$). Cows fed the DDGS diet were expected to have higher rumen pH due to lower dietary starch intake, but the lesser chewing time for cows fed DDGS may explain why the DDGS diet did not increase rumen pH.

The pH of by-products from ethanol production is low, which might be another reason explaining the DDGS diet did not increase rumen pH. Jasaitis et al. (1987) reported that the initial pH of corn-based DDGS was 4.35, while that of barley grain was 5.73. Another study (Beliveau and McKinnon, 2009) found that rumen pH did not increase with the replacement of barley grain with wheat DDGS, which may be related to the fact that the initial pH of wheat-based DDGS was lower than the initial pH of barley grain (4.31 vs. 5.36). The current study did not measure pH of DDGS and barley grain, but it is possible that the initial pH of wheat DDGS was lower than barley grain, which resulted in similar pH for both diets despite that lower starch content in the DDGS diet. The effect of replacing barley grain with DDGS on rumen pH is not consistent in literature. Beliveau and McKinnon (2009) used different amounts of DDGS (0, 7, 14, and 21%) in place of barley grain in diets of finishing beef cattle, and found that treatment did not affect rumen pH, which is similar to the results of the current study. Zhang et al. (2010) found that rumen pH tended to increase when DDGS was used to replace barley grain at 20% of dietary DM in the diets for mid–lactation dairy cows.

Some might think that the number of cows used in current study was not sufficient to detect treatment effects. In a previous study, Penner and Oba (2009) used 5 rumen cannulated Holstein cows per treatment in their study with similar experimental design and detected tendency of treatment effects on rumen pH, and the standard error of mean in their study (2009) was similar to that of the current study. In addition, power analysis conducted with SAS (Cary, NC) showed that the risk of making a Type II error was less than 1% for rumen pH; a sample size of 6 cows per treatment was required to detect the treatment effect while there were 13 rumen cannulated Holstein cows used in the current study, 6 in CON group and 7 in DDGS group, which means that the current study had enough statistical power to detect treatment effect on rumen pH.

There were no treatment effects on VFA, which is in agreement with previous studies. Decreasing dietary starch concentration did not change total VFA concentration, but acetate concentration decreased linearly with the dietary allocation of DDGS and soy hulls (SH) increased in the diets for lactation dairy cows (Ranathunga et al., 2010). Voelker and Allen (2003b) found total VFA concentration in rumen fluid was similar across treatments when beet pulp substituted for high moisture corn at 0, 6.1, 12.1, or 24.3% of dietary DM. Dietary starch concentration might not affect VFA concentration in the rumen of lactation dairy cows.

3.4.2 DMI, energy intake and milk production

We had hypothesized that cows fed the DDGS diet would have higher DMI compared with cows on the CON diet, because the DDGS diet contained 10% unit less dietary starch content than the CON diet and the excess carbohydrate fermentation often decreases DMI of dairy cows. Cows fed rapidly fermentable grain would have lower DMI because excess acid production and accumulation in the rumen causes subclinical acidosis (Fulton et al., 1979a,b), and cows that experience rumen acidosis decrease feed intake (Nocek, 1997). Janicek et al. (2008) used DDGS to replace both forage and concentrate and found that DMI and milk production increased linearly with increasing dietary allocations of DDGS (0, 10, 20 and 30%). Therefore, based on previous studies, we hypothesized that cows fed DDGS diet would have higher DMI compared with CON diet.

Although the DDGS diet had 10% lower dietary starch concentration, cows on the DDGS treatment did not increase DMI compared with cows fed the CON diet. This might be attributed to the lack of treatment effects on rumen pH. The results of the current study were similar to those reported by Beliveau and McKinnon (2009). They used different amount of DDGS (0, 7, 14, and 21%) to replace barley grain in the diets for finishing beef cattle, but DMI was not affected by treatment. Some previous studies used high-fiber byproduct to replace grain in the diets for dairy cows and reported inconsistent results. Stone (1996) found multiparous cows increased DMI by 2 kg/d when high-moisture corn was replaced with SH at 14% of dietary DM. Ranathunga et al. (2010) increased the substitution of DDGS and SH for corn grain to decrease dietary starch concentration, and found that DMI decreased linearly with the dietary starch concentration in the diets decreased. Ipharraguerre et al. (2002) used SH to replace corn grain incrementally at 0, 10, 20, 30, and 40% of DM in the diets of lactating dairy cows, and found that DMI tended to decrease (P < 0.06) linearly. Using high fiber byproduct to replace grain in diet had inconsistent results; the causes for these discrepancies are not known.

