EXTRUSION PROCESSING OF FEEDLOT DIETS

by

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AN ABSTRACT OF A DISSERTATION

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Abstract

A series of studies were conducted to evaluate extrusion processing of finishing diets on growth performance, carcass characteristics, and meat quality attributes of feedlot cattle. Extruded diets were processed in a 24:1 (length/diameter) corotating, fully intermeshing twin-screw extruder (model BCTG-62, Bühler AG CH-9240, Uzwil, Switzerland). In Experiment 1, extrusion processing of corn based diets decreased dry matter intake (DMI) and improved gain efficiency (G:F) by 15% compared to heifers fed steam-flaked corn (SFC) diets. Carcass characteristics were not different between treatments. Steaks from heifers fed SFC diets were juicier and had a less pronounced off-flavor than steaks from heifers fed extruded diets. In Experiment 2, average daily gain (ADG), DMI, G:F, carcass characteristics, and meat quality attributes were not different between heifers fed SFC and extruded processed corn diets. In Experiment 3, we evaluated different degrees of extrusion processing by altering the level of process water added to the extruder. Mechanical energy inputs, die pressure, die temperature, and torque of drive motor decreased as the level of water added to the extruder increased from 4% to 12%. Water addition did not affect DMI or ADG of feedlot heifers. However, live body weight (BW) and G:F decreased as the level of process water increased. Gain efficiency (carcass-adjusted basis) was 3% greater for extruded corn diets processed with 4% water compared with SFC diets and was 6% poorer than SFC diets when processed with 12% water. Apparent total tract digestibility was not different, but IVDMD improved with increasing levels of water. Improvements in G:F when fed extruded feed was variable among the 3 studies. This may be due, in part to severe infestation by European Starlings during Experiment 1. Impact of feed depredation by starlings was therefore evaluated. Starlings consumed 86% of the SFC diet offered to them compared to, none of the extruded corn diets. In addition, starlings preferentially selected for the energy dense portion of the rations (steam-flaked corn). Therefore, it is plausible that a portion of the 15% improvement in G:F observed in Experiment 1 for heifers fed extruded corn diets can be attributed to differences in feed depredation by starlings. Finally, two studies were conducted to evaluate extrusion processing of sorghum-based diets. In the first experiment, DMI was greater and G:F was poorer for heifers fed extruded sorghum diets compared to heifers fed steam-flaked sorghum (SFS) diets. However, carcass characteristics and meat quality attributes were not different. In the second study, particle size of the ground sorghum added to the extruder was evaluated. Processing sorghum to a smaller particle size (581 µm) prior to extrusion processing decreased DMI, improved G:F, and increased apparent total tract digestibility compared with larger particle sizes (1,264 µm). However, heifers fed SFS diets were still more efficient that heifers fed extruded diets made with either particle size of sorghum. Overall, this research suggests that extruding complete diets into homogeneous pellets may improve G:F of cattle fed corn-based diets while reducing feed depredation of starlings. It is also clear from our results that G:F is improved to a greater extent to processing diets under high shear conditions (i.e., high mechanical energy inputs) than when processed under low shear conditions.

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CHAPTER 1 - Review of literature

Introduction

Twelve billion kilograms of beef were produced in the United States in 2008 with an estimated value of $76 billion (NASS, 2009). Nearly all of this beef was produced by feeding cattle cereal grains in a confinement feeding operation. Finishing cattle with grain-based diets in confinement is more profitable and efficient than finishing cattle on forage-based diets (Berthiaume et al., 2006). Finishing diets generally contain 60 to 80% grain (DM basis), and corn is the most commonly used grain source (Vasconcelos and Galyean, 2007). Starch is the major energy component of the grain and requires processing to increase its availability for rumen microorganisms (Huntington, 1997; Owens et al., 1997). Various grain processing methods have been used to improve digestibility of the grain (Rowe et al., 1999). However, steam-flaking is the predominant grain processing method used by commercial feedlots (Vasconcelos and Galyean, 2007).

