# GRAIN PROCESSING CONSIDERATIONS INFLUENCING STARCH DIGESTION AND PERFORMANCE OF FEEDLOT CATTLE

by

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B.S., Kansas State University, 2008
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AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Animal Sciences & Industry
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# Abstract

Two studies evaluated dry-rolled corn (DRC) manufacturing considerations in feedlot finishing diets. In study 1, feedlots (n = 35) participated in a survey to evaluate dry-rolled corn (DRC) processing practices, processed corn particle size distribution, and fecal starch content in finishing cattle.  Average particle size of dry-processed corn, including DRC and hammermill-ground corn across all operations (n = 35) was 4,223 ± 1,265 µm with a range of 1,165 to 6,823 µm. Fecal starch content averaged 19.0 ± 6.5% with a range of 7.0 to 36.6%. Diet composition was evaluated for co-product [27.8 ± 13.4%] roughage concentration [8.9 ± 2.0%] and NDF concentration [19.3 ± 4.3%]. In study 2, cross-bred yearling steers (n = 360; initial BW = 395 ± 33.1 kg) were used to evaluate the effects of dry-rolled corn (DRC) particle size in diets containing 20% (DMB) wet distiller's grains plus solubles (WDGS) on feedlot performance, carcass characteristics, and starch digestibility. Treatments were Coarse DRC (4,882 µm; COARSE), Medium DRC (3,760 µm; MEDIUM), Fine DRC (2,359 µm; FINE), and Steam-flaked corn (SFC, 0.35 kg/L). Final BW and ADG were not affected by treatment ($P > 0.05$). Dry matter intake was greater and G:F was lower ($P < 0.05$) for steers fed DRC vs. SFC. There was a linear decrease ($P < 0.05$) in DMI in the final 5 weeks on feed with decreasing DRC particle size. Fecal starch decreased (linear, $P < 0.01$) as DRC particle size decreased. In situ starch disappearance was lower for DRC vs SFC ($P < 0.05$) and increased linearly ($P < 0.05$) with decreasing particle size at 8 and 24-h. The final study evaluated steam-flaked corn (SFC) manufacturing practices implemented, equipment utilized, and methods used and parameters targeted to measure flake quality from commercial feedlots (n = 17). Significant variables contributing to the final multiple linear regression model using enzymatic starch availability (Enzymatic) as the dependent variable were: SFC Moisture, cooled flake density (CoolFD), throughput, roll diameter, steam cabinet temperature (Temperature), and temper time (Enzymatic = 19.4476 - (0.6927*SFCMoisture) - (2.1664*CoolFD) - (0.5060*Throughput) + (0.6281*Roll Diameter) + (0.4312*Temperature) – (0.1963*Temper Time; $P < 0.15$).

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# Table of Contents

# List of Figures

# List of Tables

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# Dedication

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"I can do all things through Christ who strengthens me." Phillipians 4:13

# Chapter 1 - Literature Review

## Introduction

Profitability in the beef cattle industry is attributed to cattle health, nutrition, and management. One area of cattle feeding that interlinks these three factors and is critical to maximize efficiency is grain processing. Feed represents from 75 to 80 percent of the total cost of production for feedlot cattle (Richards and Hicks, 2007) so minimal improvements in feed efficiency by grain processing can translate into increased net profit gains. Grains are utilized as a primary energy source in feedlot finishing diets (Brouk, 2010). Approximately 70 to 80 percent of the dry matter in cereal grains is starch and the digestibility of starch can vary by grain species, variety, and processing technique (Guyer, 1976).

Processing grain for feedlot cattle is done to enhance the feeding value of grain by improving the dietary net energy value, improving digestibility and acceptability, and altering associative interactions with digestion (Zinn et al., 2011). Optimizing grain processing can increase digestibility and animal performance but must not negatively alter ruminal pH and induce digestive disturbances (Owens et al., 1997). The most common grain types fed in U.S. feedlots are wheat, barley, sorghum, and corn, but each grain has its own response to processing depending on kernel structure and starch composition (Richards and Hicks, 2007). Grains, such as corn, sorghum, wheat, and barley are routinely processed by rolling or grinding with or without moisture tempering, ensiling high moisture grain, and steam flaking in U.S. feedlots (Zinn et al., 2011).

Decades of research in the area of grain processing and feedlot performance have contributed to a greater understanding of grain processing methods to improve cattle performance. Currently, steam flaking, dry-rolling, and high-moisture ensiling are the most prevalent methods of processing grains in U.S. feedlots (Vasconcels and Galyean, 2007). The degree of grain processing should be optimized to maintain an acceptable level of grain digestion in the total tract and minimize the occurrence of bloat (Cheng et al., 1998). Under processed grains increases feed costs and reduces efficiencies while over processing reduces DMI resulting in poor performance (Hutjens and Dann, 2000). The first objective of this dissertation was to determine an average particle size of dry-processed corn in feedlots located in the Midwestern region of the U.S. The second objective was to take the information from objective one and determine the effects of dry-rolled corn particle size on carcass traits, performance, and starch digestibility in feedlot finishing steers fed a diet containing 20% wet distiller's grains (DMB). In steam flaking operations, additional variables, such as, tempering time, steaming time, conditioning temperature, peg feeder rate, flake density, etc. exist that contribute to considerable challenges mill managers and nutritionists face to maintain consistency on a daily basis. The third objective of this dissertation was to evaluate starch availability of steam-flaked corn comparing roll size and flake density in commercial feedlots.

## Grain Processing

### *History of processing grains for feedlot cattle*

Feeding grain-based diets to cattle was first implemented in the U.S. in the early 1800's. In 1840, the first corn sheller and hammermill was invented (Matsushima, 2006). In the late 1800's and early 1900's the majority of cattle feeding took place in the Corn-belt region of the U.S. with Iowa and Illinois being the major cattle feeding states. This was due, in part, to large supplies of corn and farmers marketing their grain to cattle feeders (Connor et al., 2000).

Grain became the primary energy source and was fed in greater proportions of the diet when commercial cattle feeding began in the early 1940's (Matsushima, 2006). Research in the area of grain processing became of interest since cattle are less able to fully masticate whole grain kernels compared to other ruminant species (Hale et al., 1966; Theurer, 1986). Several grains became available for use in livestock feeds, each varying in size, shape, texture, and nutrient content in their natural condition (Matsushima, 2006). Grain processing was developed to improve animal performance and efficiency by altering the physical and chemical composition of the grain (Matsushima, 2006). Early technology consisted mainly of grinding prior to 1960 because grain processing methods, such as rolling or crushing had little advantage over grinding (Riggs, 1958; Hale, 1973).

Allison (1917) was one of the first to evaluate the effects of feeding shelled, ground, and crushed corn grain to two-year-old yearling steers on performance and average net profit per steer. Ground corn had the greatest ADG but did not translate to greatest net profit per steer because of the additional processing cost. The earliest published research on feeding whole corn to feedlot yearlings was at an inclusion level of 40 to 60 percent of the total concentrates of the diet (Burroughs, 1945). Perry et al. (1956) first reported feeding an all corn-grain diet, demonstrating cattle can be fed greater level of concentrates to increase performance and decrease amount of feed required to fatten steers.

Steam flaking was first invented in the 1960's to better utilize sorghum grain due to the small kernel size and was a necessity to improve digestibility in cattle (Hale et al., 1966). A few years later steam flaking was implemented in corn grain and introduced into large feedlots to improve starch digestion of corn grain (Matsushima, 2006). The earliest research in the area of steam flaking grains suggested a greater feeding value for steam flaked corn compared to cracked corn when fed as a major component of feedlot diets (Matsushima et al., 1964, 1965). From 1962 to 1964 the steam flaking process was established. The first prototype for steam flaking took approximately two years to develop and consisted of No. 2 grade, 12% moisture corn processed through a gravity flow steam chamber (15" x 34" x 6') equipped with 5 steam jets. The duration of the steaming was 11 to 12 minutes with a temperature of 200˚F. Below the steam chamber were two corrugated steel rollers that produced a 1/32' thick flake with 20% moisture content (Matsushima, 2006).

The earliest research comparing steam flaked corn and cracked corn on performance of feedlot cattle was done in a first cooperative field trial at Colorado State University in 1962 and resulted in improved feed efficiency with steam flaked corn but similar daily gains between processing methods (Matsushima et al.,1964). This study raised further questions about which grain processing methods and factors contribute to improved feed efficiency and sparked decades of research contributions to further understanding the benefits of grain processing on cattle performance.

## *Grains for feedlot cattle*

Corn has historically been viewed as the most important concentrate for fattening cattle in the U.S. because of its availability, palatability, and richness in total digestible nutrients and has been the standard against which other grains are compared to such as, wheat, barley, and sorghum (Morrison, 1950). Approximately, 83% of the corn kernel is endosperm, 11% is germ, and the remainder consisting of the bran coat and tip cap (Bunge, 2015). The whole kernel consists of approximately 75% starch, 8.9% protein, 4.0% oil, 1.5% ash, 1.7% sugars, and 8.9% fiber (Bunge, 2015). Compared to other feed grains such as barley, wheat, oats, and sorghum, corn was slightly greater energy and phosphorus content but lesser in protein and calcium (NRC, 1996). Approximately 55 to 60% of the protein in corn is considered ruminally undegradable, or not fermented or degraded in the rumen; however, much is digested by the animal in the small intestine. The ruminally degradable portion is approximately 40 to 45% of the total protein and utilized in the rumen for growth and protein synthesis by ruminal microoganisms (Lardy, 2013). Although corn can be fed whole to cattle, processing corn by rolling or grinding will increase digestibility by 5 to 10 percent (Lardy, 2013).

Sorghum grain is the second most commonly utilized grain in feedlot finishing diets in the Midwest, High Plains, and Southwest regions on the U.S. according to a survey conducted by Vasconcelos and Galyean (2007). Sorghum grain is a more draught resistant crop and is grown in drier climates. It is predominantly used as a feed grain for livestock in the U.S. (Carter et al., 2015). Sorghum typically contains a greater percentage of crude protein than corn, wheat, or barley but energy values are more comparable to that of corn (NRC, 2000). The general composition of sorghum grain is similar to corn, except for a greater protein and lesser fat content. Sorghum grain contains approximately 72 to 76% starch and 8 to 12% protein (Hubbard et al., 1950). Starch granules of sorghum grain are slightly larger and have a greater gelatinization temperature range (68˚ to 76˚C) than corn starch (62˚ to 68˚C; Wall and Blessin, 1969). Previous studies have reported that sorghum grain requires processing in order to obtain optimum digestion and utilization of nutrients (Rooney and Riggs, 1971; Theurer, 1984). Sorghum can be processed by grinding, rolling, or steam-flaking and processing is necessary to disrupt the protein matrix and starch granules to improve digestion by ruminal microbes (Brouk, 2010).

Wheat can be fed as the only grain source in feedlot diets or as a substitute for corn or barley (Morrison, 1950). The composition of wheat is comparable to corn but has slightly greater protein (10.6%), lower fat (1.9%), and lesser starch content (69.7%) but can vary depending on the variety (Alais and Linder, 1991). Early on, wheat was recognized as a satisfactory grain to be fed to fatten cattle when priced comparable to corn but should be coarsely ground or rolled to prevent cattle from going “off feed” (Morrison, 1950). Zinn et al. (1994) evaluated the effects of steam-rolled wheat compared to dry-rolled wheat and reported improved energy intake and daily weight gain, improved feed efficiency, net energy value, and ruminal escape and post-ruminal absorption of feed nitrogen with steam rolled wheat. Flake thickness of steam-rolled wheat was also evaluated and no improvement was reported when decreasing flake thickness from 1.35 to .95 mm (Zinn et al., 1994). Contrarily, Brethour (1970) reported similar results when steam-rolled wheat was compared to coarse ground wheat. Previous research has evaluated ways wheat can be utilized more efficiently in beef cattle diets by feeding wheat in combination with corn (Gramlich and Thalman, 1930), oats (Trowbridge and Moffett, 1930), and barley (Vinke and Pearson, 1931).

Traditionally, Barley is considered to be the fourth most utilized cereal grain in the world and is a more drought tolerant crop that is grown in more temperate regions (Anderson et al., 2012). Similar to wheat and sorghum, barley requires processing to make the starch accessible for improved ruminal and enzymatic digestion (Anele et. al, 2014). The endosperm of barley is surrounded by the pericarp, which is resistant to microbial attack in the rumen (Dehghan-banadaky et. al, 2007). Barley is composed of approximately 11.0% crude protein, 4.7% crude fat, 3.7% crude fiber, and 55.8% starch (Alais and Linder, 1991). Toland (1976) compared whole and dry-rolled barley in beef steers and reported a 32.7% improved digestibility with dry-rolled barley. In agreement, Rainey et al. (2006) evaluated the effects of feeding whole vs. dry rolled barley on efficiency of nutrient digestion and growth and determined depressed starch digestibility with whole barley. Beauchemin et al. (1994) evaluated the effects of mastication on ruminal digestion of whole barley, corn, and wheat. Mastication influences the type and extent of processing to improve digestibility of starch and protein. Cattle spent twice as long ruminating per kilogram of DM when fed barley compared to corn indicating the need for physical processing for barley and wheat over that of corn.

Oats are a suitable option for feeding to finishing cattle but have a lesser energy value compared to other grain sources (i.e. corn, barley, sorghum, or wheat) and greater fiber content because 24-30% of the kernel is the hull (Comerford, 2015). Typically, oats are included in growing or creep feed diets because of its lesser energy and greater fiber composition (Dinusson et al., 1973). Dinusson et al. (1973) reported that cattle did not perform as well when oats were fed as the only grain in a finishing diet in terms of rate of gain, feed efficiency, or carcass characteristics. However, they reported similar performance when replacing only 30% of the barley in a finishing diet with oats. Oats can be processed by rolling to achieve approximately 5% increase in efficiency (Comerford, 2015).

Grain type and processing methods were evaluated in a review (Zinn et al., 1997). Metabolizable energy (ME), dry matter intake, and feed-to-gain values were compared for barley, corn, sorghum, oats, and wheat fed at levels greater than 55% of the diet DM ad libitum and a single grain and processing method were employed. The observed ME value and feed-to-gain was less for sorghum than any other grain evaluated except oats. Dry matter intake was less for wheat-based diets and greatest for sorghum-based diets. When fed whole, corn and sorghum have the least ruminal and total tract starch digestibility (Waldo, 1973; Owens et al., 1986). However, both grains respond favorably to extensive processing with heat and moisture because they have starch bound by insoluble protein (Rooney and Pflugfelder, 1986). Grain processing improves ME content of most grains, especially when comparing whole and processed barley (Zinn et al., 1997).

### *Grain processing in the feedlot*

Processing grain for feedlot cattle is done to enhance the feeding value of grain by improving the dietary net energy value, improving digestibility and acceptability, and altering associative interactions (Zinn et al., 2011). The most common methods practiced in feedlots in the U.S. are dry-rolling or dry-grinding with and without tempering, high-moisture grain ensiling, and steam flaking (Zinn et al., 2011). Owens and Soderlund (2006) reported improved total tract starch digestibility when grain was steam-flaked, ground, or dry-rolled compared to whole grain. Similarly, steam flaked corn has consistently showed improved starch digestibility compared to whole corn, dry-rolled corn, or ground corn (Matsushima and Montgomery, 1967; Lee et al., 1982; Zinn et al., 2002). In addition, grinding or cracking improves starch digestion and BW gain efficiency compared to whole corn (Galyean et al., 1979; Turgeon et al., 1983).

Dry-rolling grain is one of the most cost effective processing methods and is widely utilized in feedlot operations in the U.S. (Anderson et. al, 2012). Grains are sheared and compressed between two corrugated rolls operating at differential speeds to reduce the particle size (McKinney, 2006). As more surface area of the grain kernel is exposed, improved microbial and enzymatic digestion of nutritional components such as starch and protein can occur and therefore may increase animal performance (Koch, 2002). However, over-processing grains resulting in too much fine material can result in a rapid rate of fermentation that could induce digestive disturbances including acidosis and bloat (Owens et al., 1997). In addition, over-processing results in unnecessary wear on equipment and wasted electrical energy (Koch, 2002).

In the dry-rolling process, grain is evenly fed through a feeder and crushed between two corrugated steel rolls that counter rotate to pull the grain through the roll nip to make a clean, sharp cut reducing particle size and increasing surface area (Heiman, 2005). Grain that is passed through rolls that are positioned more closely together will result in a finer particle size and wider set rolls will provide a more coarsely cracked grain (Koch, 2002). Particles tend to be uniform in size and irregular in shape reducing the ability to pack. Rolled grain will have a 5 to 15% less bulk density compared to ground grain (Koch, 2002). Optimizing dry-rolling practices is important for improving ingredient performance during mixing and for improving the nutritive value of a feed ingredient (Koch, 2002). Under-processing increases feed costs and limits animal performance, while over processing can lead to reduced DMI and poorer animal performance (Hutjens and Dann, 2000).

Owens et al. (1997) published a review that compared rate of gain and DMI for grain processing methods of different grains. Dry-rolled corn, sorghum, and barley had similar rate of gain of 1.45, 1.43, and 1.45 kg/d, respectively. Oats had 1.53 kg/d and wheat a 1.38 kg/d rate of gain. Dry-rolled sorghum had the greatest DMI followed by corn, oats, wheat, and barley at 10.47, 9.45, 9.20, 8.97, and 8.96 kg/d, respectively. Feed efficiency was reported as oats, barley, corn, wheat, and sorghum having 6.01, 6.25, 6.57, 6.59, and 7.43, respectively. Observed metabolizable energy content was greatest for dry-rolled barley, followed by dry-rolled oats, wheat, corn, and sorghum at 3.40, 3.36, 3.32, 3.26, and 2.94 Mcal/kg, respectively. Stock and Britton (1993) compared dry-rolled grains for rates of ruminal fermentation and reported the most rapid rate of fermentation was dry-rolled wheat followed by dry-rolled barley, dry-rolled corn, and dry-rolled sorghum.

Grinding grain for feedlot cattle is typically accomplished using a hammermill. During the grinding process, grain enters through a delivery device and is impacted by free-swinging steel bars rotating at a very high speed causing a reduction particle size (Koch, 2002). The transfer of energy from the collision force of the rapidly moving hammer and the grain kernel with low kinetic energy causes the grain to be fractured into many pieces (Koch, 2002). The speed at which the hammers rotate influences the collision force and particle size reductions (Anderson et al., 1994). Once a particle reaches a certain size, it is discharged through a screen and conveyed to a storage bin or pile. Hammermill ground grain produces particles that are generally spherical in shape with a polished surface and can vary widely in particle size distribution (Koch, 2002).

High moisture grain has been fed to cattle for decades and consists of early harvesting corn or sorghum when the moisture level is around 25 to 30% and ensiled in air tight conditions, such as a silo or bunker (Mader and Rust, 2006). Grain can be either rolled or ground prior to packing. Rolled grain is preferred because it is easier to manage; however, ground grain packs better resulting in less spoilage and fermentation loss (Hicks and Lake, 2005). Rolled compared to ground HMC simplifies bunk management while improving DMI and ADG. Ideally, feeding ensiled high moisture grain by rolling and grinding would improve the packing and ensiling process but also improve cattle performance (Hicks and Lake, 2005). Early research determined animals fed high moisture grain have a 5% improved weight gain and consumed 2% less feed (Plasto, 1971). In a review by Owens et al. (1997) it was reported that moisture and processing form or particle size of high moisture corn influences animal performance. Average daily gain and feed efficiency was greater for ground than for rolled HMC and improved with increasing moisture. For maximum rate and extent of starch digestion, grain should be finely processed, but excessively fine processing may induce acidosis (Hicks and Lake, 2005).

Steam flaking grains is another grain processing method commonly practiced in larger commercial facilities. Steam flaking corn improves the net energy value of corn for maintenance and BW gain by 15 to 19%, respectively (Corona et al., 2005). When grain is steam flaked, whole grain can be soaked with our without a surfactant or grain conditioner to improve moisture uptake. Grain is steamed at atmospheric pressure in a steam cabinet with temperatures around 212˚F for approximately 20 to 40 min (Heiman, 2005). The steam conditioned grain is then passed through two corrugated steel rolls and flaked to a density most often ranging from 0.309 to 0.412 kg/L (Ambruster, 2006). Variations in steam cabinet size and capacity, steam pressure and temperature can influence the retention time in the steam cabinet. The rate at which the grain flows through the steam cabinet is altered by changing the speed of the peg feeder which is located directly above the rolls and rotates to move grain into the rolls. The faster the peg feeder rotates the more grain is passed through the rolls.

Prior to heat processing, grain can be tempered or soaked in water to improve moisture uptake of the grain kernel reducing the amount of time and moisture addition required in the steam chamber. This practice is more applicable when steam chambers are too small to provide sufficient time for moisture and temperature to fully penetrate each kernel (Heimann, 1999). When starch is heated continuously, grain is steam conditioned in an atmospheric pressure chamber where moisture and heat penetrate and thoroughly soften each grain kernel to achieve durable flakes with a great degree of starch gelatinization (Heimann, 2005). Flake thickness is determined by the clearance, or roll gap between the rolls; flake thickness, durability, and consistency are major factors to consider when steam flaking (Karr, 1984). As the degree of processing increases, flake density decreases, which increases the amount of available starch for digestion for corn (Zinn et al., 1990a; Sindt et al., 2006b) and sorghum (Reinhardt et al., 1997; Swingle et al., 1999).