There were no treatment effects on energy balance and milk production for cows fed experiment diets. Some studies in literature used higher-fiber byproducts to replace grain in the diets for dairy cows. Clark and Armentano (1997) showed that feeding beet pulp in place of corn grain at 15.7 % of dietary DM increased

DMI but did not affect milk yield. Voelker and Allen (2003a) used different concentrations of beet pulp (0, 6.1, 12.1 or 24.3%) to replace high moisture corn grain, and found no treatment effects on milk production. These studies indicated that using high fiber by-products to replace grain may not affect milk production.

3.4.3 Effects of feeding experiment diets on starch digestibility:

The total tract starch digestibility was decreased in the DDGS diet which contains lower starch concentration. Similarly, Oba and Allen (2003) reported that starch digestibility in the rumen and the total tract digestibility of starch were lower for the cows fed low starch diets compared with those fed high starch diets. Voelker and Allen (2003c) used beet pulp to replace high-moisture corn to decrease dietary starch concentration, and found that starch digestibility in the rumen decreased linearly with the increased dietary allocations of beet pulp. Although the total tract starch digestibility was not affected because of compensatory digestion of starch in the intestines, the lower starch digestibility for cows fed low starch diets might be caused by insufficient amylolytic activity for maximal starch digestion due to lower dietary starch intake (Oba and Allen, 2003).

3.5 Conclusion

A partial replacement of barley grain with DDGS did not increase rumen pH and DMI, and cows fed DDGS had lower apparent total tract digestibility of starch. Decreasing dietary starch concentration by substituting wheat DDGS for barley grain may not be effective as an approach to increase energy intake of dairy cows in early lactation.

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Table 3.1 Ingredients, nutrient composition, and particle size distribution of experimental diets.

Item	CON[1]	DDGS[2]
Ingredients, % of DM		
Barley silage	43.1	43.1
Corn grain, rolled	21.6	21.6
Barley grain, rolled	17.3	…
Wheat DDGS	…	17.2
Corn gluten meal	8.3	…
Urea	0.3	…
Beet pulp	3.2	12.3
Vegetable oil	2.4	1.9
Mineral and vitamin mix[3]	3.9	3.9
Nutrient composition		
DM, %	50.1	50.0
OM, % DM	89.1	89.1
CP, % DM	17.3	19.4
NDF, % DM	27.2	30.5
Starch, % DM	29.2	19.1
Ether extract, % DM	3.7	4.4
NFC, % DM	33.9	38.3
Particle size distribution, % as fed		
19 mm	16.5	16.5
8 mm	27.5	28.3
1.18 mm	45.2	27.2
Pan	10.8	28.0
PEF[4]	44.0	44.8

[1] CON: control diet

[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM

[3] Mineral and vitamin mix including: Contained 1.73% Ca; 0.47% P; 1.14% Na; 0.50% Mg; 2.14% Cl; 1.66% K; 0.75 mg/kg Co; 16.6 mg/kg Cu; 0.63 mg/kg I; 396 mg/kg Fe; 56.3 mg/kg Mn; 0.31 mg/kg Se; 55.7 mg/kg Zn; 22.6 KIU/kg vitamin A; 2.3 KIU/kg vitamin D; 74.7 IU/kg vitamin E

[4] PEF = physically effective fiber determined as the proportion of particles retained on 19- and 8-mm sieves (Lammers et al., 1996).

Table 3.2 Effects of replacing barley grain with wheat DDGS in diets for early lactating cows on DMI, body weight, body condition score, and sorting behavior.