Roughages are fed to maintain ruminal health and function. Feeding too little roughage may predispose feedlot cattle to metabolic disorders. However, feeding too much roughage will decrease digestibility and increase manure output. Roughages are expensive, have a low energy value, and are susceptible to large inventory losses due to shrink. In addition, roughages may be prone to diet selection by cattle, which may lead to reduced growth performance and metabolic disorders.

The objective of this paper is to review and discuss the literature pertaining to grain processing methods, starch digestion, diet selection by cattle, feeding roughages, and how these factors relate to rumen health of feedlot cattle.

Properties of Starch

Starch occurs in nature as granules which consist of 2 different glucose polymers (French, 1973). Amylose is a linear polymer of α1,4-linked glucose units, whereas amylopectin is a branched polymer of linear chains of α1,4-linked glucose units joined together with α1,6-linkages. Starch granules vary in size and ratio of amylose:amylopectin. Synthesis of starch starts with photosynthesis which leads to the production of sucrose. Sucrose is then imported from the leaves to the starch-storing organs (i.e., endosperm of cereal grain; Smith, 2001.) Bioconversion of sucrose to starch is carried out in the cytosol and amyloplast by 2 main enzymes (Smith, 2001). Starch synthases are responsible for elongating α1,4-linked glucose chains, and starch branching enzymes are responsible for the formation of α1,6-branch points (Smith, 2001). Ratio of these enzymes in the starch storing organs will affect the ratio of amylose and amylopectin in the starch granule. Varietal differences (i.e., waxy, normal, high amylose) in cereal grains are caused by mutations in genes that encode starch synthase and starch-branching enzymes (Smith, 2001). Development of starch granules occurs in growth rings starting at the center of the granule (hilum) and extending to the outer layer. The assembly of starch granules is complex and not well understood (Smith, 2001).

Amylopectin content is higher in normal cereal grains than high amylose grains and is the predominant polymer found in waxy varieties (Rooney and Pflugfelder, 1986). In addition, amylopectin is much larger in size than amylose (18×10^6 vs. 7×10^3 glucose units, respectively; Hizukuri, 1996; Yoo and Jane, 2002). Branch points occur every 24 to 30 glucose units (Hizukuri, 1986). Amylopectin is a highly organized structure (French, 1984) of alternating amorphous and crystalline regions (Gallant et al., 1997). The amorphous regions are less densely packed and contain branch linkages which are susceptible to acid hydrolysis (Myers et al., 2000). Crystalline lamella regions are thought to contain double helices of linear chains of glucose which are resistant to acid hydrolysis (Myers et al., 2000). These parallel left-handed helices each contain 6 glucose units per turn (Bertoft, 2004). Crystallinity of starches is classified into 2 categories (i.e., A- and B-type). A-type crystallinity is associated with shorter branch lengths whereas B-type crystallinity is associated with longer chain lengths (Hizukuri, 1985; Hizukuri, 1986). B-type crystals are more open and have more water bound between the helices than the densely packed A-type crystals (Imberty et al., 1988, Imberty and Peréz, 1988). Moran (1982) reported that starch digestibility can be a function of degree of crystallinity. In addition, starches high in amylopectin are more digestible than starches high in amylose (Rooney and Pflugfelder, 1986).

Gelatinization “is the collapse (disruption) of molecular orders within the starch granule along with concomitant and irreversible changes in properties such as granular swelling, crystallite melting, loss of birefringence, viscosity development, and starch solubilization” according to Atwell et al. (1988). Collapse of starch structure (i.e., molecular order) occurs when starch is heated in the presence of moisture. A ratio of 1.5 parts of water per 1 part starch is needed for complete gelatinization (Lund, 1984). Gelatinization can occur at lower water levels, but will require greater heat or mechanical energy (Rooney and Pflugfelder, 1986). During the steam-flaking process, the heated moist kernel is exposed to physical disruption of the starch granule when the grain is passed between the corrugated rolls of the flaking mill (Zinn et al., 2002). Zinn et al. (2002) suggest that it is the combination of mechanical force and moist heat that improves starch digestibility (availability). Preston et al. (1993) observed a positive relationship between starch digestibility and the percent of starch that was gelatinized.