When feeding sorghum grain in feedlot diets, steam-flaking is the primary processing method used (Swingle et al., 1999). During the steam flaking process, moisture, heat, and pressure is used to expose starch and protein available for ruminal digestion and influence the degree of improvement in starch and protein availability (Theurer, 1986). Steam flaked compared to dry-rolled grain has repeatedly showed differences in the amount of starch available for digestion. More extensive processing influences starch digestion in sorghum (Franks et al., 1972; Hinman and Johnson; 1974; Reinhardt et al., 1997) and corn (Galyean et al., 1976; Zinn, 1990). Greater concentrations of ruminal VFA were reported in steers fed steam flaked compared to dry-rolled sorghum (Franks et al., 1972; Hinman and Johnson; 1974). Steam flaking improves the feeding value of sorghum grain by improving ruminal and total tract starch digestion by 12 to 15% (Hale, 1973; Swingle, 1992; Huntington, 1997).

### *Factors influencing dry-processing*

Tempering or soaking grain in water prior to dry-rolling has been used to reduce mechanical wear on equipment and to standardize some variation with particle size (Mathison et al., 1997). In the tempering process, surfactants can be used to improve moisture uptake and enhance water penetration (Wang et al., 2003). Wang et al. (2003) evaluated the effects of tempering and roller setting on ruminal degradation and growth performance of backgrounding and finishing feedlot steers fed processed barley. Barley grain was soaked with or without surfactant for 4 hours prior to rolling and processed at two different roll settings to produce particles with a kernel thickness of 1.98 to 2.00 mm and 2.21 to 2.24 mm. Tempering did not affect ADG, DMI, or G:F during the backgrounding phase but those variables were improved during finishing. Surfactant also improved G:F but not DMI or ADG. The effect of tempering on animal performance was mediated by roll setting, moisture content of the whole grain, and composition of the diet. More extensively processed barley included in the diet at 85.1% DM showed a greater response in finishing cattle compared to backgrounding cattle that were fed a 47.1% DM barley grain diet (Wang et al., 2003).

Previous research has evaluated the effects of processing of dry-rolled corn in feedlot finishing diets (Secrist et al., 1996; Corona et al., 2005; Plascencia et al., 2007). Secrist et al. (1996) evaluated feedlot performance and carcass traits for steers fed dry-rolled corn ground to 1,550 µm or 3,100 µm and determined no differences for feed intake, gain, feed efficiency, or carcass merit but reported a tendency for greater DMI in cattle fed coarsely rolled corn than cattle fed finely rolled corn or whole corn. Similarly, Corona et al. (2005) compared the effects of whole corn, dry-rolled corn, ground corn, and steam flaked corn on digestion and growth performance of finishing feedlot cattle. The proportion of grain particles that were <1 mm in diameter was 68% greater for ground corn compared to dry-rolled corn. Gain efficiency and ADG were not different for DRC and GC treatments. Plascencia et al. (2007) compared cracked, coarse, or fine dry-rolled corn with densities of 0.55 kg/L, 0.50 kg/L, and 0.45 kg/L, respectively, on digestion and rumen function of feedlot finishing steers fed a 73% corn-based diet. Particle size of each treatment were calculated to be approximately 2,634, 3,512, and 3,991 µm for fine, medium, and coarse DRC, respectively. Total tract starch digestion increased linearly with increasing DRC degree of processing; however, total tract digestibility of OM and GE was not improved. Therefore, it was concluded that dry-rolling corn beyond a coarse particle size (3,991 µm) would not improve the feeding value of dry-processed corn.

Diets evaluating the degree of processing of DRC in combination with wet or dried distiller’s grains or wet corn gluten feed (WCGF) have been previously evaluated (Loe et al., 2006; Swanson et al., 2013; Schwandt et al., 2015). Loe et al. (2006) evaluated the effects of dry-rolled barley (2,150 and 2,590 µm) or corn (1,900 or 3,230 µm) particle size in diets containing varying levels of WCGF on finishing steer performance and determined that reducing particle size of either grain did not influence feedlot performance. Swanson et al. (2013) evaluated the effects of feeding coarse DRC (2,680 µm) vs fine DRC (1,460 µm) in diets containing up to 40% dried distiller's grains with solubles (DDGS) and reported decreased DMI and increased G:F with increasing inclusion level of DDGS but was not effected by DRC particle size. In addition, carcass traits were not significantly influenced by DRC particle size or DDGS inclusion level. More recently, Schwandt et al. (2015) evaluated the effects of feeding coarse, medium, and fine DRC (4,882, 3,760, and 2,359 µm, respectively) in diets containing 20% (DMB) wet distiller's grains and reported a linear decrease in DMI in the final 5 weeks on feed with decreasing particle size. Final BW, ADG, and carcass traits were not affected by treatment; however, fecal starch decreased linearly with decreasing particle size indicating improved total tract starch digestion as the degree of processing increased.

Kernel composition and starch structure can also influence the value of grain processing and the feeding value of grain. More specifically, the interaction between starch and protein can alter the digestibility of grain fed to livestock (Rooney and Pflugfelder, 1986). Vitreousness or kernel hardness describes the starch structure of certain varieties of corn. Flint corn varieties have hard or horny starch in the endosperm, whereas dent varieties are more of a cross between hard and floury endosperm (Corona et al., 2006). Corona et al. (2006) evaluated the effects of corn vitreousness comparing dry-rolling and steam flaking on the site and extent of starch digestion by feedlot steers. Steam flaked corn had greater ruminal, post-ruminal, and total tract digestion compared to dry-rolled corn. Less vitreous corn grain had greater post-ruminal digestion which contributed to improved total tract starch digestion. Additionally, adverse effects were eliminated when vitreous varieties were steam flaked indicating vitreousness becomes a factor to consider when dry processing grain.

### *Processing factors influencing steam flaking*

The steam flaking process is comprised of many essential components that contribute to increased starch availability and durability of processed grains. Processing factors to optimize efficiency and feed quality are addressed in published review articles (Osman et al., 1970; Zinn et al., 2002). Osman et al. (1970) suggested that moisture, heat, and pressure are the primary factors that influence the benefits of grain processing. As suggested by Zinn et al. (2002) there are five critical factors that influence the quality of steam flaked corn: 1) steam chest temperature; 2) steaming time; 3) roll corrugation; 4) roll gap; and 5) roll tension.

Grain is theoretically presented to the rolls at 18 to 21% moisture and 100˚C after being steamed from approximately 30 to 60 minutes; however, steaming time can vary depending on flake thickness and quality desired (Heiman, 2005). Steam can be presented to the grain primarily as wet steam or saturated steam. Wet steam is in a liquid and vapor phase and requires a 24˚ F temperature rise per percent moisture increase of the grain with 85% steam quality. Saturated steam is in a purely vapor phase and requires 28˚ F temperature rise per percent moisture increase with 100% steam quality (Heiman, 2005). To adjust for various temperatures and moisture contents of grains entering the steam chamber the steam quality should be controlled by adjusting the boiler pressure (Heiman, 2005). Typically, lower boiler pressures are used when conditioning very dry grain because less heat (BTUs/lb) is added causing more moisture added per degree of temperature rise (Heiman, 2005).

Steaming time is controlled by a feeder bar (i.e. pin feeder) located at the base of the steam cabinet directly above the rolls and determines the rate of feeding and distribution of grain entering the flaking rolls (Zinn et al., 2002). Adequate steaming time ensures that heat and moisture completely penetrate each kernel producing durable flakes with high starch gelatinization (Heiman, 2005). In some flaking operations, grain is tempered or soaked in water for a certain period of time prior to entering the steam cabinets. Moisture addition during tempering increased flake durability but did not influence starch availability in corn (Sindt et al., 2006a). To aid in moisture uptake, grain conditioning agents or surfactants can be used (Zinn, 1998; Wang et al., 2003). Sindt et al. (2006a) evaluated the effects of surfactant concentration (0 or 63 mL of SFC/t), tempering moisture concentration (0, 6, or 12% moisture, wt/wt), steam conditioning time (20 or 40 min), and flake density (.360, .335, or .310 g/L) on corn moisture content and reported that increasing tempering caused an increase in corn moisture content after tempering, steam conditioning, and flaking. In addition, adding surfactant did not influence corn moisture content after tempering, steam conditioning, or flaking.

McDonough et al. (1997) reported similar results on flake durability of sorghum grain when adding moisture; however, starch availability did increase with increased moisture addition of flaked sorghum. These differences are likely attributed to the protein-starch matrix differences between corn and sorghum. Sorghum has both hard and soft endosperm cells. Hard endosperm cells are a more tightly packed structure with no air spaces and a stronger protein and starch adherence (Hoseney et al., 1974). The tightly bound protein and starch structure allows sorghum to respond more favorable to extensive processing compared to corn (Rooney and Pflugfelder, 1986). When flaking, sorghum grain may require more moisture addition before processing due to the tightly bound protein-starch matrix allowing improved disruption and greater microbial and enzymatic starch digestion (Sindt et al., 2006b). During tempering of grain kernels prior to processing, surfactants can be used to improve the rate of moisture absorption (Zinn et al., 1998; Wang et al., 2003) and decrease the amount of moisture lost after flaking by decreasing surface moisture (Sindt et al., 2006b). Previous research by Zinn (1990b) suggested that steam conditioning grain prior to flaking can add up to 5% of moisture to the grain and steaming time may be reduced to 30 minutes which may be sufficient to achieve optimal flake quality and feeding value.

Roll corrugations or grooves along the length of the rolls aid in pulling grain through the rolls (Heiman, 2005). When flaking, the goal is to crimp the flake requiring the roll corrugations to have a flat top to the tooth profile (Heiman, 2005). The number of grooves per inch also contributes to end product results and is specific to type of grain being processed. For instance, 4, 5, or 6 grooves per inch (gr/in) are common for corn; 6, 8, or 10 for sorghum; and 12 to 15 gr/in for other small grains (Heiman, 2005). However, rolls used in steam flaking operations typically utilize relatively fine corrugations (14 to 20 gr/in) to refrain from cutting the grain (Heiman, 1999). Roll corrugations wear over time and require recorrugation approximately every 6 months to one year depending on usage. Measuring roll wear is highly subjective but can be approximated by evaluating product quality and production capacity. Production loss of 20% or more due to having to slow down throughput can be one indicator of significant roll wear and recorrugation is needed (Heiman, 2005).

The roll gap is the distance between the rolls and adjusted to achieve a desired flake thickness. Zinn et al. (1990a) reported that flake thickness was related to flake density; however, there was relatively low correlation ($R^2 = 0.74$) and likely due to variation in kernel hardness, tension across the rolls, and difficulties in measurement practices. Previous work has evaluated the effect of flake density on animal performance in corn and sorghum (Reinhardt et al., 1997; Swingle et al., 1999). Decreasing flake density increases the degree of gelatinization and starch availability in corn (Zinn et al., 1990; Sindt et al., 2006) and sorghum (Xiong et al., 1990;

Reinhardt et al., 1997; Swingle et al., 1999). Zinn et al. (1990a) evaluated steam flaked corn flaked to densities of 0.425, 0.360, and 0.301 kg/L (28, 24, and 20 lb/bu) and reported a linear decrease of ruminal pH and linear increase in postruminal and total tract digestibility of starch. Reinhardt et al. (1997) compared sorghum grain flaked to 0.283, 0.322, and 0.362 kg/L (i.e., 22, 25, and 28 lb/bu) and determined steers fed the lower density flaked grain consumed 3.2% less DM, had 6.9% lower ADG, and 3.6% lower gain efficiency compared to the 0.362 kg/L flake density indicating optimal flake density of sorghum grain to be 0.362 kg/L to refrain from greater susceptibility to subacute acidosis.

Roll tension implies the amount of ram pressure applied to the rolls to maintain a certain flake thickness. Rolls can be set to zero tolerance with zero initial roll gap and low pressure tension or at a fixed distance with greater pressure tension. The amount of pressure applied to the rolls will depend on the desired flake density (Zinn et al., 2002). Zinn et al. (2002) reported that initial roll gap can influence fecal starch excretion. Fecal starch was decreased 25% when the initial gap was 1.0 mm compared to zero tolerance and suggested that it might be due to the 1.0 mm setting allowing fewer poorly processed kernels to pass through the rolls.

## Feedlot Nutrition

### ***Starch availability & digestibility***

The chemical and physical components of feed ingredients determine the energy value and ability for the animal to efficiently utilize feed. Soluble and insoluble carbohydrates and starch provide the greatest source of energy to the ruminant animal and are the most common digestible carbohydrates in forages (Hungate, 1966). Soluble carbohydrates, or sugars, are rapidly metabolized and may constitute 30% of the dry matter in forages (Waite and Boyd, 1953). Insoluble carbohydrate includes cellulose, hemicellulose, and lignin as major components and is what forms the fiber mat that stimulates rumen function (Van Soest et al., 1991).

The majority of the digestible energy in high concentrate feedlot diets comes from starch (Owens and Soderlund, 2007). Starch is a semi-crystalline material comprised of amylose and amylopectin polymers that are hydrogen bonded and which unravel during gelatinization (Biliaderis, 1998). The degree of crystalline structures within granules is a major factor that determines the starch properties (Ratnayake and Jackson, 2006) and starch moisture content (Cleven et al., 1978). Raw starch is relatively insoluble and resistant to amylolysis (Leach and Schoch, 1961). When exposed to heat or steam during grain processing, starch granules swell and crystallites melt resulting in the separation of amylose and amylopectin chains and the starch becomes gelatinized (Ratnayake and Jackson, 2006). During gelatinization, starch molecules absorb water causing granular swelling, lose birefringence, and become more susceptible to enzyme degradation (Rooney and Pflugfelder, 1986; Atwell et al., 1988). This allows the starch granule to be more readily digested or hydrolyzed by amylases (Sullivan and Johnson, 1962) resulting in a more complete and rapid rate of fermentation (Owens, 2005). The degree of gelatinization of starch during processing is mainly attributed to grain moisture, steaming time, and roll gap (Zinn et al., 2002). A combination of heat, water, and mechanical action is involved in ensuring starch gelatinization occurs. Heat and water cause starch granules to swell and mechanical rolling provides compression to tear apart some of the swollen granules (Rooney and Pflugfelder, 1986). Ultimately, McNeill et al. (1975) stated that "processing methods which produce a change in the organization of the sorghum grain kernel to release starch granules from the protein matrix offer promise of increasing carbohydrate utilization." In addition, the change in starch during processing is often measured as the amount of gelatinized starch that is available to the rumen microbes and/or the animal (Hale, 1973). Furthermore, in previous studies where the starch portion of the grain was completely gelatinized, animal performance was reduced (Pope et al., 1963; DeBie and Woods, 1964).

The starch and protein interaction of cereal grains has a direct effect on the digestibility of starch (Rooney and Plugfelder, 1986). Each starch granule in cereal grains is surrounded by a protein matrix that contributes to the rate and site of starch digestion (McAllister and Cheng, 1996). Most often, grain processing is done to disrupt the protein matrix of the endosperm to increase the surface area and expose starch granules thus increasing enzymatic degradation of starch (Hale, 1973). Theurer (1984) reported that the extent at which protein is digested determines the extent of starch digested in the rumen. Hale (1973) addressed an interesting point regarding the alteration of grain protein during processing suggesting that of the grains typically processed for cattle, sorghum has the highest protein content and lowest apparent digestibility of protein; however the grain that is improved the most by processing is sorghum.

Starch granules of different cereal grains have varying physical characteristics that impact starch degradation by ruminal microorganisms. Shape and size of the starch granules are different between corn, barley, sorghum, wheat, and oats and influence which ruminal microorganism can most efficiently and effectively digest the starch granule (McAllister et al., 1990). Herrera-Saldana et al. (1990) evaluated rates of starch digestion of five similarly processed cereal grains using in vitro and in situ methods and determined oats to be the most rapidly fermented, followed by barley, wheat, corn, and then sorghum. Bacteria digest starch granules from the inside out and digestion varies among grain types (McAllister et al., 2006). Depending on the length of exposure, bacteria may digest all of the starch leaving all or most of the protein matrix and endosperm cell wall intact (McAllister et al., 2006). The relationship between grain type and rate of fermentation can be attributed to differences in the properties of the protein matrix (McAllister et al., 1990b).

Post-processing changes in starch digestion can be influenced by retrogradation in which starch molecules reassociate to tightly bound structures (McAllister et al., 2006). For cereal grains that contain greater levels of amylose, retrogradation may be more prevalent since retrograde starch is resistant to digestion by amylases (McAllister et al., 2006). Additionally, the storage temperature of processed grains can dictate rate of retrogradation (Jouppila et al., 1998). However, steam processed grains in a feedlot setting are rarely stored for long periods of time and retrogradation is less of a concern (McAllister et al., 2006). In addition, Zinn and Barrajas (1997) reported no difference in ruminal or total tract starch digestion between fresh and air-dried steam flaked corn. McMeniman and Galyean (2007) evaluated how different conveying systems and rate of cooling of steam flaked grain affect starch retrogradation by measuring in vitro dry matter disappearance (IVDMD). Their findings suggest that the rate of cooling alters starch availability and IVDMD possibly by affecting starch retrogradation. Flake fragmentation, which creates fine starchy material, is another post-processing concern that might influence starch digestion and occurs during mixing and handling. Tempering grain moisture level, use of surfactant, steaming time, and flake bulk density all influence flake durability (Sindt et al., 2006a). However, Montano et al. (2014) evaluated the effects of flake fragmentation (59% reduction in mean particle size) on performance and reported no negative effects on diet acceptability or growth performance of feedlot cattle. Similarly, Sindt et al. (2006) simulated excessive mixing causing a 29% reduction in mean particle size of SFC and did not report any differences in DMI or growth performance.

Methods used to measure the amount of available starch have been evaluated (Xiong et al., 1990). Bulk density is one measurement that is quick, easy, and low cost and has been used as a quality control procedure (Xiong et al., 1990); however, using bulk density as a measure of starch availability has been disputed. Starch availability for a given bulk density may differ due to processing and kernel characteristics such as kernel size and moisture, steam conditioning time and temperature, and roll wear (Karr, 1984). Vasconcelos and Galyean (2007) surveyed feedlot consulting nutritionists and determined that the enzymatic method was preferred by most of the nutritionists surveyed followed by gas production method, gelatinization, and Flake Color Index System (FCIS; Lextron Inc., Greeley, CO). Enyzme hydrolysis is one method used to determine starch availability but is costly and time consuming (Xiong et al., 1990).

### *Site and extent of starch digestion*

The rumen is the first site of starch digestion where microorganisms rely on a continuous supply of digestible feeds to convert into energy. The rate and extent of starch digestion is influenced by grain type, grain processing, diet, and ruminant species and can alter the composition of microbial fermentation acid produced, ruminal pH, and the amount and physical form of starch that is available for postruminal digestion (Theurer, 1986; Owens et al., 1986).

Ruminal bacteria such as *Steptococcus bovis*, *Ruminobacter amylophilus, Prevotella ruminicola, Butyrivibrio fibrisolvens, Succinimonas amylolytica* and *Selevonmonas ruminantium* have been identified as the primary starch digesting bacteria in the rumen (Cotta, 1988). Protozoal species in the rumen additionally degrade starch and may contribute up to 50% of starch digestion in the rumen (Jouany and Ushida, 1999). Protozoa aid in modulating ruminal pH (Ushida et al., 1991) and predate amylolytic bacteria (Nagaraja et al., 1992). Inclusion of high levels of grain in the diet increases the rate of fermentation and can reduce ruminal pH, inhibit protozoal growth and proliferation (McAllister et al., 2006). Furthermore, at lower pH amylolytic microbes are able to proliferate and out-compete cellulolytic bacteria (Mould and Orskov, 1983). Mendoza et al. (1993) compared faunated and defaunated animals fed high-grain diets with respect to starch digestion in the rumen and determined an increase in ruminal starch digestion without the presence of protozoa and a shift in starch digestion to the small intestine. Protozoa influence ruminal starch hydrolysis by ingesting bacteria to decreased ruminal fermentation rates (Clark and Bauchop, 1977; Kurihara et al., 1978) and by ingesting whole starch granules and soluble sugars thus reducing the amount of substrate available for fermentation by bacteria (Coleman, 1992). Ruminal fungi are not considered major contributors to starch digestion but a few species exhibit amylase activity and are involved in starch digestion (McAllister et al., 2006).

When feed particles enter the rumen, microbes either associate with the ruminal fluid or attach to feed particles or rumen wall (Cheng and McAllister, 1997). Upon attachment, the microbes adhere to the cell surface and are stabilized and protected within the extracellular polysaccharide glycocalyx (Chesson and Forsberg, 1989). Microorganisms receive a large proportion of the nutrients released during digestion of the feed particles (Wang and McAllister, 2002). Fermented feed particles are converted into organic acids (i.e. short chain fatty acids and lactic acid) in the rumen (Aschenbach et al., 2011). Several enzymes are required to convert starch to glucose. Enzymes involved in the hydrolysis of starch are phosphorylase, alpha-amylase, beta-amylase, amyloglucosidase, isoamylase, and pullulanase (Tester et al., 2004). Glucose is then converted to volatile fatty acids, $CO_2$, $CH_4$, and $NH_3$.

Ruminal volatile fatty acids (VFA) are the primary source of energy for ruminants (Stewart et al., 1958). The predominant volatile fatty acids produced in the rumen are acetate, propionate, and butyrate. Proportions of VFAs that are produced in the rumen are influenced by substrate composition and availability, rate of depolymerization, and microbial species present (Dijkstra, 1994). In addition, volatile fatty acid concentration has been shown to be related to dry matter intake (Williams & Christian, 1956) and observed VFA ratios can be influenced by sample location in the rumen, interval after feeding, and the level and frequency of feeding (Bath & Rook, 1963).