				P values		
Variables	CON[1]	DDGS[2]	SE	T[3]	Wk[4]	INT[5]
DMI, kg/d	19.6	19.0	1.06	0.66	0.01	0.80
BW, kg	632	642	16.6	0.68	0.03	0.40
BCS,(0~5)	3.04	3.04	0.10	0.98	0.04	0.89
Sorting index[6]						
19 mm	103	105	1.58	0.47	0.81	0.28
8 mm	93.8	98.1	1.93	0.15	0.03	0.15
1.18 mm	94.9	93.6	1.72	0.60	0.84	0.73
Pan	108	106	1.40	0.33	0.28	0.55

[1] CON: control diet
[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM
[3] T: effects of treatment
[4] Wk: effects of week
[5] INT: effects of treatment by week interaction
[6] Sorting index above 100 indicates sorting for particles and that below 100 indicates sorting against particles (Leonardi and Armentano, 2003).

Table 3.3 Effects of replacing barley grain with DDGS in diets for early lactating cows on rumen pH and rumen fermentation.

				P values		
Variables	CON[1]	DDGS[2]	SE	T[3]	Wk[4]	INT[5]
Rumen pH						
Mean	6.33	6.30	0.07	0.78	0.20	0.28
Minimum	5.60	5.67	0.07	0.52	0.18	0.78
Maximum	6.99	6.97	0.05	0.82	0.89	0.97
pH < 5.8						
Area, pH × h/d	28.8	16.6	11.3	0.53	0.09	0.69
Duration, h/d	126	108	49.4	0.80	0.07	0.60
Total VFA, m*M*	107	116	3.18	0.06	0.30	0.76
VFA profile, mol/100 mol of total VFA						
Acetate	55.8	57.0	2.23	0.07	0.12	0.77
Propionate	26.1	25.9	1.29	0.24	0.66	0.64
Isobutyrate	0.90	0.80	0.06	0.23	0.03	0.62
Butyrate	12.8	13.1	0.55	0.08	0.30	0.06
Isovalerate	1.70	1.20	0.13	0.05	0.79	0.89
Valerate	2.00	1.80	0.19	0.76	0.36	0.50
Caproic	0.61	0.60	0.05	0.99	0.03	0.47
Rumen NH_3-N, mg/dL	14.6	15.7	0.71	0.27	0.53	0.57

[1] CON: control diet
[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM
[3] T: effects of dietary treatment
[4] Wk: effects of week
[5] INT: effects of treatment by week interaction

Table 3.4 Effects of replacing barley grain with DDGS in diets for early lactating cows on feed intake and apparent total tract digestibility.

				P values		
Digestibility, %	CON[1]	DDGS[2]	SE	T[3]	Wk[4]	INT[5]
DM	58.0	59.9	3.1	0.67	0.96	0.18
OM	62.1	63.1	3.1	0.82	0.92	0.12
CP	46.4	55.9	3.2	0.06	0.75	0.21
NDF	51.4	57.8	4. 7	0.36	0.56	0.43
Starch	91.2	81.9	3.0	0.05	0.68	0.20

[1] CON: control diet
[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM
[3] T: effects of dietary treatment
[4] Wk: effects of week
[5] INT: effects of treatment by week interaction

Table 3.5 Effects of replacing barley grain with DDGS in diets for early lactating cows on energy intake, expenditure, and energy balance during early lactation.

				P values		
Variables	CON[1]	DDGS[2]	SE	T[3]	Wk[4]	INT[5]
NE_L intake, Mcal/d	26.1	27.7	2.83	0.69	0.02	0.61
NE_L output, Mcal/d	14.2	13.8	1.15	0.85	0.17	0.20
NE_M, output, Mcal/d	10.1	10.1	0.16	0.88	< 0.001	0.38
Total net energy output, Mcal/d	24.3	23.9	1.26	0.87	0.39	0.33
Net energy balance, Mcal/d	1.8	3.8	2.70	0.62	0.08	0.84

[1] CON: control diet
[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM
[3] T: effects of dietary treatment
[4] Wk: effects of week
[5] INT: effects of treatment by week interaction

Table 3.6 Effects of replacing barley grain with DDGS in diets for early lactating cows on body weight and lactation performance during the first 4 wk of lactation.