Uptake of water across the pericarp of sorghum and corn is not possible, but does occur at a rate limiting step through the hilum and tipcap of the sorghum and corn kernel, respectively (Rooney and Pflugfelder, 1986). Granular swelling occurs in the amorphous regions as a result of the water and heat and increases until the bonds between the crystalline and amorphous regions are rapidly and irreversibly broken (Svihus et al., 2005) resulting in a loss of crystallinity. Gelatinization of starch can be identified by the loss in birefringence and increase in solubility. Raw starch granules are identified by a Maltese cross when viewed under a polarized light due to the orientation of the crystallites. However, this characteristic Maltese cross is not observed in gelatinized starch due to the loss of organization.

Retrogradation is the process in which gelatinized starch molecules begin to associate in an ordered structure (Atwell et al., 1988). Retrogradation begins when 2 or more starch chains begin to realign, and under favorable conditions progresses until a crystalline order appears. Zinn et al. (2002) suggests retrogradation of starch granules is directly proportional to degree of dispersion of the starch molecules. Retrogradation results in structural changes of the starch granules that decrease porosity of the internal starch matrix, resulting in reduced starch availability (Zinn et al., 2002). Retrogradation of amylose occurs faster (i.e., hours), while retrogradation of amylopectin occurs much slower (i.e., days and weeks; Zhou et al., 2002). Factors affecting retrogradation of starch molecules include structure of amylopectin, amylose content, and presence of lipids (Yao et al., 2002). Jacobson and BeMiller (1998) suggest other factors also influence rate and extent of retrogradation, including temperature, starch-water concentration, and method of cooking (time, temperature, amount of shear). High amylose contents and shorter chain lengths of amylopectin correspond to greater retrogradation (Yao et al., 2002). The lipid portion associated with the starch granule binds to amylose and decreases the amount of amylose available to interact with the external chains of amylopectin thus reducing retrogradation (Yao et al., 2002).

Corn, wheat, sorghum, and barley are the most common sources of starch fed to finishing feedlot cattle (Vasconcelos and Galyean, 2007). These grains vary in starch content and structure and thus respond differently to grain processing methods. In a review by Huntington (1997), he reported starch contents of 77, 72, 72, and 57% for wheat, corn, sorghum, and barley, respectively. Growth rates of cattle fed different grain types (i.e., wheat, corn, sorghum, and barley) are usually not different from each other (Owens et al., 1997). However, cattle fed sorghum-based diets consume more DM and have a poorer G:F than cattle fed corn-, wheat-, or barley-based finishing diets (Owens et al., 1997).

Composition and structure of sorghum grain is similar to that of corn grain (Rooney et al., 1980). In addition, size, shape, and composition of starch granules also are similar between sorghum and corn (Rooney and Pflugfelder, 1986). Rooney and Pflugfelder (1986) suggested that the poorer digestibility of sorghum is due to the type and distribution of proteins surrounding the starch contained in the endosperm. These proteins include some of the starch synthases and branching enzymes involved in biosynthesis of starch molecules (Vermeylen et al., 2004). Concentration of protein in starch granules is usually very low (i.e., 3 g or less per kg of starch; Hoover and Vasanthan, 1994; Vasanthan and Bhatty, 1996; Abdel-Aal et al., 2002) and varies in proportion to starch based on location within the endosperm (i.e., surface vs. internal; Baldwin, 2001). Surface proteins may decrease availability of starch, which may dictate a greater degree of grain processing (Svihus et al., 2005). This may explain why the peripheral endosperm of sorghum is denser, harder, more resistant to water penetration, and more resistant to digestion than that of corn (Rooney and Pflugfelder, 1986; Baldwin, 2001). This minor difference in endosperm protein matrix combined with the small physical size of the kernel makes sorghum a difficult grain to process.