Ruminant diets are primarily composed of hexose polymers such as cellulose, starch, fructans, and pentose polymers (Martin, 1994). Hexose fermentation via the Embden Meyerhof pathway converts glucose to pyruvate (Baldwin, 1965). Lactate is converted to acetate, formate, $CO_2$, $H_2$, succinate, propionate, and butyrate (Baldwin, 1965). Acetate is a major product of fiber-digesting bacteria and exists in greater concentrations than other VFAs (Nagaraja, 2013). Acetate is absorbed by the rumen and metabolized by the body tissues for energy (Nagaraja, 2013). Propionate is the second most predominant VFA in the rumen and production increases with increasing level of grains in the diet (Nagaraja, 2013). Propionate is a hydrogen sink product so propionate production is negatively related to methane production (Nagaraja, 2013); thus, increasing efficiency of starch digestion post-ruminally (Nocek and Tamminga, 1991). Butyrate synthesis occurs from acetate, pyruvate, or glutamate (Leng, 1970).

Diet composition influences the acid-base balance (Riond et al., 2001) and finishing diets with low roughage level and high concentration of processed grains increases the concentration of total acids in the rumen (Owens et al., 1998). Greater proportions of propionate are produced with increasing amounts of starch in the diet (Reid et al., 1957; Balch et al., 1958). Bauman et al. (1971) reported a 3-times greater proportion of propionate produced for cows fed a high grain, low fiber diet. In agreement, Hungate et al. (1961) evaluated the rate of VFA production and found the ratio of propionic to acetic and butyric acids was correlated to the amount of grain fed to lactating dairy cows and reported 5% less methane and increased propionic acid production with greater levels of grain in the diet. Phillipson (1952) reported a decreased acetate-to-propionate ratio in the rumen when corn was steam flaked. Similarly, Shaw et al. (1960) determined a shift in VFA concentration to greater propionic acid when corn was steam flaked Orksov et al. (1968) reported that the extent of fermentation in the rumen is attributed to diet and intake.

### ***Post-ruminal starch digestion***

Post-ruminal starch digestion is more energetically efficient compared to ruminal fermentation (Harman and McLeod, 2001). Energy losses due to heat and methane production are reduced when digestion occurs in the intestine compared to the rumen (Owens, 2006). The amount of starch available for post-ruminal digestion is more important when ruminal starch fermentation is low and more starch is passed into the intestines (Owens, 2006). Therefore, factors such as, passage rate and rate of digestion influence retention time in the rumen and could influence ruminal starch digestion (Allen and Mertens, 1988). Huntington et al. (2006) reported that the limitations to improved growth performance were due to the amount of starch digested and absorbed in the small intestine. As grain is more extensively processed (steam flaking, high moisture, fine grinding) more digestion occurs in the rumen and the amount of starch reaching the small intestine is reduced (Theurer, 1986). Xiong et al. (1991) demonstrated that steam flaking sorghum increased starch digestion in the rumen and less starch available for digestion post-ruminally. Similarly, Zinn (1993; 1994) reported that steam-rolling grain caused an increase in ruminal retention time compared to dry-rolling. Ultimately, the residence times of feed in the rumen dictates the extent it will be digested (Cerrilla and Martinez, 2003).

Owens (2005) published a review comparing research evaluating the site and extent of starch digestion in feedlot cattle. Total tract starch digestion for high moisture, steam flaked, dry rolled, and whole corn averaged 98, 97, 90, and 84%; ruminal starch disappearance averaged 85, 77, 55, and 77%; post-ruminal starch disappearance averaged 95, 93, 72, and 53%, respectively. Total tract starch digestion was increased as the degree of processing increased (Owens, 2005). The site of starch digestion shifts more towards ruminal digestion for high moisture and steam flaked corn; however, starch digestion in the small intestine also increases with increasing processing improving overall starch utilization and improved efficiency (Rowe et al., 1999). Early on, Morrison (1959) reported that feeding whole shelled maize resulted in 18-35% of the grain goes undigested.

Processing conditions such as grain moisture, particle size, and steaming time are the main factors contributing to the site and extent of starch digestion (Zinn et al., 2002). Wu et al. (1994) reported that the main site of digestion for steam flaked sorghum was the rumen and dry-rolled sorghum was the intestine. Cheng et al. (1994) evaluated the effects of steam flaking corn and sorghum on performance of dairy cows and reported higher rumen digestibility of starch, increasing ruminal VFA concentration and VFA absorption from the rumen. In agreement, Poore et al. (1993) reported higher ruminal and total tract starch digestibility for steam flaked vs. dry-rolled sorghum. The extent of digestion, either ruminal or post-ruminal, is primarily influenced by the amount of surface area exposed for microbial and enzymatic attack (Owens, 2005). In addition, the grain type and variety also affect the site of digestion (Cerrilla and Martinez, 2003). Corona et al. (2005) determined greater (6%; $P < 0.01$) starch digestibility of ground corn compared to that of dry-rolled corn but no difference in the feeding value of either processing method. Processing grains improves ruminal and total tract starch digestion particularly in sorghum and corn (Hale, 1973).

The amount of starch in the feces is reflective of undigested fecal starch concentrations, and can be used as a measure of total tract starch digestion have been used in previous research

(Zinn et al., 2002; Coronoa et al., 2005; Fredin et al., 2014). Correlations of fecal starch concentration with total tract starch digestion in feedlot animals have been reported (R2 = 0.91 and R2 = 0.97; Zinn et al., 2002 and Corona et al., 2005, respectively). Similarly, Fredin et al. (2014) evaluated the relationship between fecal starch and fecal pH and total tract starch digestibility and found a high correlation (R2 = 0.94) with fecal starch and no relation with fecal pH when fecal starch levels were 1 to 3% indicating fecal pH is not a good indicator of total tract starch digestion. Fecal starch concentration explained 91 to 94% of the variation in total tract starch digestion, and 68% of variation in ruminal starch digestion for feedlot cattle fed corn-based diets (Zinn et al., 2002; Owens and Zinn, 2005).

### *Feeding processed grains*

Processing methods alter rates of fermentation when comparing dry-rolling, grinding, steam-flaking, and feeding whole. Steam-flaking improves starch digestion compared to whole corn, dry-rolled corn, and ground corn (Matsushima and Montgomery, 1967; Lee et al., 1982; Zinn et al., 2002). Dry-rolling and grinding improve starch digestion compared to whole corn (Galyean et al., 1979; Turgeon et al., 1983; Corona et al., 2005). Feeding whole kernels reduces digestion because the pericarp, or protective outer layer limits microbial and enzymatic digestion (Owens, 1997). Galyean et al. (1979, 1981) reported that decreasing dry-rolled corn particle size increased DM and starch digestibility. However, conflicting results indicate decreasing dry-rolled corn particle size does not improve DMI, ADG, or G:F (Turgeon et al., 1983; Swanson et al., 2013). Swanson et al. (2013) evaluated the effects of feeding coarse DRC (2,680 µm) vs fine DRC (1,460 µm) in diets containing up to 40% dried distiller's grains with solubles (DDGS) and reported decreased DMI and increased G:F with increasing inclusion level of DDGS but was not effected by DRC particle size. In addition, carcass traits were not significantly influenced by DRC particle size or DDGS inclusion level.

A common practice for processing grain for feedlot cattle is rolling or grinding to achieve a coarse crack, or approximately the corn kernel fractioned into thirds, which allows for rumen microbes to digest the inner floury endosperm and begin breaking down the outer pericarp layer for enzymatic digestion in the small intestine. In a survey conducted by Schwandt et al. (2014) evaluating DRC practices in feedlots located in the Midwestern region of the U.S. (n = 31) the average geometric mean particle size ($d_{gw}$) of DRC across all feedyards was 4,534 ± 899 µm with a range of 2,167 to 6,823 µm.

### *Roughages*

Roughage is included in high-concentrate feedlot diets to improve rumination and serve as an energy dilution to maintain a healthy rumen pH (Gill et al., 1981). Roughage inclusion level varies with roughage type and influenced by grain processing method (Gill et al., 1981). Including low levels of roughage in processed grain finishing diets can reduce digestive dysfunction (Owens et al., 1998) and maximize energy intake (Defoor et al., 2002; Galyean et al., 2003). Previous research indicates that decreasing the bulk density of steam flaked sorghum or corn decreases DMI (Zinn, 1990; Xiong et al., 1991; Reinhardt et al., 1997). Additionally, previous research has evaluated different roughage levels fed in grain processed diets (Stock et al., 1990; Bartle et al., 1994; Hales et al., 2010). Stock et al. (1990) reported a quadratic response in ADG when feeding 0, 3, 6, and 9% roughage with SFC, high-moisture corn, or a 50:50 mixture. Bartle et al. (1994) evaluated the effects of feeding 10, 20 or 30% roughage equivalent (RE) in steam flaked sorghum grain-based finishing diets and reported a linear decrease in ADG with increasing roughage content, Roughage source (cottonseed hulls vs alfalfa) was also compared and steers fed cottonseed hulls consumed more feed but gained less compared to the alfalfa roughage source diets (Bartle et al., 1994). Hales et al. (2010) compared steam flaked corn with a density of 335 or 386 kg/L (26 or 30 lb/bu, respectively) fed with 6 or 10% alfalfa hay on animal performance and reported results that suggested SFC flaked to 335 g/L fed with 6% alfalfa hay would provide optimal performance with reduced digestive dysfunction.

Roughage source and inclusion level have been reported in surveys conducted in feedlots located throughout the U.S. (Galyean and Gleghorn, 2001; Vasconcelos and Galyean, 2007; Schwandt et al., 2015). Galyean and Gleghorn (2001) reported an average roughage inclusion level of 8.9% with a range of 4.5 to 13.5% in Midwestern feedlot diets. The primary roughage source was alfalfa and secondary was corn silage. Vasconcelos and Galyean (2007) additionally reported roughage inclusion levels by season were 8.3% and 9.0% for Summer and Winter, respectively. The primary roughage source was corn stalks (41.4%) followed by alfalfa (31.0%)

but provided information from a wider geographical area compared to Galyean and Gleghorn (2001). In addition, Vasconcelos and Galyean (2007) reported the most frequently used bulk density for steam flaked corn and sorghum grain (350 and 330 g/L, respectively) and may have influenced roughage source and inclusion level. More recently, Schwandt et al. (2015) reported roughage concentration [8.9 ± 2.0%] in Midwestern U.S. feedlot finishing diets. Furthermore, roughage sources were primarily a ground hay mixture comprised of a blend of CRP, brome, or prairie hay (60%), followed by corn silage (38%), corn stalks (22%), and wheat straw (13%).

## ***Coproducts***

Coproducts are described as feed ingredients that are produced from either dry-milling or wet-milling processes (Stalker et al., 2010). Dry-milling is the process used to make ethanol and results in dried distiller's grain with solubles (DDGS) or wet distiler's grains with solubles (WDGS; Stalker et al., 2010). Wet-milling is used to create several products from corn and results in wet corn gluten feed (WCGF) or dried corn gluten feed (DCGF; Stalker et al., 2010). Co-products vary considerably between type, source, location, and contribute to varying feeding values dependent on type, inclusion level, and other feed ingredients.

Trenkle et al. (2008) reported that finishing diets can be comprised of up to 40% wet or modified distiller's grains without negatively affecting feedlot or carcass performance. Vander Pol et al. (2009) reported the effects of feeding WDGS at 40% diet DM resulted in improved cattle performance that was attributed to additional fat content. Stock et al. (2000) suggested the reason for the greater feeding value of corn processing by-products versus that of corn is the additional RUP and fat content of dried distiller's grains with solubles, which alters the rate of rumen fermentation and results in reduced risk of digestive upset. Corrigan et al. (2009) reported that inclusion of dried distiller's grains in finishing diets may influence optimal grain processing method. Grinding corn to a finer particle size when the grain is fed in combination with distiller's grains may result in improved total tract starch utilization without causing reduced ruminal pH and digestive disturbances.

### *Associative effects*

Associative effects are considered digestive and metabolic interactions that influence intake and/or digestibility of fibrous components of forages (Dixon and Stockdale, 1999). Positive associative effects improve voluntary intake and digestibility and negative associative effects inhibit voluntary intake and digestion of roughage cause low efficiency of grain utilization (Dixon and Stockdale, 1999). Previous research has evaluated positive associative effects when feeding combinations of dry-rolled grain with WCGF (Ham et al., 1995; Loe et al., 2006). Contrarily, Swanson et al. (2013) evaluated the effects of feeding coarse DRC (2,680 µm) vs fine DRC (1,460 µm) in diets containing up to 40% dried distiller's grains with solubles (DDGS) and reported decreased DMI and increased G:F with increasing inclusion level of DDGS but was not effected by DRC particle size. Furthermore, Schwandt et al. (2015) reported a linear decrease in DMI with decreasing particle size of DRC in diets containing 20% wet distiller's grains suggesting potential subacute acidosis indicating the possibility of a negative associative effect.

## Summary and Objectives

Grain processing strategies to improve feed efficiency have been thoroughly researched. However, improving production efficiencies and determining nutrient composition of processed grains remains a challenge industry professionals fight on a daily basis. The objective of this dissertation was to provide information on the following current questions that our industry faces: What is the average particle size of dry-rolled corn fed to feedlot cattle located in the U.S.? Is performance, carcass traits, and starch digestibility influenced by dry-rolled corn particle size in feedlot finishing diets containing 20% wet distiller's grains? Do roll size, steaming time, and pre-soak time affect starch availability of steam flaked corn? What are current practices and equipment utilized in steam flaking operations located in commercial U.S. feedlots?

# Chapter 2 - A survey of dry-processed corn particle size and fecal starch in Midwestern United States feedlots[1]

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# Abstract

Feedlots (n = 35) were asked to participate in a survey to evaluate dry-rolled corn (DRC) processing practices, processed corn particle size distribution, and fecal starch content in finishing cattle. Feedlots were located in the central U.S. states of Kansas, Nebraska, South Dakota, Minnesota, Colorado, and Iowa. Samples of dry processed corn and finishing diet were collected from each feedlot, along with samples of freshly voided feces collected from 3 pens of finishing cattle with samples collected from 3 animals per pen with a total of 9 samples per feedlot composited. Average particle size of dry processed corn, including dry-rolled and hammermill-ground corn across all operations (n = 35) was 4,223 ± 1,265 µm with a range of 1,165 to 6,823 µm. Dry rolled corn (DRC) average particle size (n = 31) was 4,534 ± 899 µm with a range of 2,167 to 6,823 µm. Hammermill-ground corn (n = 4) average particle size was 1,817 ± 1,158 µm with a range of 1,165 to 3,552 µm. Fecal starch content averaged 19.0 ± 6.5% with a range of 7.0 to 36.6%. Diet composition was evaluated for co-product [27.8 ± 13.4%] roughage concentration [8.9 ± 2.0%] and NDF concentration [19.3 ± 4.3%]. Data from this survey provide an indication of DRC particle size and dietary formulation practices for feedlots located in the Midwest and Northern Plains regions of the U.S. Fecal starch values indicate the amount of undigested starch in the feces, which may be influenced by corn particle size. Some feedlots may have the opportunity to increase the degree of grain processing to improve total tract starch utilization.

**Key words:** beef cattle, dry rolled corn, fecal starch, feedlot, grain processing, particle size

# Introduction

Optimizing grain processing practices in cattle feeding operations is critical to reaching maximum feed utilization efficiency. An increased degree of grain processing improves DM and starch digestibility (Galyean et al., 1981) but led to conflicting results on improving performance in finishing cattle (Turgeon et al., 1983; Corona et al., 2005). These inconsistencies are likely due to diet composition, such as roughage and coproduct level, that could offset the effects of reduced particle size on rate of fermentation, thus reducing the risk of digestive dysfunction (Swanson et al., 2014).

Finishing diets are commonly formulated with processed grain to increase utilization of starch and improve animal performance (Corrigan et al., 2009). Processing methods including steam-flaking, grinding, or dry-rolling improve total tract starch digestibility compared with that of whole grain (Owens and Soderlund, 2006). When dry-rolling corn for finishing cattle, recommendations often suggest that grain be coarsely processed, or cracked to prevent production of an excessive quantity of fine material that could potentially result in an increased rate of fermentation, reduced rumen pH, and digestive disturbances (Owens et al., 1998). However, Corrigan et al. (2009) reported that inclusion of dried distiller's grains in finishing diets may influence optimal grain processing method. Grinding corn to a finer particle size when the grain is fed in combination with distiller's grains may result in improved total tract starch utilization without causing reduced ruminal pH and digestive disturbances.

Galyean et al. (1979, 1981) suggested that DRC be processed to a fine particle size increased both DM and starch digestibility but others have reported that decreasing particle size does not improve DMI, ADG, or G:F (Turgeon et al., 1983; Swanson et al., 2014). Different definitions of "fine," "medium," and "coarse" ground corn is a likely source of these conflicting results. For instance, Galyean et al. (1979) reported a "fine" DRC grind as 3,180 μm, whereas Swanson et al. (2014) reported a "coarse" DRC as 2,680 μm and a "fine" DRC as 1,460 μm.

The objective of this survey was to provide the feedlot industry with an indication of average particle size distribution from current manufacturing practices of dry processed corn, fecal starch content, and co-product and roughage inclusion levels in Midwestern feedlots.

# Materials and Methods

Animal Care and Use Committee approval was not required for this study because no animals were used.

Feedlots (n = 35) were selected to represent those that regularly use dry processed corn as a portion of their finishing diet. Four feedlots processed their grain using a hammermill, and the other 31 used a roller mill. The survey was conducted on cattle that were adapted to a finishing diet.

## *Data Collection*

The survey was conducted from November 2013 through March 2014. Sample collection included a dry processed corn sample, diet sample, and fecal samples. Dry processed corn samples were collected from the ground corn storage pile. Grain samples (~500 mL) were typically collected from 3 locations in the pile from approximately 15 cm deep. If corn was ground directly into the mixer truck (n = 2), the sample was collected in the mixer truck during loading. Diet samples (~500 mL) were collected across 5 locations in the bunk immediately after feeding. Diet samples (n = 5 per pen) were placed in an 18.9-L bucket, hand-mixed, and poured onto a clean concrete surface. Piles were quartered, and 2 aliquots of diet were sub-sampled from 2 opposite quarters, placed in a plastic bag and frozen. Diet samples were analyzed at SDK Labs (Hutchinson, KS) for moisture, DM, CP, ADF, NDF, fat, calcium, phosphorus, potassium, and magnesium. The moisture content of the samples was measured according to the National Forage Testing Association (NFTA) Method 2.1.4 (Shreve et al., 2006). Crude protein was determined according to Association of Official Analytical Chemists International (AOAC) Official Method 976.06 (AOAC, 2002), ADF and NDF were analyzed using a filter bag technique Ankom Technology Methods 5 and 6, respectively (ANKOM, 2006a; ANKOM, 2006b), Fat (AOAC, 2002; Ba 3-38), Ca and K (AOAC, 2002; 956.01), Mg (AOAC, 2002; 968.08 AA), and P (AOAC, 2002; 965.17).

Fecal samples were collected from 3 pens of cattle per feedlot which were consuming the finishing diet. Samples were collected from 3 animals per pen, composited, and frozen, for a total of 9 composited samples per feedlot. Cattle were required to be transitioned on to finishing diet for a minimum of 5 days prior to taking fecal samples so fecal starch wasn’t influenced by step-up diets. Fecal samples were analyzed for moisture, DM, and total starch at SDK

Laboratories (Hutchison, KS). The moisture content of the samples was measured according to NFTA Official Method 2.1.4 (Shreve et al., 2006). Starch content was determined according to AOAC Method 979.10 (Glucoamylase Method; AOAC, 2002) using enzyme hydrolysis of starch to glucose and then determination of glucose concentration by the ‘glucose oxidase’ method.

Formulated diet composition was provided by nutritionists (one from each feedyard) (n = 32). Dry-processed corn was the primary energy source in all operations involved in this survey. In addition, there were other sources of starch, such as earlage, high moisture corn, and corn silage in most of the feedlots surveyed, which compromised the ability to determine any relationship between fecal starch and DRC particle size. Co-products were in the form of wet distiller’s grain (WDG), wet corn gluten feed (WCGF), and modified wet distiller’s grains (MWDG). Roughage sources included ground hay (CRP, brome, prairie, or mixture), corn silage, corn stalks, and wheat straw.

Dry processed corn samples were analyzed for particle size distribution (ANSI/ASAE S319.2 FEB03; ASABE, 2007) at the Kansas State University Feed Technology Innovation Center (Manhattan, KS) Corn samples were split using a riffle divider and 100-g subsample was weighed and sieved through a set of 13 circular sieves using a sieve shaker (model RX-29, W. S. Tyler Ro-Tap, Mentor, OH, USA; Table 2.1) for 10 min. After the sample was shaken, the weight of the material on each sieve was recorded. Shaken samples were re-analyzed if there was not a 97% or greater recovery compared with the starting weight. No agitators or dispersion agents were used in analysis. Analysis was conducted in duplicate per sample, and averages of duplicates were used in this report.

### *Data Analysis*

All data were entered and tabulated in a Microsoft Excel spreadsheet (Microsoft, Richmond, VA). Mean, standard deviation, and minimum and maximum values were calculated using spreadsheet formulas.

## Results and Discussion

Dry-processed corn was the primary energy source in all feedlots in this survey; however, energy, in the form of starch, was additionally provided by corn silage (n = 12), earlage (n = 8), and high moisture corn (n = 8) in the feedlots surveyed (Table 2.2). This survey was conducted in the Midwest and Northern Great Plains regions, where producers often feed corn silage and earlage. Corn silage and earlage are common feedstuffs and prime examples of a concentrate and roughage source in one ingredient. No further effort was made to determine interactions between particle size and dietary ingredients as inclusion of corn silage, earlage, and variable concentrations of coproducts prevented this.