				P values		
Variables	CON[1]	DDGS[2]	SE	T[3]	Wk[4]	INT[5]
Yield, kg/d						
Milk	40.1	37.9	2.65	0.57	0.0002	0.38
Fat	1.51	1.52	0.01	0.95	0.02	0.13
CP	1.09	1.12	0.07	0.80	0.22	0.30
Lactose	1.85	1.75	0.11	0.62	<.0001	0.30
ECM[6]	40.4	40.1	2.45	0.91	0.34	0.15
Milk composition, %						
Fat	3.89	4.00	0.31	0.82	<.0001	0.48
CP	2.73	3.00	0.08	0.80	0.22	0.30
Lactose	4.62	4.66	0.07	0.66	<.0001	0.26
MUN, mg/dL	10.1	9.80	0.57	0.69	0.04	0.01
SCC	39.0	109	48.5	0.33	0.22	0.85
Feed efficiency						
Milk yield/DMI	2.12	2.02	0.35	0.57	0.17	0.24
ECM /DMI	2.18	2.14	0.51	0.85	0.001	0.03

[1] CON: control diet
[2] DDGS: diet containing wheat-based dried distillers grains with solubles at 17% of dietary DM
[3] T: effects of dietary treatment
[4] Wk: effects of week
[5] INT: effects of treatment by week interaction
[6] ECM = [0.327 × milk yield (kg) + 12.95 × fat yield (kg) + 7.2 × protein yield]; Tyrrell and Reid, 1965.

CHAPTER 4 GENERAL DISCUSSION

4.1 Summary of findings

The objective of this study was to evaluate the effects of partially replacing dietary barley grain with wheat DDGS, a high-fibre byproduct feedstuff, on dry matter intake (DMI), sorting activity, milk production, plasma metabolites, rumen pH and rumen fermentation of early-lactating dairy cows. Sixty-one Holstein cows (22 PP cows and 39 MP cows) including 13 multiparorus ruminally cannulated Holstein cows were fed diets containing either steam-rolled barley grain (control) or wheat DDGS at 17% of dietary DM after calving for 12 weeks. There were no treatment effects on milk production, but cows fed the DDGS diet consumed more PEF than cows in CON group and tended to have a higher plasma NEFA concentration. There were no treatment effects on DMI for PP cows, but MP cows fed DDGS diet had a slower increase rate of DMI compared with MP cows fed the CON diet.

For 13 MP ruminally cannulated Holstein cows, DMI and rumen pH of cows fed the DDGS diet did not increase as expected. There were no treatment effects on body weight, body condition score or sorting behavior. Cows fed the DDGS diet tended to have higher digestibility of CP, but the digestibility of starch was lower compared with cows fed the CON diet.

There were no negative effects on milk production and rumen pH, so DDGS can be effectively used as a partial replacement of barley grain to early lactation cows. However, the postpartum DMI of MP cows fed the DDGS diet increased more slowly compared with those fed the CON diet, and plasma NEFA concentration tended to be higher for cows fed the DDGS diet. These results suggested that feeding wheat DDGS instead of grain might be associated with the risk of decreasing energy intake of dairy cows in early lactation.

The early lactation period is important because cows have a high risk of NEB and rumen acidosis. Although many studies evaluated nutritional strategies to increase energy intake, no study has evaluated using wheat DDGS as a substitute for barley grain in the diets of cows in early lactation. The current study compared the effects of different dietary starch concentrations in the diets of dairy cows in early lactation. For the current study, wheat DDGS is used as a model of high fiber byproducts such as soy hulls. The results of the current study provided valuable information about the effects of feeding high fiber byproducts instead of grain in the diets of dairy cows in early lactation. Based on the results of this study, if the price of grain is higher or if cows experience rumen acidosis in the early lactation period, some high fiber byproducts such as DDGS will be a good option for dairy producers in Western Canada to consider. Current studies filled the knowledge gap by evaluating the effects of feeding non-forage fiber to replace starch from barley grain in the diets fed to early lactation cows in order to mitigate the extent of NEB and rumen acidosis through nutritional management during the early lactation period.

4.2 Economic analysis

Economic benefits are a big concern for dairy producers. Table 4.1 showed the cost of the feedstuffs used in experimental diets and the total diet costs. Both experimental diets were fed at 110% of expected feed intake and the price of premix of minerals and vitamins were assumed to be $1,000/T. The price of barley grain and wheat DDGS used for this calculation was the average price from 2009 to 2011: $195/T and $194/T, respectively. The results of this calculation showed that DDGS diet saved the diet cost by $ 0.47 /cow /d compared with the diet with barley grain. The price of barley grain and DDGS from June 2009 to June 2011 varies in the Edmonton area (Figure 4.1). Assuming that the price of barley grain will not change, the cost of the DDGS diet will be lower than CON diet as long as the price of DDGS is lower than $340 /T.