Starch Digestion in Ruminants

Rumen

Ruminant animals lack salivary amylase so the first opportunity for starch digestion occurs in the rumen. The rumen is the primary site of starch digestion in feedlot cattle. Fifty to

94% of the starch consumed by feedlot cattle is digested in the rumen depending on grain type and grain processing method (Huntington, 1997). The rumen ecosystem is a complex and dynamic mixture of many types and species of organisms. Ruminal bacteria are responsible for the majority of the starch digested in the rumen; however, protozoa do have a small role (Huntington, 1997). Fifteen different strains of starch digesting bacteria have been identified in the rumen (Kotarski et al., 1992), including 5 primary species: 1) *Ruminobacter amylophilus*, 2) *Selenomonas ruminantium*, 3) *Streptococcus bovis,* 4) *Succinimonas amylolytica*, and 5) *Succinivibrio dextrinoslvens*. Of these bacteria, *Ruminobacter amylophilus*, *Selenomonas ruminantium*, and *Streptococcus bovis* have the highest growth rates and amylolytic activity (Cotta, 1988). Starch digesting enzymes used by the bacteria include amylases (α and β), glucoamylases, pullulanases, and isomaltases (Kotarski et al., 1992). Starch digestion in the rumen is largely dictated by the attachment of bacteria to the feed particles (McAllister et al., 1994). The protective pericarp layer surrounding the cereal is resistant to enzymatic activity of the bacteria and thus needs to be disrupted, allowing access by bacteria to the endosperm. Therefore, grain processing methods that disrupt the pericarp and increase the surface area of feed particles can improve bacterial attachment and, hence, ruminal digestion. Microbial digestion of wheat- and barley-starch granules starts at a central point on the surface of the granule and then proceeds in an outward direction away from the central attachment site (McAllister et al., 1990a, 1990b). Digestion of corn-starch granules also starts on the surface but then proceeds to the center of the starch granule via narrow tunnels (McAllister et al., 1990a, 1990b). Digestion then progresses from the inside to the outside of the granules (McAllister et al., 1990a, 1990b). Rumen bacteria digest starch granules, leaving the surrounding protein matrix and endosperm cell wall (McAllister et al., 2006). As mentioned previously, differences in starch digestion rates between grains may be attributed to differences in the properties of the protein matrix rather than differences in starch granules (McAllister et al., 1990b).

Protozoa are much larger and have a slower growth rate than bacteria. These factors provide protozoa with a unique role in starch digestion. First, protozoa can ingest whole bacteria (Kotarski et al., 1992). Through this mechanism, rate of ruminal fermentation can be controlled when the slower growing protozoa consume the faster growing bacteria. Secondly, protozoa can consume whole starch granules, thereby sequestering substrate and limiting access by bacteria (Kotarski et al., 1992). Engulfed starch granules will require a longer period of time to be completely metabolized by protozoa as compared to the time required for metabolism by bacteria (Coleman, 1986). In either case, protozoa can serve an important role in modulating ruminal pH by slowing the rate of starch digestion in the rumen. It is also possible for protozoa to shift the site of starch digestion from the rumen to the small intestine. Mendozoa et al. (1993) observed a reduction in the amount of starch digested in the rumen and an equal increase in the amount of starch digested in the small intestine of faunated cattle compared to defaunated cattle. Although rumen bacteria are likely responsible for digesting the majority of starch within the rumen, protozoa can account for up to 50% of ruminal starch digestion (Jouany and Ushida, 1999).