Coproduct sources included wet distiller's grains (n = 15), wet corn gluten feed (n = 7), and modified wet distiller's grains (n = 10; Table 2.2). The fuel ethanol industry has increased the amount of corn and sorghum milled for ethanol production, which has increased the availability of distiller's grains as a protein and energy source for ruminants (Vasconcelos and Galyean, 2007). All but 2 feedlots fed at least one form of co-product, which is most likely due to location of those feedlots. Wet or modified distiller's grains have a relatively short shelf life of maximum 5 d (DiCostanzo, 2012) and are often included in finishing diets in regions in close proximity to the ethanol plants. Wet distiller's grains with solubles (WDGS) typically contain 28 to 32% DM and influences cattle performance depending on inclusion level (Larson et al., 1993; Ham et al., 1994). Modified wet distiller's grains with solubles (MWDS) typically contain 48 to 54% DM (Trenkle, 2007) or are partially dried at the ethanol plant to reduce transportation costs.

Coproducts included in the finishing diets [27.8 ± 13.4%] (Table 2.3). Trenkle (2008) reported that finishing diets can be comprised of up to 40% wet or modified distiller's grains without negatively affecting feedlot or carcass performance. Watson et al. (2014) determined that WDGS has 121 to 178% the feeding value of corn and MDGS has 111 to 125%; furthermore, feedlot diets can effectively replace a portion of DRC or high-moisture corn (HMC) with WDGS or MDGS to improve gain and efficiency in finishing steers and utilize an ingredient that has a greater feeding value than corn (Watson et al., 2014). Stock et al. (2000) suggested the reason for the greater feeding value of corn processing coproducts vs. that of corn is the additional RUP and fat content of DGS, which alters the rate of rumen fermentation and results in reduced risk of digestive upset. Vander Pol et al. (2009) reported the effects of feeding WDGS at 40% diet DM resulted in improved cattle performance that was attributed to additional fat content. In addition, Lodge et al. (1997) evaluated the fat and protein content of DGS and determined that fat and protein in combination improve the feeding value of DGS. Swanson et al. (2014) evaluated DRC processing particle size in diets containing 20 to 40% dried distiller's grains with solubles (DDGS) and determined that decreasing particle size did not influence growth performance but, previous research indicated that optimal inclusion levels of distiller's grains may differ for dry and wet distiller's grains (Klopfenstein et al., 2008) and could be influenced by corn processing (Corrigan et al., 2009).

Roughage sources in this survey were ground hay, corn silage, corn stalks, and wheat straw (Table 2.2). Ground hay comprised of CRP, brome, prairie, or a mixture of these and was used in 60% of the diets. Additionally, corn silage (38%), corn stalks (22%), and wheat straw (13%) was also used. Roughage inclusion level [8.9 ± 2.0%] (Table 2.3) was typical of a finishing diet and was comparable to results from a consulting nutritionist survey reported by Vasconcelos and Galyean (2007). Roughage is mainly included in high concentrate diets to aid in rumination and increase saliva flow to maintain rumen health (Gill et al., 1981). Roughage inclusion level varies with roughage type and influenced by grain processing method (Gill et al., 1981).  Results from this survey may reflect formulation constraints of forages that limit inclusion levels in efforts to optimize energy intake and reduce digestive disturbances (Salinas-Chivira et al., 2013).

Crude protein (% of DM) averaged 14.84 ± 1.91% with a range from 9.85 to 19.17% (Table 2.3) which is approximately 1.5% higher than average values reported by a survey conducted by Vasconcelos and Galyean (2007). Furthermore, fat [5.08 ± 0.92], P [0.44 ± 0.11], Ca [0.86 ± 0.23], and K [0.87 ± 0.12] were all included at higher levels compared to Vasconcelos and Galyean (2007),  This is likely due in response to higher inclusion levels of co-products in these diets. Magnesium (Mg) [0.22 ± 0.04] was similar to values reported by Vasconcelos and Galyean (2007) and could have been negated from additional supplementation because of sufficient concentration in cereal grains included in finishing cattle diets (NRC, 1996).

Neutral detergent fiber level [19.3 ± 4.3%] was measured to evaluate the concentration of fiber contributed by all sources (Table 2.3). Salinas-Chivira et al. (2013) reviewed differences among forage sources when comparing similar dietary forage NDF assayed with amylase and expressed exclusive of residual ash (aNDFom) concentration and determined no differences in feedlot cattle growth performance. In addition, Benton et al. (2007) reported an increase in and a tendency for increased gain efficiency with NDF inclusion levels from 25g/kg to 50g/kg DM. Feeding greater levels of aNDFom than 110 g/kg DM results in decreased energy intake and ADG (Zinn et al., 1994; Zinn and Plascencia, 1996; Galyean and Defoor, 2003). Galyean and

Defoor (2003) suggested measuring NDF concentration to determine roughage inclusion and reduce inconsistencies in DMI and performance when exchanging roughage sources in practice.

Particle size distribution results are reported as geometric mean diameter ($d_{gw}$) and the log normal standard deviation of the geometric mean diameter ($S_{gw}$). The average $d_{gw}$ [4,223 ± 2,191µm] is approximately the corn kernel fractioned into thirds. The range for the $d_{gw}$ across all feedlots (n = 35) in the survey was 1,165 to 6,823 µm (Table 2.4). The average $S_{gw}$ [1.86 ± 0.41] indicates a measure of the distribution width of the geometric mean particle size within each sample and could have been influenced by grinding method. Dry-rolled corn using a roller mill produces particles more uniform in size than hammermill ground corn (Koch, 2002). Dry-rolled corn was used in 31 of the feedlots surveyed. The geometric mean diameter for dry-rolled corn averaged 4,534 ± 899 µm with a range of 2,167 to 6,823 µm and the $S_{gw}$ [1.75 ± 0.29] with a range of 1.34 to 2.50 (Table 2.4). Hammermill ground corn (n = 4) averaged 1,817 ± 1,158 µm with a range of 1,165 to 3,552 µm and the $S_{gw}$ [2.69 ± 0.10] with a range of 2.55 to 2.78 (Table 2.4). Although sampling procedures were strictly repeated for each feedlot, the survey was conducted over a few months and samples were collected in various weather conditions. In addition, there were no specifications on the frequency of grinding at the feedlot; therefore, corn could have been either freshly ground or in storage for some time, which could have influenced segregation in the dry processed corn pile, thus influencing results.

The concentration of starch in the feces (FS, % of DM; Table 2.4) indicates the amount of undigested starch and may be influenced by corn particle size. Fecal starch [19.0 ± 6.5%] ranged from 7.0 to 36.6% in this survey. Given that some starch escapes digestion and ends up in the feces, feedlots may be able to increase the degree of grain processing to improve total tract starch utilization. Zinn et al. (2002) reported a close relationship ($R^2 = 0.91$) between FS and total tract starch digestion (TSD) in feedlot steers fed a diet with corn as the primary energy source. Similarly, Corona et al. (2005) conducted a study evaluating the effects of corn processing methods on digestion and growth performance in feedlot cattle and reported a relationship between FS and TSD ($R^2 = 0.97$). Similar regression coefficients from both studies indicate a high correlation between FS and TSD, confirming that FS concentrations can be used as a means of assessing total tract starch digestion. However, a primary drawback of FS as an indication of TSD is the large potential variability among feedlots in other dietary components, cattle type (age, weight, background, and genetics), and intake level, all of which may greatly influence rate and of passage and ruminal and post-ruminal nutrient digestibility. For these reasons, the authors recommend FS only be used to monitor changes in starch digestion within a single feedyard and a single finishing diet, within similar cattle.

## Implications

Results from this survey provide the industry with a greater understanding of the degree of processing that is currently practiced and the resulting fecal starch concentration, and diet formulation. Research in the area of DRC particle size in finishing feedlot diets and its influence on feedlot performance and carcass characteristics is needed. These results do not directly compare DRC particle size and fecal starch concentration, but the combined results suggest that DRC particle size may affect total tract starch digestion. Diets formulated with higher co-product level could include more finely processed grain in the diet. Coproducts fed at higher levels could dilute the concentration of rapidly fermentable starch found in finely processed grain, thus achieving greater total tract starch digestion without affecting rumen function.

**Table 2.1 Sieve stack used to evaluate dry processed corn particle size of Midwestern U. S. finishing cattle diets**

| US Sieve Number | Tyler Sieve Number | Opening, microns |
|---|---|---|
| - | 2.5 | 8,000 |
| 4 | 4 | 4,760 |
| 6 | 6 | 3,360 |
| 8 | 8 | 2,380 |
| 12 | 10 | 1,680 |
| 16 | 14 | 1,190 |
| 20 | 20 | 841 |
| 30 | 28 | 595 |
| 40 | 35 | 420 |
| 50 | 48 | 297 |
| 70 | 65 | 210 |
| 100 | 100 | 149 |
| 140 | 140 | 105 |
| pan | pan | - |

**Table 2.2 Ingredient use in Midwestern U.S. finishing cattle diets.[1]**

| Item | No. of feedlots | Feedlots, % |
|---|---|---|
| Grain | | |
| Corn | 32 | 100 |
| Earlage | 8 | 25 |
| High moisture corn | 8 | 25 |
| By-product | | |
| Wet distillers grains (WDG) | 15 | 47 |
| Wet corn gluten feed | 17 | 22 |
| Modified WDG | 10 | 31 |
| Roughage | | |
| Ground hay[2] | 20 | 63 |
| Corn silage | 12 | 38 |
| Corn stalks | 7 | 22 |
| Wheat straw | 4 | 13 |

[1] Values from 32 feedlots located in the central United States.

[2] Ground hay sources consist of CRP, brome, prairie, or a mixture of hay source.

**Table 2.3 Diet nutrient analysis (% of DM) of Midwestern U.S. finishing cattle diets.[1]**

| | | | Range | |
|---|---|---|---|---|
| Item | Mean | s.d. | Min | Max |
| CP, % | 14.84 | 1.91 | 9.85 | 19.17 |
| Fat, % | 5.08 | 0.92 | 2.90 | 7.48 |
| P, % | 0.44 | 0.11 | 0.25 | 0.63 |
| Ca, % | 0.86 | 0.23 | 0.31 | 1.38 |
| K, % | 0.87 | 0.12 | 0.31 | 1.05 |
| Mg, % | 0.22 | 0.04 | 0.12 | 0.61 |
| Roughage, %[2] | 8.9 | 2.0 | 5.3 | 15.6 |
| By-product, %[2] | 27.8 | 13.4 | 0.0 | 51.0 |
| NDF, %[2] | 19.3 | 4.3 | 11.2 | 27.5 |

[1] Values from 32 feedlots located in the central United States.

[2] Roughage, by-product, and NDF values from 32 feedlots located in the central United States.

**Table 2.4 Dry processed corn particle size of Midwestern U.S. finishing cattle diets.**[1]

| | | | Range | |
|---|---|---|---|---|
| Item | Mean | s.d. | Min | Max |
| Dry-rolled | | | | |
| $d_{gw}$[2] | 4,534 | 899 | 2,167 | 6,823 |
| $S_{gw}$[3] | 1.75 | 0.29 | 1.34 | 2.50 |
| Hammermill | | | | |
| $d_{gw}$[2] | 1,817 | 1,158 | 1,165 | 3,552 |
| $S_{gw}$[3] | 2.69 | 0.10 | 2.55 | 2.78 |
| Overall | | | | |
| $d_{gw}$[2] | 4,223 | 1,265 | 1,165 | 6,823 |
| $S_{gw}$[3] | 1.86 | 0.41 | 1.34 | 2.78 |
| Fecal starch, %[4] | 19.0 | 6.5 | 7.0 | 36.6 |

[1] Overall values from 35 feedlots located in the central United States.

[2] $d_{gw}$: Geometric mean diameter (μm)

[3] $S_{gw}$: Standard deviation of the geometric mean diameter

[4] Fecal starch values obtained from 34 feedlots.

# Chapter 3 - The effects of dry-rolled corn particle size on performance, carcass traits, and starch digestibility in feedlot finishing diets containing wet distiller's grains[1, 2]

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# Abstract

Cross-bred yearling steers (n = 360; initial BW = 395 ± 33.1 kg) were used to evaluate the effects of dry-rolled corn (DRC) particle size in diets containing 20% (DMB) wet distiller's grains plus solubles (WDGS) on feedlot performance, carcass characteristics, and starch digestibility. Steers were utilized in a randomized complete block design and allocated to 36 pens (9 pens/treatment; 10 animals/pen). Treatments were Coarse DRC (4,882 µm; COARSE), Medium DRC (3,760 µm; MEDIUM), Fine DRC (2,359 µm; FINE), and Steam-flaked corn (SFC, 0.35 kg/L). Final BW and ADG were not affected by treatment ($P > 0.05$). Dry matter intake was greater and G:F was lower ($P < 0.05$) for steers fed DRC vs. SFC. There was a linear decrease ($P < 0.05$) in DMI in the final 5 weeks on feed with decreasing DRC particle size. Fecal starch decreased (linear, $P < 0.01$) as DRC particle size decreased. In situ starch disappearance was lower for DRC vs SFC ($P < 0.05$) and increased linearly ($P < 0.05$) with decreasing particle size at 8 and 24-h. Reducing DRC particle size did not influence growth performance but increased starch digestion and influenced DMI of cattle on finishing diets. No differences ($P > 0.10$) were observed among treatments for any of the carcass traits measured. Results indicate improved ruminal starch digestibility, reduced fecal starch concentration, and reduced DMI with decreasing DRC particle size in feedlot diets containing 20% wet distiller's grains on a dry matter basis.

**Key words:** dry rolled corn, fecal starch, feedlot, particle size

## Introduction

Dry-rolling corn is a common practice in feedlots located in the Midwestern and Northern Plains regions of the U.S. Optimizing total tract starch utilization in diets containing dry rolled corn (DRC) is essential for maximizing efficiency. However, recommendations often suggest that grain be coarsely cracked to refrain from producing an excessive amount of fine material that could potentially increase the rate of fermentation, reduce rumen pH, and cause digestive disturbances (Owens et al., 1998).

Wet distiller's byproducts may be effectively used as a protein and energy source for feedlot finishing cattle (Larson et al, 1993; Ham et al., 1994; Watson et al., 2014) and can replace a portion of the dry-rolled corn in the diet. Corrigan et al. (2009) reported that the inclusion of wet distiller's grains in finishing diets may influence the optimal grain processing method. Swanson et al. (2013) evaluated the effects of feeding coarse DRC (2,680 µm) vs fine DRC (1,460 µm) in diets containing up to 40% dried distiller's grains with solubles (DDGS) and reported decreased DMI and increased G:F with increasing inclusion level of DDGS but was not effected by DRC particle size. In addition, carcass traits were not significantly influenced by DRC particle size or DDGS inclusion level.

In a survey conducted by Schwandt et al. (2014) evaluating DRC practices in feedlots located in the Midwestern region of the U.S. (n = 31) the average geometric mean particle size ($\mathbf{d_{gw}}$) of DRC across all feedyards was 4,534 ± 899 µm with a range of 2,167 to 6,823 µm.

The objective of this study was to evaluate the effects of DRC particle size on animal performance, carcass traits, and starch digestibility in feedlot finishing diets containing 20% wet distiller's grains on a dry matter basis.

## Materials and Methods

The study was conducted in accordance with a protocol approved by Colorado State University Institutional Animal Care and Use Committee (14-5091A).

### *Animals*

Cross-bred yearling steers (n = 360; initial BW = 395 ± 33.1 kg) were used in a randomized complete block design to evaluate the effects of dry-rolled corn particle size in diets containing 20% wet distiller's grains on feedlot performance, carcass characteristics, and starch digestibility. Steers originated from northcentral Oklahoma and were shipped approximately 1,100 km to the Agriculture Research, Development & Education Center (ARDEC; Fort Collins, CO). Cattle received long-stemmed hay and water upon arrival at the facility for the first 24-h. Starter diet and ground grass hay were fed until processing on d 7 and 8 post arrival.

Steers were individually weighed on 2 consecutive days (d 7 and 8 post arrival) to determine an initial BW and were divided into 9 weight block replicates, each consisting of 40 steers, and randomly allocated to one of 4 treatments. Steers were vaccinated against infectious bovine rhinotracheitis virus, and type I and type II bovine virus diarrhea, parainfluenza-3, and bovine respiratory syncytial virus (Bovi-Shield Gold; Zoetis, Kalamazoo, MI); clostridial bacterin-toxoid (Ultra Choice 7; Zoetis, Kalamazoo, MI); and treated for parasites (Noromectin, Injectable Ivermectin; Norbrook Laboratories Limited and Safe-Guard, Fenbendazole; Merck Animal Health, Summit, NJ). Steers were implanted with Revalor-XS (40 mg estradiol and 200 mg of trenbolone acetate; Merck Animal Health, Summit, NJ) administered in the right ear and were not re-implanted prior to slaughter. Steers were housed in 10-hd feedlot pens where they received their dietary treatment throughout the duration of the study. Each pen measured 6.1 x 40 m, contained a 22.3 $m^2$ concrete feeding apron, 6.1 m of bunk space, and each 2 adjacent pens shared a common continual flow water fountain. Pen was used as the experimental unit.

Dietary treatments were Coarse DRC (4,882 µm; **COARSE**), Medium DRC (3,760 µm; **MEDIUM**), Fine DRC (2,359 µm; **FINE**), and Steam-flaked corn (0.35 kg/L; **SFC**). All diets contained 20% wet distiller's grains (DM basis) and were formulated to meet or exceed National Research Council (2000) requirements for growing-finishing beef cattle. Wet distiller's grains inclusion level was based on the data from a survey by Vasconcelos et al. (2007) that reported an average inclusion level of grain coproducts (DM basis) in finishing diets of 16.5% with the majority of producers feeding 20%.

Steers were transitioned to the finishing diet over a 23-d period following arrival using a series of 4 diets (Table 3.1) including: Starter (d 1 – 7), Step-1 (d 8 – 14), Step-2 (d 15 – 23), Finisher without Ractopamine hydrochloride (d 24 – 113), and Finisher with Ractopamine hydrochloride (d 114 – 142). Steam-flaked corn was used in the starter and step-up diets and all diet changes during the step-up program were simultaneous for all pens and all treatments. Steers were allocated to treatment pens (study d 1) on d 8 post arrival and received the finishing diet containing the appropriate corn treatment for the first time on d 24 post arrival (study d 17). Bunk reading was conducted daily at 0700 h, and steers were fed one time daily using a Mohrlang 452c feed truck (MMI International, Brush, CO) equipped with scales accurate to the nearest 4.54 kg. Complete mixed diet and feed ingredient samples were collected weekly for DM and nutrient content determination (Table 3.2). Target nutrient concentrations for the finishing diet were 16% CP; 3% CP from NPN; 4.5% NDF from diet corn silage; 0.72% Ca; and 90 mg supplemental Zn, 20 mg supplemental Cu, and 75 mg supplemental Mn per kg DM. Rumensin (Elanco Animal Health, Indianapolis, IN) and Tylan (Elanco Animal Health, Indianapolis, IN) were included in all diets. Target Rumensin dosage was 24.5, 24.5, 36.7 and 48.9 mg/kg (DMB) in the Starter, Step-1, Step-2, and Finisher diets, respectively. Optaflexx was fed to all treatments the final 29 d in the feedlot at 30.1 mg/kg DMB, providing approximately 300 $mg\bullet hd^{-1}\bullet d^{-1}$.

Steers were pen weighed on study d 17 (d 24 post-arrival) prior to the initial feeding of the finishing diets. Final individual BW was obtained prior to feeding on study d 132 and steers remained on their respective dietary treatments until slaughter on d 136 of the study. A 4% shrink was applied to all BW data prior to statistical analysis. On the day of slaughter, steers were shipped approximately 49 km to a commercial abattoir in Greely, CO and randomly presented for slaughter using standard USDA/FSIS inspection criteria. Carcass data including HCW, 12th rib fat depth, ribeye area, USDA yield grade, marbling score, and USDA quality grade were collected by trained Colorado State University Meats specialists.

### *Corn Processing*

A common corn supply was used for all DRC treatments. Dry-rolled corn was processed once weekly at the ARDEC using an electric powered single-pair roller mill (R & R Machine Works, Dalhart, TX) with 2, 25.4 x 50.8 cm rolls with 3.2 corrugations per cm. Corn processed for the COARSE and MEDIUM treatments were passed through dial settings 8 and 9.5, respectively. Corn processed for the FINE treatment was initially processed using the MEDIUM setting then and returned through the roller mill at dial setting 17 to achieve the FINE particle size. Steam-flaked corn was manufactured weekly at Ault Feedmill, LLC (Ault, CO) and transported approximately 32 km to the feedlot facility. Target density for the SFC was 0.35 kg/L, starch availability averaged 43.0%, and the total starch content of the corn averaged 76.7% (Table 3.3).

Particle size analysis was conducted weekly on DRC samples. The average particle size within each sample is described as the geometric mean particle size (**$d_{gw}$**) and log normal standard deviation (**$S_{gw}$**) represents the range of particle size within each sample. The $d_{gw}$ and $S_{gw}$ were calculated using equations presented in the standard method for measure fineness of feed materials (ANSI/ASAE S319.2 FEB03; ASABE, 2007) at the Kansas State University Feed Technology Innovation Center (Manhattan, KS). Each DRC sample was initially divided using a riffle divider and a 100-g subsample was sieved through a set of 13 circular-sieves (model RX-29, W.S. Tyler Ro-Tap, Mentor, OH, USA; Table 3.4) for 15 min. Each shaken sieve was individually weighed. Analysis was completed in duplicate and an average of the duplicates was reported (Table 3.5). If there was not a 97% or greater recovery of the initial weight from the shaken samples the sample was re-analyzed.

### *Fecal Starch*

Fecal starch was evaluated on d 79, 114, and 132 of the study which correspond to 63, 91, and 119 d on the finishing diets, respectively. Approximately 300 g of freshly voided feces were collected from ground piles of the first 6 individual steers to defecate per pen for all pens in the study for each collection period. Samples were composited by pen within each sampling date and frozen. Fecal samples were analyzed for moisture, DM, and total starch content at the Kansas State University Ruminant Nutrition Laboratory using enzymatic hydrolysis (Technicon Industrial Method #SE3-0036FJ4). Samples were analyzed in duplicate and those samples which differed in total starch content between duplicates by 5% or greater were re-analyzed. Duplicates were averaged (Table 3.6).