DDGS can be used as a substitute for barley grain when the price of DDGS is lower than the breakpoint ($340/T). Based on the results of both studies, there were no negative effects of feeding DDGS on milk production or composition. Using DDGS instead of barley grain will not have a negative effect on the income from milk production, but the cost of feedstuff will be lower, so the net income is ultimately expected to be higher with the use of DDGS. The feed cost of the Dairy Research Technology Center (DRTC) for high producing cows was $7.70 /cow /d, so both diets formulated in this experiment would decrease feeding costs.

4.3 Future research

Using wheat DDGS to replace barley grain at 17% of dietary DM did not negatively affect milk yield or milk composition, indicating that wheat DDGS can be used as a substitute for barley grain in the diets of dairy cows in early lactation. Research data on feeding values of DDGS were inconsistent among studies. One reason for the discrepancy is the different percentage of DDGS used in the diets among studies. Another reason is the huge variation in chemical composition of DDGS (Belyea et al., 1989 and 1998). First, the difference in grain quality may affect the quality of DDGS. Secondly, the variation in DDGS quality can result from different processing methods such as drying temperature. During the drying process, protein may be damaged by overheating. In addition, the amount of residual starch in DDGS can be different. Therefore, the effects of feeding DDGS to replace barley grain are affected by its actual chemical composition. As such, for any future studies evaluating DDGS, actual chemical composition needs to be measured and reported as it greatly affects feeding values of DDGS.

To better understand the feeding values of wheat DDGS, there are several aspects that warrant further research. First of all, cows in different parities had responded differently to the diets. Sorting behavior was different between PP and MP cows. Both parities sorted against particles retained on 8-mm screen, but MP cows sorted to a greater extent than PP cows. Both PP and MP cows sorted for particles collected in the bottom pan, but PP cows consumed more particles on the pan than MP cows. The MP cows fed DDGS diet had a slower increase rate of DMI than cows fed CON diet. Different sorting behavior might have been related to different DMI responses between PP and MP cows. Therefore, further research is warranted for the relationship between sorting behaviors and DMI for cows differing in parity. Cows fed DDGS had higher plasma NEFA concentration than cows in CON group, which means that cows fed DDGS mobilized more body reserves. However, the calculated energy intake and energy expenditure were not affected by treatment. Reasons for the discrepancy cannot be identified for the current study. Further study should find out why plasma NEFA concentration was affected by treatment.

We expected that feeding DDGS instead of barley grain would decrease the incidence of rumen acidosis because DDGS is lower in NFC content, but the current study showed that DDGS diet did not increase rumen pH and DMI in the early lactation period, contrary to our hypothesis. Although the purpose of this study was to evaluate the feeding value of DDGS as a substitute for barely grain as an energy source and as an approach to avoid rumen acidosis, the cows in both groups did not really experience rumen acidosis based on the rumen pH measured in the study. Rumen acidosis often affects DMI, but cows in both groups did not experience rumen acidosis, which may explain why DMI was not affected by treatment. Furthermore, the CON diet might not have contained enough grain to increase rumen fermentation to an extent causing rumen acidosis.

Therefore, replacing barley grain with DDGS may have not increased rumen pH. Based on the results of the current study, if a similar study is to be conducted again, I would increase the amount of barley grain in CON diet to increase rumen fermentation, which would challenge the cows to experience rumen acidosis. If cows are more likely to experience rumen acidosis, it might be easier to detect the effects of replacing barley grain with DDGS. Therefore, the effects of using DDGS fed to early lactation cows on rumen pH warrant further investigation.

In the current study, we compared two levels of dietary starch content. Contrarily, Nelson et al. (2011) used soy hulls to replace corn grain, and evaluated the effect of three levels of dietary starch content in corn silage-based diets fed to multiparous cows in the early lactation. The DMI tended to be higher for cows fed low starch diet (21.0 % of DM) compared with cows fed high starch diet (25.5 % of DM) or medium starch diet (23.2 %), but milk production was higher for cows fed the medium starch diet than cows fed the high starch or the low starch diet. The dietary starch concentrations of the current study were 29.0% and 19.0% for CON and DDGS diets, respectively. The difference in dietary starch concentration between the CON and DDGS diets was about 10%, and this might be too wide, and both diets might not have resulted in optimum animal responses. If a similar study is to be conducted again, I would evaluate the effects of incremental increases in the dietary allocation of DDGS to replace barley grain; the experimental diets will contain several levels of dietary starch content.