### *In Situ DM Disappearance and Starch Digestibility*

Two mature cross-bred steers (BW ≥ 725 kg), fitted with rumen cannula were fed gradually decreasing amounts of low-quality mixed grass hay and increasing amounts of the SFC based finishing diet (Table 3.1) over a 14 d adaptation period followed by ad libitum amounts of the SFC based finishing diet for an additional 7 d prior to the start of the in situ study. One g of unmasticated SFC, COARSE, MEDIUM, and FINE corn samples were placed into separate Dacron bags (10 x 20 cm; Ankom Inc. Fairport, NY) with an average pore size of 50 µm, and the bags were sealed. Four bags per time period (0, 2, 4, 8, 12, and 24 h) per steer (n = 2) were used.

All samples were suspended in the rumen at times appropriate for the desired incubation time interval and removed simultaneously. Upon removal, all samples were hand-washed individually for approximately 20 sec per bag under a continuous stream of luke-warm tap water. Samples that were not incubated were washed using the same procedure and were used to determine the amount of sample that was washed out.

Washed *in situ* bags were dried for 48-h at 60°C in a forced-air oven to determine *in situ* DM disappearance (Figure 3.1). Residual corn samples were removed from the bags, composited by time period, ground with a mortar and pestle, and frozen. A 50 mg subsample was weighed and analyzed for starch disappearance at the Kansas State University Ruminant Nutrition Laboratory using enzymatic hydrolysis. Samples were analyzed in duplicate and if samples differed in total starch between duplicates by 5% or greater they were re-analyzed. Duplicates were averaged (Figure 3.2).

### *Statistical Analysis*

Fecal starch, feedlot performance, and continuous carcass data were analyzed on a pen mean basis and dry rolled corn particle size data were analyzed on a collection mean basis as a randomized complete block design using PROC MIXED of SAS (SAS Institute, Inc., Cary, NC). Treatment (TRT) was included in the model as a fixed class variable and weight block pen replicate (REP) was included in the model as a random effect. Average daily DMI for each week was evaluated using MIXED model procedures with TRT, week, and TRT x week included in the model as fixed effects.

Quality grade (Low Choice and greater vs. Select and lower) and yield grade (Yield grade 1, 2, or 3 vs. Yield grade 4 and 5) data were evaluated as categorical responses using PROC GLIMMIX of SAS and assuming a binomial distribution. The Link = Logit option of the model statement and the ILINK option of the LSMEANS statement were used to calculate the likelihood ± SEM that an individual within each pen qualified for a specific category. Significance was determined at $P \leq 0.05$. Pen initial BW was used as a covariate in the analysis of feedlot performance during the diet step-up period (d 1 – 16) or overall cumulative feedlot performance (d 1 – 132) and d 17 pen BW was used as a covariate in the analysis of feedlot performance during the finishing period (d 17 – 132) when the covariate effect was significant ($P \leq 0.10$). Treatment means were separated using orthogonal contrasts if the effect for TRT approached significance ($P \leq 0.05$). Contrasts of interest were SFC vs. DRC and the linear and quadratic effects of decreasing particle size among the DRC treatments.

## Results and Discussion

### *Cattle Health*

Very few respiratory issues were encountered during the study. A total of 7 steers either died or were removed from the study: 3 were from the SFC treatment, 2 from the FINE, 1 from the MEDIUM, and 1 from the COARSE treatments. All statistical analysis excluded animals that died prior to study termination.

### *Feed Ingredient and Diet Nutrient Analysis.*

The SFC used for the study had slightly lower ($P \leq 0.05$) DM than the DRC. Corn used for the DRC treatments was from a common source and thus nutrient profiles are similar among the DRC treatments. Corn used for the SFC treatment was from a different source and may have contained slightly lower NDF and slightly greater starch as compared with the DRC. Available starch was measured using enzymatic hydrolysis (SDK Laboratories, Hutchinson, KS) and as a percentage of total starch was over 2-fold greater for the SFC vs. DRC. This large increase in available starch for SFC as compared with DRC likely has a much larger effect on potential performance differences as compared with relatively minor differences in total starch concentration. Total starch concentrations as well as the concentrations for other analyzed nutrients were similar among all treatments.

COARSE, MEDIUM, and FINE DRC $d_{gw}$ were 4,882 ± 93.9, 3,760 ± 166.0, and 2,359 ± 112.3 µm, respectively ($P < 0.01$; Table 3.5). The DRC $S_{gw}$ averaged 1.54, 1.71, and 2.00 for the COARSE, MEDIUM, and FINE DRC, respectively ($P < 0.01$). Achieving consistency within the grain processing procedures for each DRC treatment was critical to maintain an acceptable distribution between treatments throughout the duration of the study. Dry-rolled corn $d_{gw}$ and $S_{gw}$ was different ($P < 0.01$) between treatments. Differences in $S_{gw}$ distribution might have influenced total tract starch digestion. As particle size decreases, $S_{gw}$ increases indicating a wider particle size range which might have influenced rumen function and digestibility different between DRC treatments. The larger the $S_{gw}$ the wider the distribution of particle size (Stark and Chewning, 2012). This may be a contributing factor to the rate and site of starch digestion and should be evaluated when determining improved total tract starch digestion with decreasing particle size of DRC. Additionally, in order to achieve FINE DRC particle size the corn had to be processed twice, which likely is unrealistic in most operations. Two- or three-stage roller mills would be more equipped to achieve a finer, more consistent particle size.

Corn *in situ* DM disappearance was 18.5, 31.4, 58.7, and 70.2%, for the COARSE, MEDIUM, FINE, and SFC treatments, respectively (Fig. 3.2). These results are in agreement with Galyean et al. (1981) who reported increased *in situ* DM and starch disappearance for 12- and 24-h incubation periods with smaller DRC particle sized; however, consideration of percentage of fines (< 750 µm) may be important in determining the extent of ruminal digestion. Although differences in DM disappearance for larger particle sizes (6,000 and 3,000 µm) were not different, DM disappearance values were nearly double as particle size decreased from 3,000 µm to 750 µm (Galyean et al., 1981). In the present study, comparing the MEDIUM to FINE DRC treatments, decreasing the particle size by 1,400 µm increased DM disappearance by 27.3%. These results suggest improved DM disappearance with decreasing particle size of DRC and over a two-fold difference when decreasing particle size from MEDIUM to FINE DRC particle size.

After 24 h incubation, *in situ* starch disappearance was approximately 18.0, 36.2, 52.0, and 63.1 ± 5.44% for the COARSE, MEDIUM, FINE, and SFC treatments, respectively (SFC vs. DRC, $P < 0.05$; DRC linear, $P < 0.05$). Treatment ($P < 0.01$), time ($P < 0.01$), and the treatment-by-time interaction ($P < 0.01$) effects for *in situ* starch disappearance were significant (Fig. 3.2). These results indicate increased ruminal starch disappearance with decreased DRC particle size and agrees with Galyean et al. (1981) who demonstrated increased *in situ* starch digestion as DRC particle size was reduced. An interaction between particle size and time is most likely due to greater starch availability in SFC compared to DRC and could contribute to increased starch disappearance (Galyean et al., 1981). Additionally, differences in SFC starch disappearance are consistent with previous research evaluating rumen digestibility of SFC compared to ground or cracked corn (Orskov et al. 1969; Galyean et al. 1976). Total tract starch digestibility is affected by grain processing, which greatly affects the rate and extent of digestion of starch in the rumen (Theurer, 1986). Although treatment differences for starch disappearance were not as large as those differences seen for DM disappearance, there was a linear effect of particle size on starch disappearance at 8-h and 24-h ($P < 0.05$) indicating decreasing DRC particle size increases starch digestibility in the rumen, thus likely contributing to improved total tract starch digestion.

Fecal starch concentrations can be used as an indicator of assessing total tract starch digestion with a high correlation of $R^2 = 0.91$ and $R^2 = 0.97$ (Zinn et al., 2002; Corona et al., 2005) respectively. Zinn et al. (1995) evaluated the influence of intake on total tract starch digestibility and determined that corn processing is the primary factor affecting site and extent of starch digestion. Huntington et al. (2006) reported that the main limit to improved cattle performance from the dietary use of starch is the amount that is digested and absorbed from the small intestine. As grain is more extensively processed the amount of starch reaching the small intestine is reduced (steam-flaking, high moisture, fine grinding; Theuer, 1986). Fecal starch was lower ($P < 0.01$; Table 3.6) for the SFC vs. COARSE, MEDIUM, and FINE DRC treatments. Reduced fecal starch indicates greater starch digestion for SFC as compared with DRC. Fecal starch concentration decreased linearly ($P < 0.01$) with decreasing DRC particle size indicating improved total tract starch digestion as DRC particle size is reduced. These results are in agreement with Galyean et al. (1979) who reported improved total tract starch digestion with decreasing particle size; however, Turgeon et al. (1983) determined that starch digested post-ruminally was not influenced by corn particle size suggesting that improved total tract starch digestion was due to extent of ruminal digestion. Owens and Sonderlund (2006) reported that particle size reduction postruminally is minimal, indicating improved starch digestion would be attributed to more extensively processed grain, or increased surface area for improved microbial and enzymatic digestion. Furthermore, particle size contributes to the efficiency of total tract starch digestion by the amount of endosperm cells exposed to microbial and enzymatic digestion (McAllister et al., 2006). Decreased fecal starch concentrations with decreasing DRC particle size could be attributed to improvements in both ruminal and post-ruminal starch digestion.

### *Feedlot Performance*

Following the step-up period, study d 1 – 16, average pen BW tended ($P = 0.06$) to be influenced by treatment (Table 3.7) and averaged 412, 420, and 418 kg for the COARSE, MEDIUM, and FINE DRC treatments, respectively (linear, $P = 0.08$; quadratic, $P = 0.07$). Day 17 BW was therefore used as a covariate to evaluate feedlot performance during the finishing period (d 17 – 132). During the finishing period, ADG was not different ($P > 0.10$) among treatments. Dry matter intake for SFC compared to DRC was different ($P = 0.02$) during the finishing period. Additionally, upon closer evaluation DMI was reduced ($P < 0.01$) for SFC vs. the DRC treatments and DRC (linear, $P < 0.01$) treatments during the final 5 weeks of the finishing period. This reduction in DMI resulted in improved feed efficiency ($P < 0.01$) and NE recovery (approximately 7.5% for $NE_g$) for the SFC vs. DRC treatments. Performance measures among the DRC treatments were not different ($P > 0.10$), which agrees with previous research (Swanson et al., 2014). Reduced DMI and improved G:F (6.9%) for the SFC vs DRC treatments suggests that investments in steam flaking equipment remains a viable option for all but the very smallest capacity cattle feeders. Additionally, since there was a linear effect of decreasing DMI with reduced particle size of DRC and no differences in animal performance or carcass traits for DRC treatments suggest a potential sub-acute acidotic event could have occurred. Owens et al. (1998) reported that feed intake and growth performance can be compromised when sub-acute acidosis occurs.

The treatment-by-week interaction was significant ($P < 0.05$; Fig. 3.3) indicating the effect of treatment on DMI depended upon which weeks of the study were considered. In addition, over the final 5 weeks of the study, linear ($P < 0.01$) effects of DRC particle size on DMI were observed (13.05, 12.50, and 12.22 kg/head/d for the COARSE, MEDIUM, and FINE treatments, respectively).

### *Carcass Merit*

No differences ($P > 0.10$) among treatments were observed for any of the carcass traits measured suggesting that corn processing did not impact carcass merit in yearling steers fed diets containing 20% WDG (Table 3.8). These results are similar results reported by Swanson et al. (2014) in that decreasing DRC particle size with the inclusion of 20 and 40% DDGS had no effect on HCW, $12^{th}$ rib fat thickness, rib-eye area, and marbling score.

Our results indicate improved ruminal starch digestibility, reduced fecal starch concentration, and reduced DMI with decreasing DRC particle size in feedlot diets containing 20% wet distiller's grains on a dry matter basis. A better understanding of DRC particle size on the influence of feedlot performance with the addition of various levels of WDG is needed. Based on these data, feeding finely processed corn in diets containing 20% wet distiller's grains appears to be acceptable in binding fines and improving homogeneity of diet; however, it is not clear the reason for reduced DMI with decreasing DRC particle size towards the end of the finishing period and could have potentially been associated with a sub-acute acidotic event. Reducing DRC particle size in diets containing WDGS may improve starch digestion but additional processing increases the cost of production and may not be offset by improved cattle performance. Furthermore, given that DRC particle size had a linear effect on fecal starch concentrations in this study, reducing the particle size from current manufacturing practices of the industry average would improve total tract starch utilization and potentially reduced DMI in diets containing 20% wet distiller’s grains.

**Figure 3.1 The effects of corn processing treatment on ruminal DM disappearance from corn samples placed in Dacron bags and suspended in the rumen for 0, 2, 4, 8, 12, and 24 h. Treatments were COARSE, Coarse dry-rolled corn (4,882μm); MEDIUM, Medium dry-rolled corn (3,760 μm); FINE, Fine dry-rolled corn (2,359 μm); SFC, Steam-flaked corn (0.35 kg/L).**

**(*SFC vs. DRC, *P* < 0.05; ‡DRC Quadratic, *P* < 0.05; †DRC linear, *P* < 0.05). SEM = 5.30**

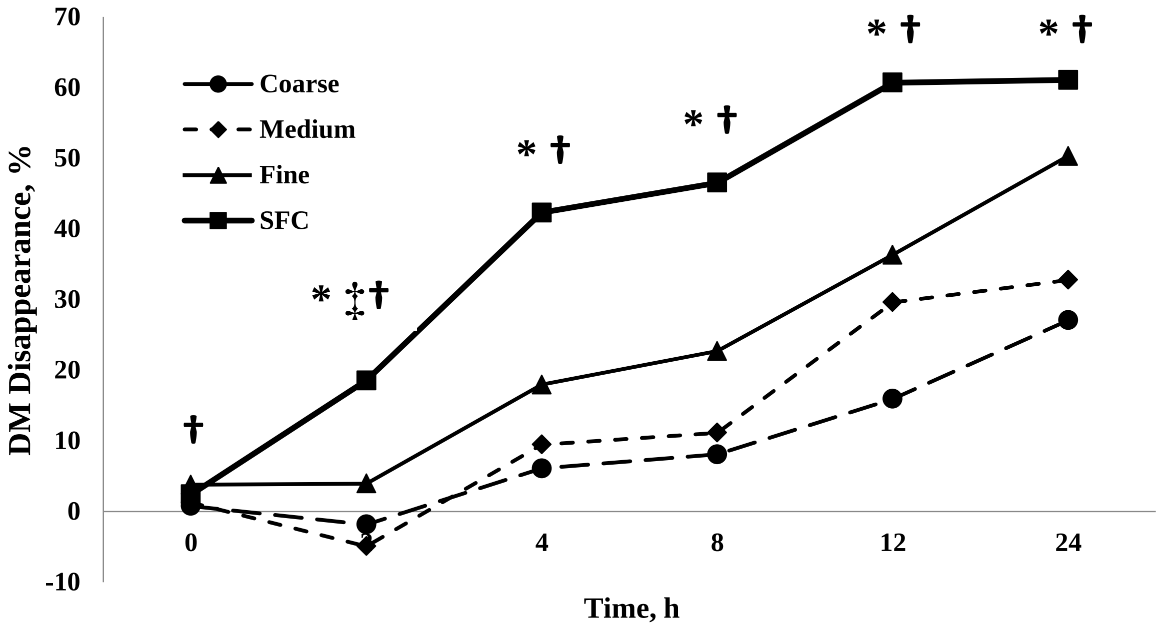

**Figure 3.2 The disappearance of starch from Dacron bags suspended in the rumen for 0, 2, 4, 8, 12, or 24 hours. Treatments were COARSE, Coarse dry-rolled corn (4,882µm); MEDIUM, Medium dry-rolled corn (3,760 µm); FINE, Fine dry-rolled corn (2,359 µm); SFC, Steam-flaked corn (0.35 kg/L). Treatment (*P* < 0.01), time (*P* < 0.01), and the treatment by time interaction (*P* < 0.01) effects for *in situ* starch disappearance were significant. After 24 h incubation, *in situ* starch disappearance was approximately 18.0, 36.2, 52.0, and 63.1 % (SEM = 5.44) for the COARSE, MEDIUM, FINE, and SFC treatments, respectively (*SFC vs. DRC, *P* < 0.05; †DRC linear, *P* < 0.05).**

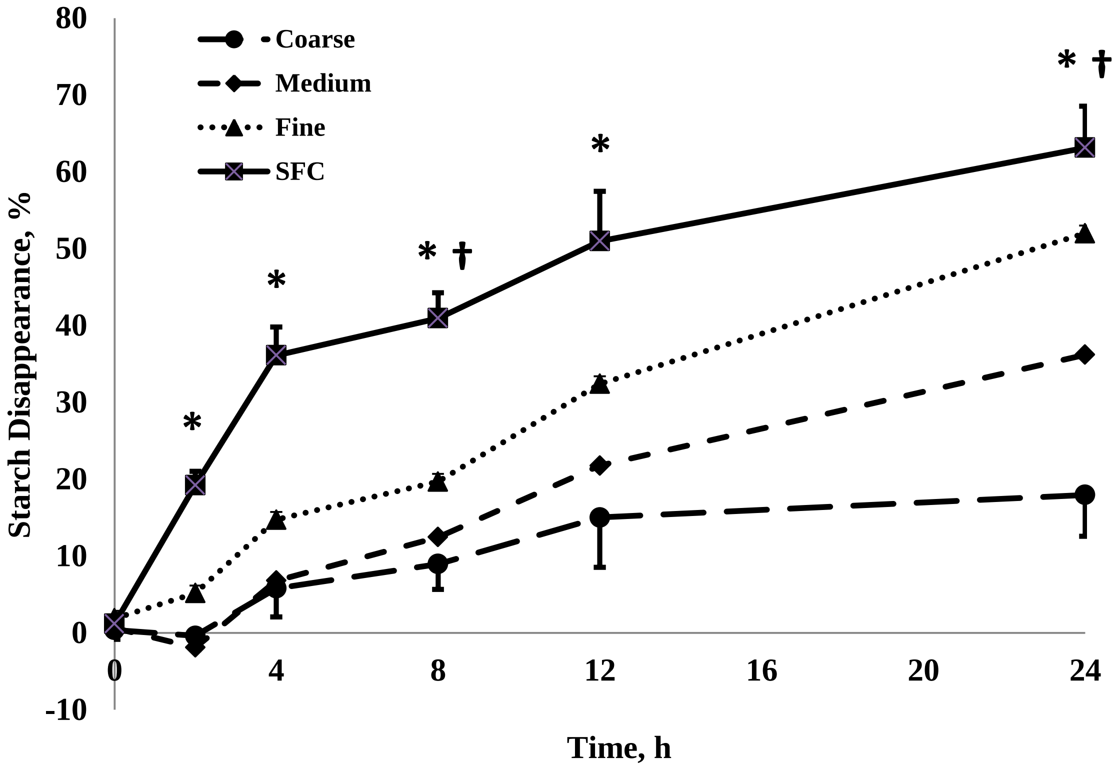

**Figure 3.3 Weekly average daily DMI by treatment for cattle fed COARSE, Coarse dry-rolled corn (4,882µm); MEDIUM, Medium dry-rolled corn (3,760 µm); FINE, Fine dry-rolled corn (2,359 µm); SFC, Steam-flaked corn (0.35 kg/L). Treatment by week interaction was significant (*P* < 0.05). For any given week, means without a common superscript are different (*P* < 0.05). SEM = 0.501.**

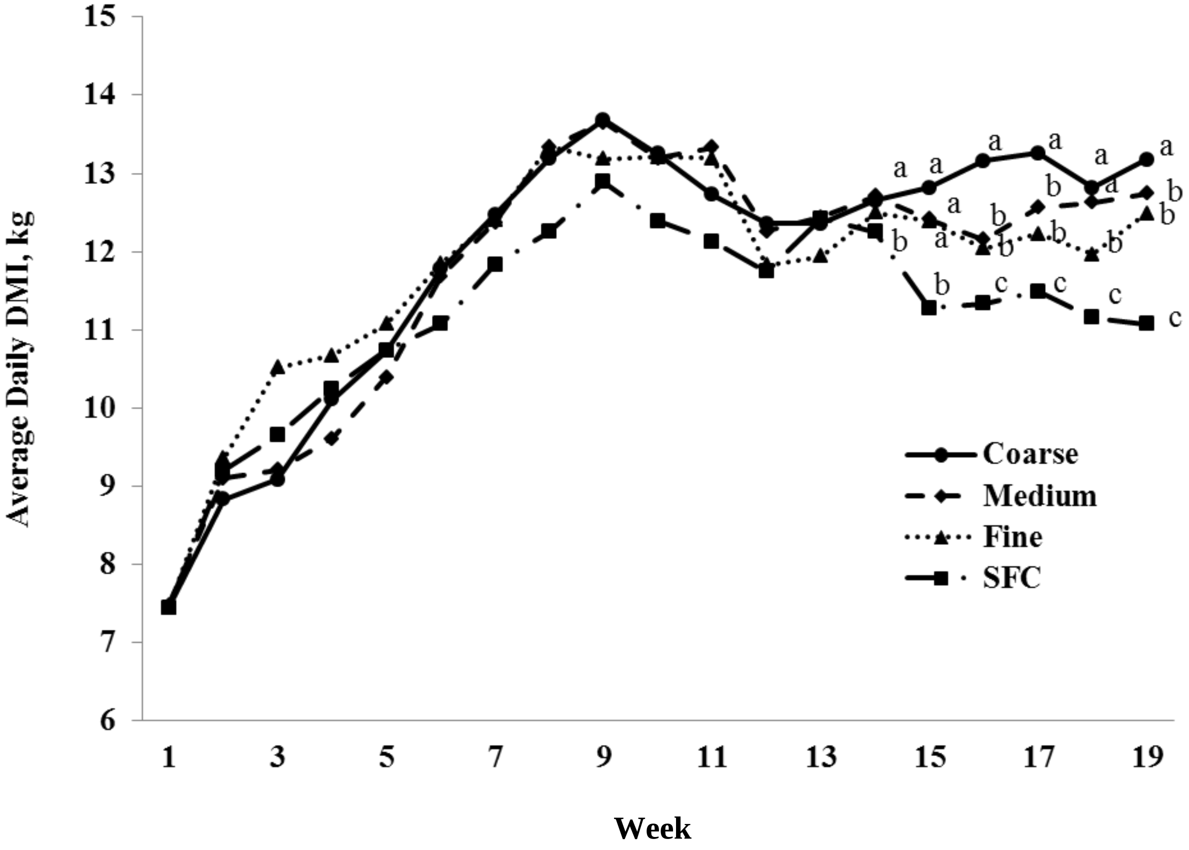

**Table 3.1 Ingredient composition of study diets to evaluate dry-rolled corn particle size on feedlot performance in yearling steers fed a diet containing wet distiller's grain (DMB).**

| | Diet[1] | | | | |
|---|---|---|---|---|---|
| Ingredient | Starter | Step – 1 | Step – 2 | Finish, Without Ractopamine hydrochloride | Finish, With Ractopamine hydrochloride |
| Wet distillers grains | 12.33 | 22.76 | 18.93 | 19.99 | 20.79 |
| Corn[2] | 38.56 | 39.04 | 57.44 | 64.90 | 63.10 |
| Corn silage | 17.25 | 26.71 | 13.61 | 8.75 | 7.18 |
| Alfalfa hay | 28.58 | 8.79 | 5.30 | -- | -- |
| Liquid Supplement[3] | 3.27 | 2.68 | 4.71 | 6.36 | 6.47 |
| Medicated pellet[4] | -- | -- | -- | -- | 2.46 |

[1] Starter period (d 1 – 7 post arrival); Step-1 (d 8 – 14 post arrival); Step-2 (d 15 – 23 post arrival); Finish without Ractopamine hydrochloride (d 24 – 113 post arrival); Finish with Ractopamine hydrochloride (d 114 – 142 post arrival).

[2] Steam-flaked corn was included in the starter and step-up diets for all treatments,

[3] Midwest PMS, Firestone, CO; CP, 40%; CP from non-protein nitrogen, 33.71; fat, 0.6%; calcium, 6.1%; phosphorus, 0.15%; salt, 3% salt; potassium, 2%; vitamin A, 28,650 IU/kg; monensin, 551 mg/kg; and tylosin, 115.7 mg/kg.

[4] Scott Pro Optaflexx pellet, 882 mg/kg, added to the batch at 0.34 kg/head daily.

**Table 3.2** **Analyzed nutrient composition (DMB) of diets used to evaluate the effects of dry-rolled corn particle size on feedlot yearling steers.**

| | Diet[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| Item | Starter | Step – 1 | Step – 2 | COARSE | MEDIUM | FINE | SFC |
| DM[2] | 65.0 | 55.8 | 59.3 | 62.6 | 61.1 | 61.4 | 60.4 |
| CP | 14.1 | 15.2 | 15.0 | 15.7 | 15.9 | 16.3 | 16.2 |
| NPN[3] | 1.8 | 1.5 | 2.8 | 3.2 | 3.2 | 3.3 | 2.9 |
| NDF[4] | 29.1 | 22.1 | 17.8 | 14.2 | 14.5 | 13.9 | 14.6 |
| Fat | 2.97 | 4.89 | 4.16 | 5.2 | 5.2 | 5.2 | 5.1 |
| Ca | 0.94 | 0.46 | 0.65 | 0.83 | 0.71 | 0.88 | 0.80 |
| P | 0.29 | 0.36 | 0.35 | 0.37 | 0.37 | 0.37 | 0.40 |
| K | 1.46 | 1.10 | 0.94 | 0.83 | 0.84 | 0.84 | 0.88 |
| Mg | 0.27 | 0.22 | 0.18 | 0.19 | 0.19 | 0.19 | 0.20 |
| S | 0.20 | 0.23 | 0.19 | 0.24 | 0.20 | 0.20 | 0.20 |
| Starch | 34.5 | 42.0 | 50.7 | 53.2 | 54.0 | 54.3 | 52.0 |

[1] COARSE, Coarse dry-rolled corn (4,882µm); MEDIUM, Medium dry-rolled corn (3,760 µm); FINE, Fine dry-rolled corn (2,359 µm); SFC, Steam-flaked corn (0.35 kg/L).

[2] Percentage of as-fed.

[3] Crude protein equivalent.

[4] Neutral detergent fiber of the diet

**Table 3.3 Nutrient analysis[1] (DMB) for corn used to evaluate the effects of dry-rolled corn particle size on feedlot finishing diets containing 20% wet distiller's grains (DMB).**

| Item[2] | DM[3] | Total Starch | Avail. Starch[4] |
|---|---|---|---|
| FINE | 86.9 ± 0.26 | 73.5 ± 1.03 | 19.8 ± 0.66 |
| MEDIUM | 86.7 ± 0.42 | 74.0 ± 0.76 | 20.0 ± 0.32 |
| COARSE | 86.9 ± 0.63 | 74.2 ± 0.72 | 20.0 ± 0.32 |
| SFC | 83.5 ± 0.51 | 76.7 ± 0.92 | 43.0 ± 2.98 |

[1] SDK Laboratories, Hutchinson, KS.

[2] FINE, Fine dry-rolled corn (2,359 µm); MEDIUM, Medium dry-rolled corn (3,760 µm); COARSE, Coarse dry-rolled corn (4,882µm); SFC, Steam-flaked corn (0.35 kg/L).

[3] Percentage of as-fed ± standard error of the mean.

[4] Available starch. Percentage of total starch evaluated by enzymatic hydrolysis.

**Table 3.4 Sieve stack used to evaluate dry processed corn particle size of Midwestern U. S. finishing cattle diets**

| US Sieve Number | Tyler Sieve Number | Opening, microns |
|---|---|---|
| - | 2.5 | 8,000 |
| 4 | 4 | 4,760 |
| 6 | 6 | 3,360 |
| 8 | 8 | 2,380 |
| 12 | 10 | 1,680 |
| 16 | 14 | 1,190 |
| 20 | 20 | 841 |
| 30 | 28 | 595 |
| 40 | 35 | 420 |
| 50 | 48 | 297 |
| 70 | 65 | 210 |
| 100 | 100 | 149 |
| 140 | 140 | 105 |
| pan | Pan | - |

**Table 3.5 Dry-rolled corn particle sizes used to evaluate the effects of dry rolled corn particle size on feedlot finishing diets containing 20% wet distiller's grains (DMB).**

| | Treatment[2] | | | | |
|---|---|---|---|---|---|
| Item | COARSE | MEDIUM | FINE | SEM[1] | Prob. > F |
| $d_{gw}$[3] | 4,882 | 3,760 | 2,359 | 127.6 | < 0.01 |
| $S_{gw}$[4] | 1.54 | 1.71 | 2.00 | 0.55 | < 0.01 |

[1] Standard error of the least squares mean.

[2] COARSE, Coarse dry-rolled corn (4,882µm); MEDIUM, Medium dry-rolled corn (3,760 µm); FINE, Fine dry-rolled corn (2,359 µm); SFC, Steam-flaked corn (0.35 kg/L).

[3] $d_{gw}$: geometric mean diameter (µm).

[4] $S_{gw}$: standard deviation of the geometric mean diameter.

**Table 3.6 Least squares means illustrating the effect of dry-rolled corn particle size on fecal starch content in yearling steers fed diets containing 20% wet distiller's grains (DMB).**

| | Treatment[1] | | | | | Prob. > F[4] | | | |
|---|---|---|---|---|---|---|---|---|---|
| Item[2] | COARSE | MEDIUM | FINE | SFC | SEM[3] | TRT | SFC vs DRC | DRC Linear | DRC Quadratic |
| Fecal Starch, % | 13.92 | 10.41 | 7.64 | 2.12 | 0.594 | < 0.01 | < 0.01 | < 0.01 | 0.66 |

[1] COARSE, Coarse dry-rolled corn (4,882µm); MEDIUM, Medium dry-rolled corn (3,760 µm); FINE, Fine dry-rolled corn (2,359 µm); SFC, Steam-flaked corn (0.35 kg/L).

[2] Percentage of dry matter.

[3] Standard error of the least squares mean.

[4] TRT, Treatment effects; SFC vs. DRC, Steam-flaked vs dry-rolled corn; DRC L, Dry-rolled corn linear; DRC Q, Dry-rolled corn quadratic.

**Table 3.7 Least squares means illustrating the effect of dry-rolled corn particle size on feedlot performance in yearling steers fed diets containing 20% wet distiller's grains (DMB).**

| | Treatment[1] | | | | | | Prob. > F | | |
|---|---|---|---|---|---|---|---|---|---|
| Item[2] | COARSE | MEDIUM | FINE | SFC | SEM[3] | TRT[4] | SFC vs DRC | DRC Linear | DRC Quadratic |
| Initial weight, kg | 381 | 381 | 381 | 381 | 9.4 | 0.76 | 0.58 | 0.50 | 0.49 |
| Day 17 weight, kg[5] | 412 | 420 | 418 | 416 | 2.0 | 0.06 | 0.99 | 0.08 | 0.07 |
| Final weight, kg[6] | 637 | 640 | 636 | 641 | 4.5 | 0.81 | 0.60 | 0.87 | 0.42 |
| Step-up Period | | | | | | | | | |
| ADG, kg | 1.83 | 2.31 | 2.16 | 2.11 | 0.122 | 0.06 | 0.99 | 0.10 | 0.07 |
| DMI, kg[5] | 8.23 | 8.38 | 8.51 | 8.43 | 0.120 | 0.39 | | | |
| GF | 0.223 | 0.277 | 0.254 | 0.250 | 0.0138 | 0.07 | 0.96 | 0.16 | 0.05 |
| Calc. $NE_m$[7] | 99.4 | 113.5 | 107.2 | 106.0 | 3.69 | 0.08 | 0.86 | 0.18 | 0.05 |
| Calc. $NE_g$[7] | 68.6 | 81.0 | 75.4 | 74.3 | 3.24 | 0.08 | 0.86 | 0.18 | 0.05 |
| Finish Period | | | | | | | | | |
| ADG, kg | 1.98 | 1.93 | 1.91 | 1.96 | 0.040 | 0.61 | | | |
| DMI, kg[6] | 12.31 | 12.15 | 12.17 | 11.50 | 0.256 | 0.11 | 0.02 | 0.68 | 0.77 |
| GF[6] | 0.162 | 0.159 | 0.158 | 0.171 | 0.0035 | 0.05 | < 0.01 | 0.43 | 0.84 |
| Calc. $NE_m$[7] | 88.9 | 88.5 | 88.0 | 93.5 | 1.35 | 0.03 | < 0.01 | 0.69 | 0.97 |
| Calc. $NE_g$[7] | 59.3 | 59.0 | 58.6 | 63.4 | 1.19 | 0.03 | < 0.01 | 0.69 | 0.97 |
| DMI last 5 weeks, kg | 13.05 | 12.50 | 12.22 | 11.27 | 0.216 | < 0.01 | < 0.01 | < 0.01 | 0.15 |
| Overall | | | | | | | | | |
| ADG, kg[5] | 1.97 | 2.00 | 1.96 | 2.00 | 0. 034 | 0.80 | 0.58 | 0.50 | 0.49 |
| DMI, kg[5] | 11.82 | 11.70 | 11.73 | 11.14 | 0.233 | 0.14 | 0.02 | 0.77 | 0.78 |
| caFinal BW, kg[8] | 635 | 642 | 637 | 639 | 4.6 | 0.74 | 0.088 | 0.076 | 0.26 |
| caADG, kg[8] | 1.96 | 2.00 | 1.97 | 1.99 | 0.035 | 0.79 | 0.83 | 0.82 | 0.29 |
| G:F[5] | 0.168 | 0.171 | 0.168 | 0.180 | 0.0030 | 0.03 | < 0.01 | 0.87 | 0.47 |
| Calc. $NE_m$[7] | 90.0 | 91.0 | 90.0 | 94.9 | 1.23 | 0.02 | < 0.01 | 0.99 | 0.55 |
| Calc. $NE_g$[7] | 60.4 | 61.2 | 60.3 | 64.7 | 1.08 | 0.02 | < 0.01 | 0.99 | 0.55 |

[1] COARSE, Coarse dry-rolled corn (4,882µm); MEDIUM, Medium dry-rolled corn (3,760 µm); FINE, Fine dry-rolled corn (2,359 µm); SFC, Steam-flaked corn (0.35 kg/L).

[2] Least-squares treatment mean.

[3] Standard error of the least-square mean.

[4] Treatment as a fixed model effect.

[5] Initial BW used as a covariate, $P < 0.10$.

[6] d 17 BW used as a covariate, $P < 0.10$.

[7] Calculated from performance, Mcal/45.4 kg diet DM.

[8] Carcass adjusted for average dressing percent 66.0%.

**Table 3.8 Least squares means illustrating the effect of dry-rolled corn particle size on carcass merit in yearling steers fed diets containing 20% wet distiller's grains (DMB).**

| | Treatment[1] | | | | | |
|---|---|---|---|---|---|---|
| Item[2] | COARSE | MEDIUM | FINE | SFC | SEM[3] | Prob. > F |
| Hot carcass weight, kg[4] | 419 | 423 | 420 | 422 | 3.2 | 0.79 |
| Dressing percentage | 65.8 | 66.2 | 66.1 | 65.8 | 0.25 | 0.49 |
| Marbling score, units[5] | 409 | 420 | 413 | 408 | 8.0 | 0.67 |
| USDA Quality grade[6] | 10.5 | 10.6 | 10.5 | 10.5 | 0.11 | 0.81 |
| USDA Quality grade distribution[7] | | | | | | |
| ≥ Low Choice | 52.3 | 53.4 | 56.3 | 52.4 | 5.45 | 0.94 |
| ≤ Select | 47.7 | 46.6 | 43.7 | 47.6 | | |
| 12th rib fat depth, cm | 1.30 | 1.32 | 1.30 | 1.37 | 0.051 | 0.70 |
| Ribeye area, sq. cm | 91.6 | 91.0 | 91.0 | 91.6 | 1.16 | 0.81 |
| USDA Yield grade[8] | 3.14 | 3.25 | 3.20 | 3.26 | 0.088 | 0.71 |
| USDA Yield grade distribution[7] | | | | | | |
| Yield grade 1, 2, and 3 | 87.5 | 86.2 | 86.0 | 86.9 | | |
| Yield grade 4 and 5 | 12.5 | 13.8 | 14.0 | 13.1 | 3.99 | 0.99 |

[1] COARSE, Coarse dry-rolled corn (4,882µm); MEDIUM, Medium dry-rolled corn (3,760 µm); FINE, Fine dry-rolled corn (2,359 µm); SFC, Steam-flaked corn (0.35 kg/L).

[2] Least-squares treatment means unless specified otherwise.

[3] Standard error of the least-squares mean.

[4] Initial weight was used a covariant in the analysis (*P* < 0.10).

[5] Marbling score units: 400 = Small$^{00}$, 500 = Modest$^{00}$.

[6] Quality grade numeric scale: 10 = Select; 11 = Low Choice, 12 = Average Choice.

[7] Percentage of individual carcasses within a treatment qualifying for each category.

[8] USDA Yield grade calculated from carcass measurements.

# Chapter 4 - A survey of starch availability of steam flaked corn in commercial feedlot evaluating roll size and flake density[1]

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# Abstract

Commercial feedlots (n = 17) located in Kansas, Nebraska, Texas, New Mexico, Arizona, and California were asked to participate in a survey to evaluate steam-flaked corn (SFC) manufacturing practices implemented, equipment utilized, and methods used and parameters targeted to measure flake quality. Manufacturing practice parameters evaluated included dry corn moisture, grain water addition, tempering time, steaming time, steam cabinet temperature, rate of processed grain production throughput, mill electrical load, steam-conditioned corn moisture content, SFC moisture content, and SFC flake thickness; equipment evaluated included roll size and steam cabinet dimensions and capacity; flake quality parameters evaluated included hot and cooled SFC flake density, SFC volumetric flake weight, and starch availability of SFC samples. Samples of steam conditioned corn and SFC were collected from each flaker (n =49) within each feedlot. Flake density was measured on hot (immediately from below the rolls) and cooled flakes and volumetric weight was measured only on cooled flakes. Steam-flaked corn samples were evaluated for starch availability using enzymatic hydrolysis (Servi-Tech Laboratories, Dodge City, KS) and the Flake Color Index System (Lextron, Inc., Greeley, CO). Significant variables contributing to the final multiple linear regression model using enzymatic starch availability (Enzymatic) as the dependent variable were: steam flaked corn moisture (SFC Moisture), cooled flake density (CoolFD), throughput, roll diameter, steam cabinet temperature (Temperature), and temper time (Enzymatic = 19.4476 - (0.6927*SFCMoisture) - (2.1664*CoolFD) - (0.5060*Throughput) + (0.6281*Roll Diameter) + (0.4312*Temperature) – (0.1963*Temper Time; $P < 0.15$).

**Key words:** beef cattle, flake density, roll size, starch availability, steam-flaked corn

# Introduction

Steam-flaked corn (SFC) is commonly fed in feedlot finishing diets and steam-flaking improves starch availability and nutrient utilization, thus improving the overall feeding value of corn (Zinn et al., 2002). In most operations which utilize SFC, grain is processed to a pre-determined flake density by setting the rolls to a specific separation distance and tension holding rolls together. Owens and Zinn (2005) reported flaking corn to lesser densities improved total tract starch and protein digestion, particularly increasing small intestinal starch and protein digestion. Flaked grain is generally produced to a bulk density between 0.31 kg/L (24 lb/bu) and 0.41 kg/L (32 lb/bu; Owens et al., 1997), with an average recommendation of 0.35 kg/L (27 lb/bu) for corn and 0.33 kg/L (26 lb/bu) for sorghum grain (Vasconcelos and Galyean, 2007); however, the optimum flake density among steam flakers within a single mill and among feedlots can vary greatly. Flaking to a similar density using two flakers does not ensure similar starch availability (Armbruster, 2006).

The degree of starch gelatinization or starch availability of SFC can be estimated using analytical procedures such as enzymatic hydrolysis, gas production, and SFC gelatinization methods (Vasconcelos and Galyean, 2007). More recently, an optical method (Flake Color Index System [**FCIS]**; a proprietary color intensity measurement device [Lextron Inc., Greeley, CO]; $R^2 = 0.89$; $P < 0.01$; Hubbert, 2015, personal communication) has been shown to be another reliable option to estimate starch availability. Routinely evaluating starch availability provides an effective quality control method to standardize the steam flaking process to ensure within-day and day-to-day manufacturing consistency. The concentration of readily available starch in SFC is indicative of the rate of starch fermentation in the rumen. When starch is too readily available and is fermented at an excessively rapid rate, volatile fatty acids can accumulate in the rumen, reducing ruminal pH, and ultimately resulting in increased prevalence of digestive disturbances.

Factors that contribute to variation between feedlot operations with respect to SFC quality include type and dimensions of flaking equipment, grain type, grain variety and moisture content, and steam-flaking procedures. Sampling and handling procedures contribute to precision of results; therefore, sampling procedures need special attention and consistency must be evaluated when attempting to determine starch availability of SFC. Equipment required for steam flaking consists of the grain handling system, the boiler system, soak tanks, steam cabinets, flaking-rolls, and storage facilities, all of which can influence SFC quality. Within each operation, different elements of production capacity, energy costs, and operational efficiencies exist which all affect efficiency of processing grain (Peters, 2006).

The objective of this study was to evaluate starch availability of SFC comparing roll dimensions and SFC flake densities among flaking systems and feedyards and to provide information on equipment utilized, SFC flaking procedures, and to define current manufacturing practices of steam flaking in commercial feedlot operations.

## Materials and Methods

Animal Care and Use Committee approval was not required for this study because no animals were used.

Commercial feedlots (n = 17) which regularly steam-flake grain in their operations were selected for inclusion in this study. Data were collected from August through October 2015. Each individual roll set (n = 49) within each feedlot was considered the observational unit; samples were collected during normal operating procedures.

### *Data Collection*

***Steam-conditioned corn.*** Steam-conditioned corn samples were most commonly collected directly above the rolls located at the peg feeder. Investigators were unable to collect steam-conditioned grain from two flakers. Flaker design dictated that steam-conditioned corn samples from 14 flakers be collected below the rolls with the rolls separated and temporarily not in operation. Grain samples were placed in an air-tight plastic container and transported to the Ruminant Nutrition Laboratory (Manhattan, KS) for complete DM analysis.