Cows fed the DDGS diet tended to have higher digestibility of CP compared with cows fed the CON diet, but we could not explain why. Two experimental diets contained different feedstuffs, and we only measured the apparent total tract digestibility of the diets, and therefore do not know the digestibility of individual feedstuffs. For a future study, I would measure in situ digestibility of individual feedstuffs. In situ digestibility may help us to identify the feedstuff lower in rumen digestibility, and figure out the reason for the tendency of higher digestibility of CP for cows fed DDGS diet.

4.4 Conclusions:

In the current study, DDGS was used as a non-forage high-fiber feedstuff to replace grain in a diet for early lactation cows. The DDGS diet did not have negative effects on milk production, indicating that DDGS can be effectively used as a partial replacement of barley grain in the diets of early lactation cows. Feeding DDGS instead of barley grain will decrease the cost of feed, but this approach may be associated with the risk of decreasing energy intake of dairy cows in early lactation.

4.5 References

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Table 4.1 The cost of feed ingredient and the feed cost.

Ingredient, % of DM	Price $/T	Control % DM	Control Cost	DDGS % DM	DDGS Cost
Barley silage	100	43.1	43.1	43.1	43.1
Corn grain, rolled	236	21.6	51.0	21.6	51.0
Barley grain, rolled	195	17.3	33.7	…	0
Wheat DDGS	194	…	0	17.2	33.3
Corn gluten meal	650	8.3	54.0	…	0
Urea	865	0.3	2.60	…	0
Beet pulp	348	3.2	11.1	12.3	42.8
Concentrate[2]	1000	6.2	62	6.2	62
Total / T			257.5		232.2
Feed cost[1], $/d/cow	/	/	5.12	/	4.65

[1]Feed cost = DMI $\times$ 110% $\times$ cost of diets

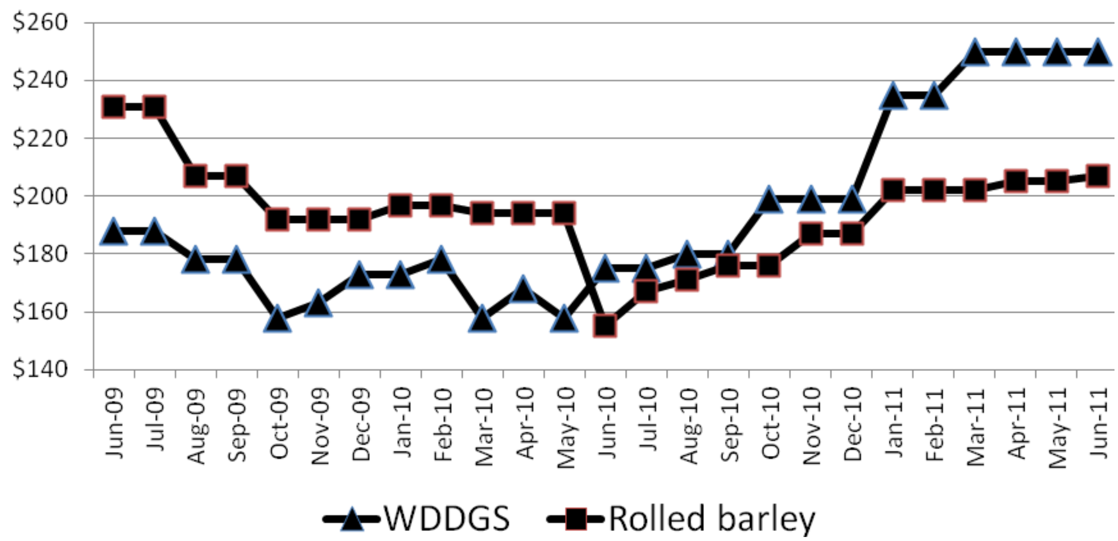

Figure 4.1 Price of DDGS and barley grain in Edmonton area ($/ton) (Jun 2009 to June 2011)