***Steam-flaked corn.*** Steam-flaked corn was collected directly below the rolls and across the entire length of the roll. Flake density was measure 3 separate ways: 1) Measured by yard personnel under normal operating procedures immediately after collection (YardFD); 2) Measured by the investigator using a standardized procedure at all yards (HotFD); 3) Measured by the investigator using the same standardized measurement procedure after samples were taken from the rolls, immediately spread out on a flat surface (thickness of approximately 3 centimeters), and allowed to cool for 15 min (CoolFD). Volumetric weight (g/L) was measured using a 1.23 L plastic cylinder and was over-filled with cooled SFC, leveled off with a ruler, and weighed (Volumetric). Cooled flake density and volumetric weight measurements were taken in duplicate. Flake Color Index System (FCIS, Lextron, Inc., Greeley, CO) analysis was conducted on cooled SFC samples from each roll set. Each individual SFC sample was ground for 30 s in a high-speed blender, sieved, and placed in a transparent plastic bag. Individual FCIS readings were taken 15 times and recorded using FCIS software. This same ground sample of SFC was subsequently submitted to Servi-tech laboratories (Dodge City, KS) for total starch (F-502.001) and available starch using enzyme hydrolysis (Servi-Tech Laboratories F-502.001; Xiong et al., 1990). Subsamples of steam conditioned corn and steam-flaked corn were analyzed for complete DM analysis at the Kansas State University Ruminant Nutrition Lab (500.39; Undersander, 1993). Cooled SFC samples were also analyzed for flake thickness using a micrometer. Twenty five whole, intact flakes from each set of rolls were measured at the center of the flake and thickness was recorded; average thickness values for each roll set were recorded.

### *Survey questions*

The survey portion of this study recorded general steam flaking equipment information including the following: manufacturer, roll dimensions [diameter (in) x length (in)], steam cabinet height (ft), steam cabinet width (ft) and steam cabinet capacity (bu). All questions were asked of yard personnel with respect to each individual flaking system at the time of sample collection and were recorded a single investigator. All feedyards provided information about flaker manufacturer and roll dimensions. Feedyards (n = 2) that did not provide information about steam cabinet dimensions and capacity were not included in the survey results.

### *Statistical Analysis*

Data were analyzed as a multiple linear regression using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pearson's correlation coefficients (r) were determined for each pair of continuous variables considered for potential use as independent variables in the multiple linear regression model using PROC CORR of SAS to determine potential collinearity ($r \geq 0.70$; $P < 0.05$). For pairs of variables which were determined to be collinear, only one variable was selected for inclusion in the regression model. Manual forward selection was used to fit a regression model to the response variables and determine significant ($P < 0.15$) explanatory variables. The ultimate model statement included starch availability measured using enzymatic hydrolysis as a response variable and cooled flake density, SFC moisture, rate of grain volume throughput, roll diameter, steam cabinet temperature, and tempering time ($P < 0.15$) were used as Fixed-effects. A simple linear regression using the REG procedure of SAS was used to evaluate the following variables: investigator flake density (hot) vs. yard personnel flake density, hot flake density vs cooled flake density measurement, yard personnel flake density vs. enzymatic starch availability, flake thickness vs. hot flake density, and flake thickness vs. cooled flake density.

## Result

### *Part 1: Survey data*

### *General Information*

Consulting Nutritionists (n = 7) suggested names of feedlots (n = 17) to participate in this survey. Each individual flaker (n = 49) was considered an independent observational unit. Feedyards were located in Kansas (n = 9), Texas (n = 2), Nebraska (n = 1), Colorado (n = 1), New Mexico (n = 2), California (n = 1), and Arizona (n = 1). Feedyard one-time capacity ranged from approximately 20,000 – 140,000 animals (hd) with 20,000 – 39,999 hd (n = 6); 40,000 – 59,999 hd (n = 4); 60,000 – 79,999 hd (n = 1); 80,000 – 99,999 hd (n = 3); or > 100,000 hd (n = 2). Number of flakers per feedyard ranged from 1 to 10 with 1 flaker (17.7% of feedyards); 2 flakers (47.1%); 3 flakers (11.8%); 4 flakers (11.8%); 6 flakers (5.9%); and 10 flakers (5.9%).

### *Steam flaking equipment*

***Roll size.*** Roll size varied considerably between feedyards. There were 7 different dimensions of roll sizes across 17 feedyards. The most prevalent roll size was 24” x 48” (24.5%) followed by 24” x 36” (20.4%), 20” x 36” (18.4%), 18” x 36” (16.3%), 32” x 68” (10.2%), 24” x 56” (8.2%), 18” x 24” (2.0%; Table 4.1). Roll diameter ranged from 18” to 32” and roll length ranged from 24” to 68” in this survey. In addition to roll size, the ratio of length to diameter (L/D) was also reported and averaged 1.9 with a range from 1.33 to 2.33. The L/D ratio used for flaking is generally 1.5 to 2.5 (Heiman, 2006).

***Steam cabinet size and capacity.*** Steam cabinet height ranged from 12’ to 70’ with most of the feedyards using a 25’ tall steam cabinet (%; Table 4.1). Steam cabinet width ranged from 2’ to 8’ with most of the feedyards using 6.5’ wide steam cabinet (35.0%; Table 4.1). The steam cabinet capacity (bu; corn) ranged from approximately 18 to over 2,100 bu. The majority of the feedyards had steam cabinet capacity between 501 and 700 bu (27.5%; Table 4.1).

***Temper system.*** All but one feedyard added water to dry grain prior to steaming; however, several flakers (n = 19) only had capacity to add water either using a mixing auger above the steam cabinet or utilized a small amount of head space above the top steam inlet in the steam cabinet for soaking. Three feedyards (n = 6) utilized grain surfactant, or grain conditioner during water addition prior to steaming. Thirteen flakers flaked grain which had been soaked overnight in soak bins and the remaining flakers flaked grain which had been soaked from 1.5 to 4.5 hrs on average. Water addition (gal/min) was also evaluated and was dependent on the moisture content of the dry corn. The majority of this survey was conducted prior to fall corn harvest, which standardized the quality and moisture content of in-bound grain to some degree. One feedyard (n = 10) had begun receiving new crop corn so their samples were considered to be a blend of new and old crop. One feedyard (n = 2) had a greater dry corn moisture content (17.1%) indicating they were possibly flaking new crop corn at the time.

### *Steam flaked corn measurements*

***Flake density.*** The results for the three measures of flake density are presented in table 4.2. Flake density measured by yard personnel averaged 27.5 lb/bu with a range of 24 to 31 lb/bu; investigator flake density measurement averaged 27.7 lb/bu with a range of 24.5 to 31 lb/bu; and cooled flake density measured by the investigator was 24.1 lb/bu with a range of 18.5 to 29.5 lb/bu.

***Roll corrugations.*** Roll corrugations were measured by evaluating the number of grooves per inch from various flakes from each sample. Corrugations ranged from 14 to 16 grooves per inch and were reported by mill personnel as either round-bottom V (RBV) or Stevens Tooth profile.

***Roll gap.*** The roll gap is the distance between the rolls and adjusted to achieve a desired flake thickness. Results for flake thickness are presented in Table 4.2. Average flake thickness across all flakers was 1.76 mm with a range of 1.22 to 2.45 mm.

***Nip angle.*** The nip angle is the angle encountered between the flaking rolls at the point at which the grain kernel is compressed between the rolls and was calculated for each roll set (Figure 4.1). The average nip angle was 4.6º with a range from 3.5 to 5.6º (Table 4.2).

***Compression length.*** The compression length (mm) was defined as the length at which the kernel was compressed between the rolls (Figure 4.1) and was calculated using 1.8 mm for the kernel radius for all rolls so that [$b$ = (r + 1.8)]. The average flake thickness measurement from each flaker was used as the roll gap value and was calculated as [$c$ = r + 0.5(roll gap)]. The average compression length was 23.06 mm and ranged 17.82 to 29.47 mm (Table 4.2).

***Volumetric density (g/L)*** Steam flaked corn was also measured using a volumetric weight (g/L) to provide a different shape and volume. The average volumetric weight was 320.2 g/L and ranged from 237.8 to 380.9 g/L (Table 4.2).

***Starch Availability.*** Starch availability using enzymatic hydrolysis was completed at Servi-Tech Laboratories (Dodge City, KS) and values ranged from 37 to 65% with an average of 51% (Table 4.2). The FCIS was also used on all samples and average FCIS value was 8534 with a range from 8247 to 8755. The FCIS value increases with decreasing starch availability. All feedyards routinely submitted samples to commercial laboratories for starch availability analysis using enzymatic hydrolysis method. Most of the feedyards surveyed submitted weekly (66.7%) samples, while the remaining feedyards submitted monthly (33.3%) samples. Two feedyards also routinely evaluated starch availability using the FCIS.

***Retention time.*** The amount of time that the grain is in the steam cabinet exposed to steam at atmospheric pressure is considered the retention time. Retention time results are presented in Table 4.2. Average retention time across all flakers was approximately 50 min. with a range of 30 to 75 min. Most of the flakers used a retention time of 60 min but typically gave a range from 30 to 45 min or from 45 to 60 min.

### *Part II: Multiple linear regression*

All continuous independent variables were evaluated for potential collinearity using Pearson correlation ($r < 0.70$; Table 4.3). Coefficients that were selected for the multiple linear regression model were: cooled flake density, roll diameter, investigator flake density, nip angle, L/D ratio, and steam flaked corn moisture. Additional independent variables that were not collinear with any other variables also included in the model were: steam cabinet temperature, temper time, steaming time, flake thickness, and throughput. Significant variables contributing to the final multiple linear regression model using enzymatic starch availability as the dependent variable were: SFC moisture, cooled flake density, throughput, roll diameter, steam cabinet temperature, and temper time (Enzymatic = 19.4476 - (0.6927*SFCMoisture) - (2.1664*CoolFD) - (0.5060*Throughput) + (0.6281*Roll Diameter) + (0.4312*Temperature) – (0.1963*Temper Time; Table 4; $P < 0.15$).

Regression coefficient estimates for the variables determined to be significant and ultimately included in the final model were used to calculate enzymatic starch availability using the multiple linear regression equation. Simple linear regression analyses were conducted on the following combinations of independent variables: investigator flake density vs. yard personnel flake density, investigator flake density vs cooled flake density measurement, yard personnel flake density vs. enzymatic starch availability, flake thickness vs. investigator flake density, and flake thickness vs. cooled flake density. Investigator flake density was moderately related to yard personnel flake density ($R^2 = 0.60$; Figure 4.2) and enzymatic starch availability was poorly correlated to yard personnel flake density ($R^2 = 0.3126$; Figure 4.3) All other variables had poor relationships ($R^2 < 0.34$).

## Discussion

The steam flaking process is comprised of many essential components that contribute to increased starch availability and durability of processed grains. Processing factors to optimize efficiency and feed quality are addressed in published review articles (Osman et al., 1970; Zinn et al., 2002). Osman et al. (1970) suggested that moisture, heat, and pressure are the primary factors that influence the benefits of grain processing. Zinn et al. (2002) reported steam cabinet temperature, steaming time, roll corrugation, roll gap, and roll tension to be five critical factors contributing to optimal steam flaked corn quality. Based on the results of this study, SFC moisture, cooled flake density, throughput, roll diameter, steam cabinet temperature, and temper time were significant variables influencing starch availability (Table 4.4; $P < 0.15$).

Figure 4.4 illustrates predictive values using the multiple linear regression equation of each individual contributing variable as affected by starch availability across the range (min through max) of measured values holding the remaining 5 values constant at the mean value of those measurements. Figure 4.5 illustrates differences in min and max starch availability using the mulitple linear regression equation (Enzymatic = 19.4476 - (0.6927*SFCMoisture) - (2.1664*CoolFD) - (0.5060*Throughput) + (0.6281*Roll Diameter) + (0.4312*Temperature) –

(0.1963*Temper Time). As expected, roll diameter and steam cabinet temperature were negatively related to starch availability and SFC moisture, cooled flake density, throughput, and temper time were positively related to starch availability.

Results from this study report 7 different roll sizes across 17 commercial feedyards with a range in roll diameter from 18” to 32”. As the roll diameter increases the nip angle increases and reduces slippage, which is a major source of wear on the roll (Heiman, 1999). In addition, because of the longer nip angle grain is pulled through the rolls more easily improving overall effectiveness of processing (Heiman, 1999). Heiman (1999) reported improved effectiveness of flaking grain using 10” or 12” diameter rolls compared to 6.5” or 9” rolls because of the greater nip angle with larger rolls. Results from this study indicate for every 1” increase in roll diameter there is an increase in 0.63% starch availability ($P = 0.02$). When comparing 18” vs 32” rolls there are major differences in setting the roll gap and roll tension to compress the flakes. Zinn et al. (2002) report two methods to setting flaking rolls: 1) zero tolerance or initial roll gap with low roll tension so that grain passing through the rolls will force a gap between the rolls; or 2) the roll gap is set to a fixed distance and higher roll tension so grain passing through the rolls cannot increase the roll gap. All feedyards but 1 had a fixed roll setting due to the size and capacity of most flakers in this survey. In addition, compression length (mm) was considered the length at which the grain is compressed between the two rolls and was moderately correlated with roll diameter (r = 0.7399); however, this measurement was influenced by flake thickness which varied between flakers. Due to the collinearity ($r > 0.70$) of compression length and roll diameter, roll diameter was selected to be included in the regression model. As roll diameter increases, compression length increases which may influence flake quality and consistency.

Ideally, steamed corn should be presented to the rolls at 18 to 21% moisture and 212˚F (Heiman, 2005). Steam cabinet temperature in this study averaged 204.8˚ and ranged from 188˚ to 212˚. Multiple linear regression estimates suggest that for every 1˚F increase in steam cabinet temperature there was a 0.43% increase in starch availability ($P = 0.04$). This could be attributed to greater steam cabinet temperature contributing to adequate heat and moisture available to completely penetrate each kernel improving starch gelatinization (Heiman, 2005).

Sindt et al. (2006a) evaluated processing effects of adding 6 or 12% moisture content during tempering and flake density of steam flaked corn and reported a linear decrease in DM and increase in starch availability with increasing tempered moisture content; however, feeding high moisture steam flaked corn (36%) actually decreased dry matter intake and ADG compared to cattle fed 18% moisture steam flaked corn (Sindt et al., 2006b). Contrarily, in this study, steam conditioned corn and SFC moisture were determined to be collinear (r = 0.70; $P < 0.01$) and SFC moisture was selected to be included in the multiple linear regression model. Estimates in the regression model suggest that for every 1% increase in SFC moisture there was a 0.70% decrease in starch availability ($P = 0.12$). Given the range of steam flaked corn moisture was 14.4 to 20.7%, differences in starch availability using the regression equation would range from 51.2 to 58.6%.

Some feedyards have implemented tempering, or soaking the grain prior to flaking to improve moisture uptake. Zinn et al. (2008) evaluated tempering and steaming requirements and determined that implementing tempering improved moisture uptake and may reduce steam requirements in the steam cabinet (Zinn et al., 2008). During tempering of grain kernels prior to mechanical processing, surfactants can be used to improve the rate of moisture absorption (Zinn et al., 1998; Wang et al., 2003) and decrease the amount of moisture lost after flaking by decreasing surface moisture (Sindt et al., 2006). Previous research by Zinn (1990) suggested that steam conditioning grain prior to flaking can add up to 5% of moisture to the grain and steaming time may be reduced to 30 minutes which may be sufficient to achieve optimal flake quality and feeding value.

Steaming time is controlled by a feeder bar (i.e. peg feeder) located at the base of the steam cabinet directly above the rolls and determines the rate of feeding and distribution of grain entering the flaking rolls (Zinn et al., 2002). Adequate steaming time ensures that heat and moisture completely penetrate each kernel producing durable flakes with high starch gelatinization (Heiman, 2005). Different capacity steam cabinets will determine steaming time and essentially peg feeder rate and throughput. Results from this study determined throughput (t/hr) is related to starch availability. Multiple linear regression estimates indicate that for every 1 t/hr increase in throughput there was a 0.05% decrease in starch availability ($P < 0.01$). Given that throughput is controlled by the peg feeder rate and influences retention time in the steam cabinet these results seem intuitive; however, the difference in starch availability is minimal and likely unaffected given the total range of throughput was 2 to 25 t/hr with a much more narrow range of production rate capacity depending on roll dimensions.

Moisture uptake, flake density, flake thickness and in vitro starch digestibility (IVSD) have been measurements used to set quality standards for SFC (Zinn, 1990a; 1990b); however, flake density is one of the most important quality control measures when adequate moisture and heat are applied (Zinn et al., 2002). Flake density is one measurement that is quick, easy, and low cost and has been used as a quality control procedure (Xiong et al., 1990); however, using bulk density as a measure of starch availability has been disputed. Starch availability for a given bulk density may differ due to processing and kernel characteristics such as kernel size and moisture, steam conditioning time and temperature, and roll wear (Karr, 1984).

Procedures of measuring flake density varied between yards. All feedyards measured flake density on hot flakes immediately taken from below the rolls, but some feedyards sifted out fines prior to measuring and some did not. The relationship between yard personnel (YardFD, lb/bu) and investigator (InvFD, lb/bu) measurement of flake density was moderate (InvFD = 5.392 + 0.811 * YardFD; $R^2$ = 0.6058; Figure 4.2) indicating differences in flake density measurements between individuals and methods even when using the same equipment. When using flake density as a quality control measure, measurement should be taken consistently because timing (i.e. hot immediately from the rolls or cooled) can influence flake density measurements (Zinn et al., 2002; InvFD = 14.408 + 0.5517 * CoolFD; $R^2$ = 0.6179). In addition, Karr (1984) suggested that the moisture content of flaked grain during flake density measurements can influence accuracy of the measurement. Steam conditioned corn moisture and SFC moisture measures were evaluated to estimate the amount of surface moisture removed during cooling. Differences between SCC moisture and SFC moisture averaged 4.50 ± 1.42% with a wide range from 1.03 to 8.16% and most likely influenced the poor correlation between the InvFD vs. CoolFD measurement.

Flake density is a very effective tool for managing flaking procedures over time within a single flaker. Flake density is also useful when evaluating flaking procedures within a single feedyard, provided that the flaking equipment and grain is similar and the sampling and measurement procedures are identical between flakers and among yard personnel. However, the utility of flake density diminishes when comparing flakes produced in different feedyards or in different feed mills within a single feedyard because of the effects of differences in sampling and measurement procedures, the personnel doing the measurement, and because of differences in the various factors identified in the present study, such as roll diameter, steam temperature, and others. The authors recommend that enzymatic starch availability be used when comparing flakes that were produced on different flakers or in different feed mills. Also, the authors recommend that enzymatic starch availability be used as an objective identifier in place of flake density when reporting the extent of grain processing in subsequent scientific literature since flake density is not highly correlated to enzymatic starch availability when comparing across flaking systems (Enzymatic = 124.85 – 2.6979 * YardFD; $R^2 = 0.3126$; Figure 4.3). Conversely, this survey has shown that starch availability is subject to more factors in the flaking process than flake density alone.

Previous research has reported that decreasing flake density increases the degree of gelatinization and starch availability in corn (Zinn et al., 1990a; Sindt et al., 2006) and sorghum (Reinhardt et al., 1997; Swingle et al., 1999). Zinn et al. (1990a) evaluated steam flaked corn flaked to densities of 0.425, 0.360, and 0.301 kg/L (28, 24, and 20 lb/bu) and reported a linear decrease of ruminal pH and linear increase in postruminal and total tract digestibility of starch. Zinn et al. (2002) determined flake density to be closely related related to enzyme reactivity ($R^2 = 0.79$). Contrarily, results from this study indicate poor correlation between enzymatic starch availability (Enzymatic, %) and yard personnel measurement of flake density (YardFD, lb/bu; $R^2 = 0.31$; Enzymatic = 124.85 – 2.6979*YardFD; Figure 4.3). In addition, there were similar findings when evaluating the relationship between enzymatic starch availability (Enzymatic, %) and investigator flake density (InvFD; $R^2 = 0.32$; Enzymatic = 124.31 – 2.6586*InvFD). These results include a single measure from each individual roll set and represent a snap-shot in time of manufacturing practices, flake density, and enzymatic starch availability.

Zinn et al. (1990) determined that flake thickness was related to flake density; however, the relationship was a relatively poor ($R^2 = 0.74$) and likely due to variation in kernel hardness, tension across the rolls, and difficulties in measurement practices. In agreement, in the present study, flake thickness was poorly correlated to investigator flake density (InvFD, lb/bu) and cooled flaked density measured by the investigator (CoolFD, lb/bu; $R^2 = 0.34$ and 0.33, respectively).

Roll corrugations or grooves along the length of the rolls aid in pulling grain through the rolls (Heiman, 2005). When flaking, the goal is to crimp the flake requiring the roll corrugations to have a flat top to the tooth profile (Heiman, 2005). The number of grooves per inch also contributes to end product results and is specific to type of grain being processed. For instance, rolls used in steam flaking operations typically utilize relatively fine corrugations (14 to 20 gr/in) relate to data to refrain from cutting the grain (Heiman, 1999). Roll corrugations in this study were reported as 14 or 16 gr/in and either round-bottom V or Stevens Tooth profile. Last recorrugation date was provided by 4 feedyards (n = 12). Roll corrugations wear over time and require replacement approximately every 6 months to one year depending on usage. Measuring roll wear is highly subjective but can be approximated by evaluating product quality and production capacity. Production loss of 20% or more due to having to slow down throughput can be one indicator of significant roll wear and recorrugation is needed (Heiman, 2005).

Methods used to measure the amount of available starch have been evaluated (Xiong et al., 1990). Vasconcelos and Galyean (2007) surveyed feedlot consulting nutritionists and determined that the enzymatic method was preferred by of the nutritionists surveyed followed by gas production method, gelatinization, and Flake Color Index System (FCIS; Lextron Inc., Greeley, CO). Enyzme hydrolysis is one method used to determine starch availability but is costly and time consuming (Xiong et al., 1990). In addition, sampling procedures and inherent variation within the assay could influence results. However, this was the method of choice by all (n = 17) feedyards surveyed. Two feedyards also routinely evaluated starch availability using the FCIS.

As noted, manufacturing equipment and quality control measures vary greatly across commercial feedyards in the United States. Within each feedyard, each roll set should be managed as an individual unit given that no two units are the same. Each roll set is unique in roll wear, roll gap, mill load, steam cabinet temperature, retention time, etc. all variables that can influence steam flaked corn production capacity and quality. This study defines cooled flake density, throughput, roll diameter, SFC moisture, temperature, and temper time to be significant variables contributing to enzymatic starch availability in commercial feedyards located in the United States.

**Table 4.1 General information of steam flaking equipment used in 17 commercial feedyards surveyed in Nebraska, Kansas, Colorado, Texas, New Mexico, Arizona, and California**

| Item | No. of flakers | % of flakers |
|---|---|---|
| **Flaker Manufacturer** | | |
| R & R | 36 | 73.5 |
| Ferrill Ross | 12 | 24.5 |
| Memco | 1 | 2.0 |
| **Roll size, diameter (in) x length (in)** | | |
| 18 x 24 | 1 | 2.0 |
| 18 x 36 | 8 | 16.3 |
| 20 x 36 | 9 | 18.4 |
| 24 x 36 | 10 | 20.4 |
| 24 x 48 | 12 | 24.5 |
| 24 x 56 | 4 | 8.2 |
| 32 x 68 | 5 | 10.2 |
| **Steam Cabinet Height, ft[1]** | | |
| 12 | 1 | 2.5 |
| 20 | 14 | 35.0 |
| 25 | 4 | 10.0 |
| 30 | 4 | 10.0 |
| 33 | 6 | 15.0 |
| 40 | 3 | 7.5 |
| 45 | 1 | 2.5 |
| 51 | 2 | 5.0 |
| 54 | 3 | 7.5 |
| 70 | 2 | 5.0 |
| **Steam Cabinet Width, ft[1]** | | |
| 2 | 1 | 2.5 |
| 5 | 11 | 27.5 |
| 5.7 | 2 | 5.0 |
| 6 | 1 | 2.5 |
| 6.3 | 2 | 5.0 |
| 6.5 | 14 | 35.0 |
| 7 | 6 | 15.0 |
| 8 | 3 | 7.5 |
| **Steam Cabinet Capacity, bu[1]** | | |
| < 300 | 1 | 2.5 |
| 301- 500 | 8 | 20.0 |
| 501 - 700 | 11 | 27.5 |
| 701 - 900 | 3 | 7.5 |
| 901 - 1,100 | 10 | 25.0 |
| 1,101 - 1,400 | 4 | 10.0 |
| > 1,400 | 3 | 5.0 |

[1] 40 responses.

**Table 4.2 Steam flaking measurements in 17 commercial feedyards surveyed in Nebraska, Kansas, Colorado, Texas, New Mexico, Arizona, and California**

| Item | Mean | No. of flakers | Std Dev | Min | Max |
|---|---|---|---|---|---|
| **Pre-flaking measures** | | | | | |
| Dry corn moisture, % | 14.2 | 49 | 0.95 | 11.9 | 17.1 |
| Water addition, gal/min | 9.1 | 43 | | 3.0 | 13.5 |
| Temper time, hr | 4.7 | 49 | 6.00 | 0.0 | 20.0 |
| **Steam flaking measurements** | | | | | |
| Steam cabinet temperature, ºF | 204.8 | 49 | 5.19 | 188.0 | 212.0 |
| Flaker electrical mill load, amps | 59.4 | 44 | 21.66 | 21.7 | 110.0 |
| Throughput, ton/hr | 11.6 | 43 | 5.57 | 2.0 | 25.0 |
| Retention time, min | 49.2 | 49 | 12.00 | 320.0 | 75.0 |
| **Steam flaked corn quality measurements** | | | | | |
| Yard flake density, lb/bu[1] | 27.5 | 49 | 1.70 | 24.0 | 31.0 |
| Investigator flake density, lb/bu[2] | 27.7 | 49 | 1.80 | 24.5 | 31.0 |
| Cooled flake density, lb/bu[3] | 24.1 | 49 | 2.51 | 18.5 | 29.5 |
| Volumetric weight, g/L[4] | 319.2 | 49 | 32.58 | 237.8 | 380.9 |
| FCIS value[5] | 8534 | 49 | 132.60 | 8247.0 | 8755.0 |
| Starch availability, %[6] | 50.6 | 49 | 8.02 | 37.0 | 65.0 |
| Steamed corn moisture, %[7] | 21.8 | 46 | 2.14 | 14.2 | 24.8 |
| Flaked corn moisture, %[7] | 17.5 | 49 | 1.87 | 14.6 | 21.1 |
| Flake thickness, mm[8] | 1.8 | 49 | 0.27 | 1.2 | 2.5 |
| Nip angle, °[9] | 4.6 | 49 | 0.51 | 3.5 | 5.6 |
| Compression length, mm[10] | 23.1 | 49 | 2.63 | 17.8 | 29.5 |

[1] Yard flake density was measured by yard personnel under normal standard operating procedures.

[2] Investigator flake density was measured using standardized procedures by a single investigator at every feedyard.

[3] Cooled flake density was measured by the same investigator after cooling on a flat surface for 15 min

[4] Volumetric weight was measured on cooled SFC by filling and weighing a 1.23 L plastic cylinder.

[5] FCIS, Flake Color Index System, Lextron Inc.

[6] Starch availability using enzymatic hydrolysis (citation of methodology) from Servi-Tech Laboratoris (Dodge City, KS)

[7] Complete dry matter analysis

[8] An average of 25 flakes measured at the center of whole flakes using a micrometer.

[9] Nip angle was calculated using the roll radius, roll gap, and a standard kernel radius.

[10] Compression length was calculated using the roll radius, roll gap, and a standard kernel radius.

**Table 4.3 Pearson correlation coefficients for measurements observed 17 commercial feedyards surveyed in Nebraska, Kansas, Colorado, Texas, New Mexico, Arizona, and California**

| Selected coefficient | Rejected coefficient | r | p > \|r\| |
|---|---|---|---|
| Cool FD, lb/bu[1] | Volumetric weight, g/L[2] | 0.9151 | < 0.01 |
| Roll diameter, in | Roll length, in | 0.8399 | < 0.01 |
| Invesigator FD, lb/bu[3] | Cool FD, lb/bu[1] | 0.7905 | < 0.01 |
| Cool FD, lb/bu[1] | Nip angle[4] | -0.7838 | < 0.01 |
| Invesigator FD, lb/bu[3] | Yard FD, lb/bu[5] | 0.7822 | < 0.01 |
| Roll diameter, in | Compression length, mm[6] | 0.7399 | < 0.01 |
| Nip angle[4] | Volumetric weight, g/L[2] | -0.7359 | < 0.01 |
| Invesigator FD, lb/bu[3] | Nip angle[4] | -0.7246 | < 0.01 |
| Roll diameter, in | Nip angle[4] | -0.7154 | < 0.01 |
| Enzymatic starch availability, %[7] | FCIS[8] | -0.7147 | < 0.01 |
| Cool FD, lb/bu[1] | Yard FD, lb/bu[5] | 0.7137 | < 0.01 |
| L/D ratio[9] | Roll length, in | 0.7127 | < 0.01 |
| Invesigator FD, lb/bu[3] | Volumetric weight, g/L[2] | 0.7049 | < 0.01 |
| Steam flaked corn moisture, %[10] | Steam conditioned corn moisture, %[10] | 0.6999 | < 0.01 |

[1] Cooled flake density was measured by the same investigator after cooling.
[2] Volumetric weight was measured on cooled SFC by filling and weighing a 1.23 L plastic cylinder.
[3] Investigator flake density was measured by a single investigator at every feedyard using the same procedures.
[4] Nip angle calculated using roll radius, corn kernel radius, and roll gap
[5] Yard flake density was measured by yard personnel under normal standard operating procedures.
[6] Compression length calculated by roll radius, roll gap, and kernel radius
[7] Starch availability using enzymatic hydrolysis from Servi-Tech Laboratoris (Dodge City, KS)
[8] FCIS, Flake Color Index System, Lextron Inc.
[9] Roll length to diameter ratio
[10] Complete dry matter analysis

**Table 4.4 Multiple linear regression coefficient estimates for variables related to changes in starch availability of steam-flaked corn in 17 commercial feedyards surveyed in Nebraska, Kansas, Colorado, Texas, New Mexico, Arizona, and California**

| Variable | Estimate | Std Err | Pr < F |
|---|---|---|---|
| Intercept | 19.4476 | 48.6116 | 0.6915 |
| Cool FD, lb/bu[1] | -2.1664 | 0.3664 | <0.01 |
| Throughput, t/hr[2] | -0.0560 | 0.1496 | <0.01 |
| Roll diameter, in | 0.6281 | 0.2625 | 0.02 |
| Steam cabinet temperature, ˚F[3] | 0.4312 | 0.1989 | 0.04 |
| Steam flaked corn moisture, %[4] | -0.6927 | 0.4367 | 0.12 |
| Temper time, hr[5] | -0.1963 | 0.1339 | 0.15 |

[1] Cooled flake density was measured by the same investigator after cooling.

[2] Estimated production rate reported by feedyard personnel

[3] Average steam cabinet temperature between all temperature guages on the steam cabinet

[4] Complete dry matter analysis

[5] Amount of time dry grain was tempered prior to entering the steam cabinet.

**Figure 4.1 Flaker roll diagram used to describe nip angle and compression length calculations for 17 commercial feedyards surveyed in Nebraska, Kansas, Colorado, Texas, New Mexico, Arizona, and California.**

**Compression length, a = $\sqrt{c^2 - b^2}$; Nip angle, $\theta$ = $\cos^{-1}\left(\frac{b}{c}\right)$**

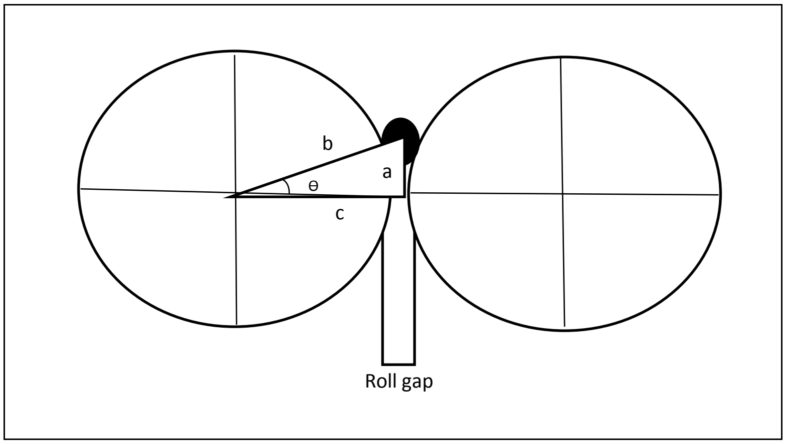


**Figure 4.2 Simple linear regression model comparing the relationship between investigator flake density (HotFD) and yard personnel flake density (YardFD) for 17 commercial feedyards surveyed in Nebraska, Kansas, Colorado, Texas, New Mexico, Arizona, and California (InvFD = 14.408 + 0.5517 *YardFD).**

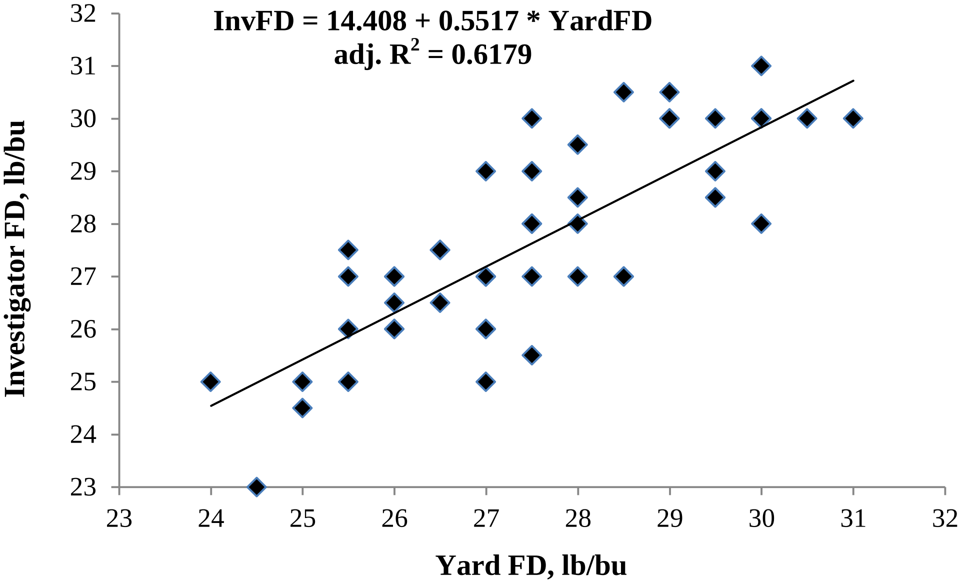


**Figure 4.3 Simple linear regression model comparing the relationship between enzymatic starch availability (Enzymatic) and yard personnel flake density (YardFD) for 17 commercial feedyards surveyed in Nebraska, Kansas, Colorado, Texas, New Mexico, Arizona, and California (Enzymatic = 124.85 – 2.6979*YardFD).**

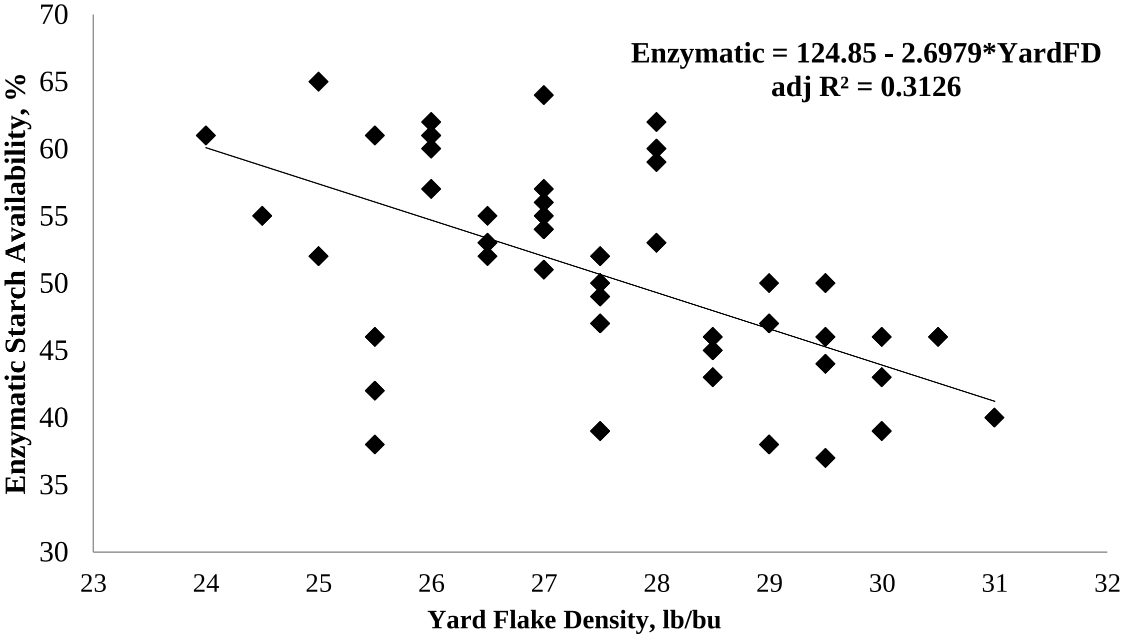


**Figure 4.4 Multiple linear regression equation predictive values of changes in starch availability as affected by each individual contributing variable, across the range (min through max) of measured values holding the remaining 5 values constant at the mean value of those measurements for 17 commercial feedyards surveyed in Nebraska, Kansas, Colorado, Texas, New Mexico, Arizona, and California (Enzymatic = 19.4476 - (0.6927*SFCMoisture) - (2.1664*CoolFD) - (0.5060*Throughput) + (0.6281*Roll Diameter) + (0.4312*Temperature) – (0.1963*Temper Time)**

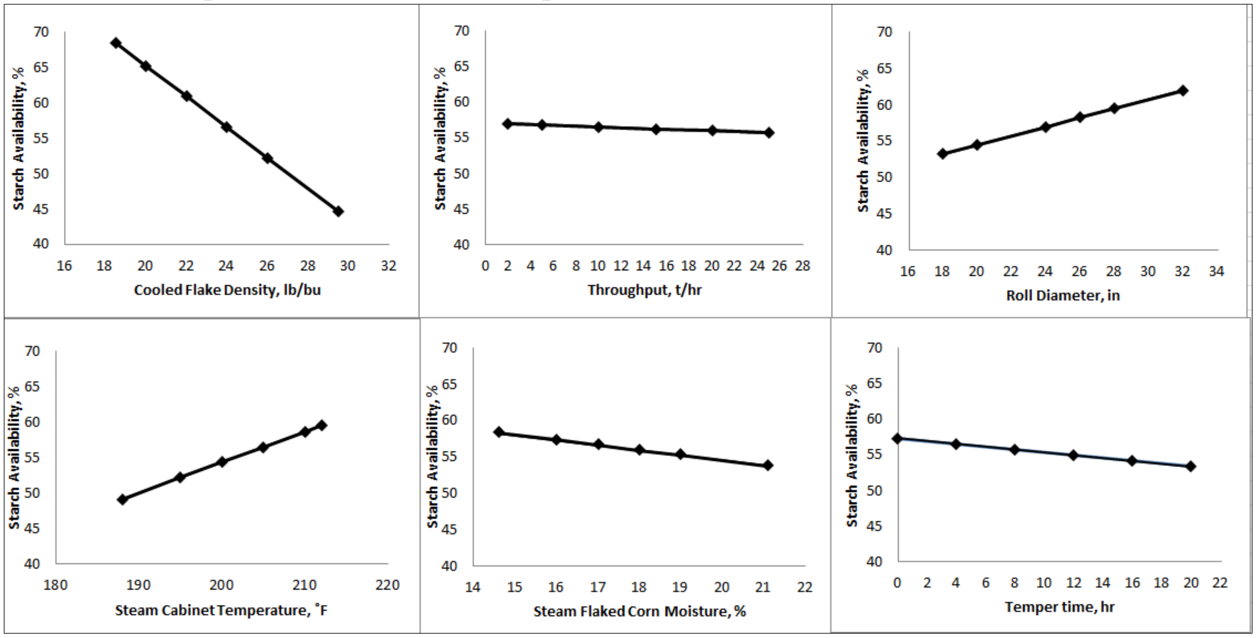
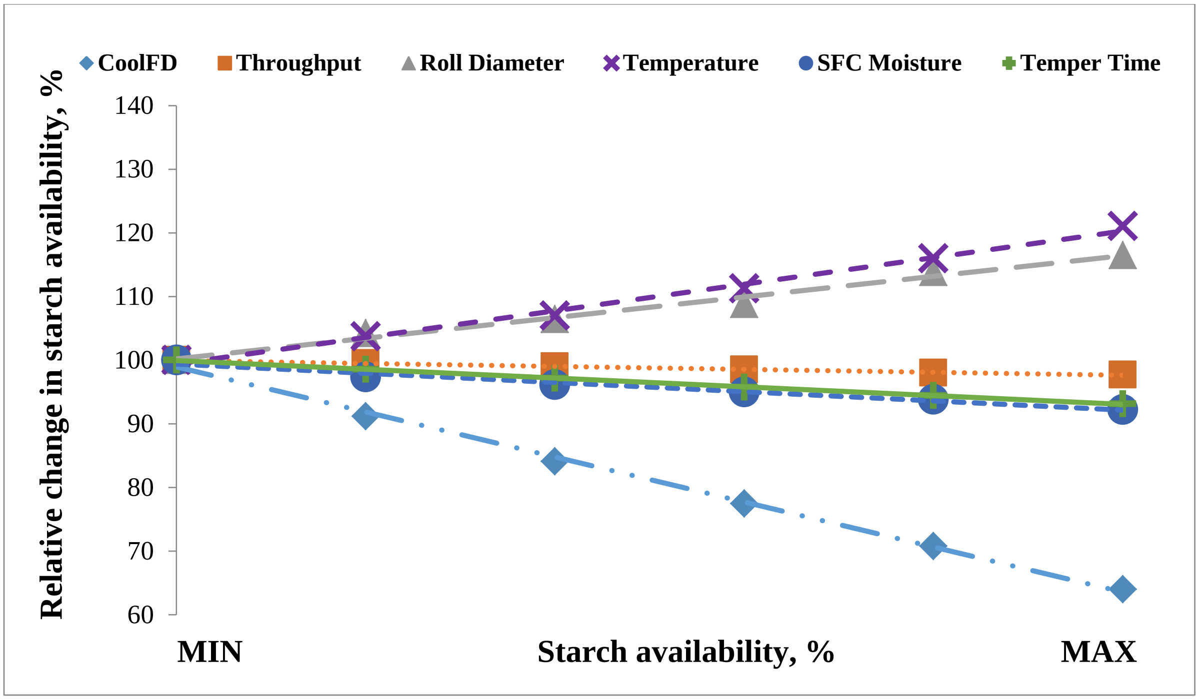


**Figure 4.5 Multiple linear regression equation illustrating the relative effects of starch availability for the complete range of values within dataset for 17 commercial feedyards surveyed in Nebraska, Kansas, Colorado, Texas, New Mexico, Arizona, and California. (Enzymatic = 19.4476 - (0.6927*SFCMoisture) - (2.1664*CoolFD) - (0.5060*Throughput) + (0.6281*Roll Diameter) + (0.4312*Temperature) – (0.1963*Temper Time). All but one variable were held constant at the mean of the data collected, and values for the fifth variable were entered from the minimum to the maximum values within the dataset. Then, the relative effect of each change was calculated as:** $\frac{\textbf{change in starch availability}}{\textbf{original starch availability}} \textbf{ x 100}$



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