Fermentation end-products of starch digestion in the rumen include acetic acid, propionic acid, butyric acid, succinic acid, formic acid, lactic acid, and methane. Propionic acid is one of the key sources of carbon for gluconeogenesis. It is estimated that propionate is responsible for 70% of the glucose produced in the liver (Huntington et al., 2006). Fermentation of starch to volatile fatty acids in the rumen is inefficient in terms of energy recovery by the host animal when compared to post-ruminal enzymatic digestion. First, a portion of the starch supplied to the ruminant animal will be used by the microorganisms to support their growth and maintenance. Secondly, energy loss in the form of methane occurs via eructation. Owens et al. (1986) suggested that starch digested in the small intestine to glucose will provide 42% more energy than when the starch is fermented in the rumen to volatile fatty acids. Using indirect calorimetry, McLeod et al. (2001) observed that abomasal infusion of hydrolyzed starch resulted in a greater partial efficiency than hydrolyzed starch infused into the rumen. These results would suggest that shifting site of starch digestion from the rumen to the small intestine would improve growth efficiency of feedlot cattle. However, as will be discussed later, starch digestion in the small intestine has its limitations.

Production of organic acids from ruminal fermentation usually coincides with an equal rate of absorption across the rumen wall. However, a normal accumulation of organic acids does occur immediately following a meal. Healthy ruminal papillae support a better rate of absorption of organic acids compared with keratinized papillae (Hinders and Owen, 1965). Rapid changes in the consumption of highly fermentable carbohydrates (i.e., starch) can lead to situations where production of organic acids exceeds that of absorption. When this occurs, ruminal pH will decrease leading to reductions in rumen motility and a shift in the population of ruminal microorganisms toward lactic acid producing bacteria. The ruminant animal has several defense mechanisms to help combat low ruminal pH. First, saliva produced by the bovine has a strong buffering capacity. Therefore, cattle should be fed diets that stimulate saliva production. This topic will be discussed in greater detail later on in this paper. Secondly, absorption of organic acids is increased when ruminal pH decreases below 5.6. Absorption across the rumen wall is presumably increased because the organic acids become more protonated due to their low pKa (≈4.9; Bergman, 1990).

Cattle exhibiting a ruminal pH between 5.0 and 5.6 are considered to have subacute acidosis, and considered to have acute acidosis when pH is below 5.0 (Britton and Stock, 1989; Owens et al., 1998; Krause and Oetzel, 2006). Diurnal variation in ruminal pH occurs in all cattle with a sharp decrease in pH following a meal and gradually increasing to pre-meal levels. It is common for pH to be below 5.6 for at least a portion of the time following consumption of a meal (Cooper et al., 1998; Uwituze et al., 2008). Therefore cattle may be capable of withstanding a lower ruminal pH by making changes in feed consumption patterns (i.e., reduced DMI). However, chronic exposure to low ruminal pH will decrease the health and function of the rumen papillae, leading to ulceration of the rumen wall (i.e, rumenitis). The compromised rumen wall then becomes susceptible to invasion and colonization by *Fusobacterium necrophorum*, which can then enter portal circulation (Nagaraja and Chengappa, 1998). *Fusobacterium necrophorum* can colonize the liver and cause liver abscesses (Nagaraja and Chengappa, 1998). Liver abscesses can decrease growth performance of cattle and can also decrease value of the animal at harvest (Nagaraja and Chengappa, 1998). Condemned livers account for approximately 2% of the animal weight and cannot be sold for human consumption (Nagaraja and Chengappa, 1998).

Small intestine

Starch escaping ruminal fermentation can undergo acid hydrolysis in the abomassum prior to enzymatic digestion in the small intestine. Amount of starch entering small intestine is largely influenced by grain type and grain processing method. As will be discussed in a later section, starch entering small intestine can also be influenced by the level of roughages fed. Approximately 47% to 88% of the starch reaching the small intestine is digested (Owens et al., 1986). However, the efficiency of starch digestion decreases as the amount of starch reaching the small intestine increases (Nocek and Tamminga, 1991). Huntington et al. (2006) concluded that small intestinal starch digestion is greater than 70% when the total amount of starch reaching the small intestine is less than 700 g/d. However, as amount of starch reaching the intestine increases to 1,500 g/d, digestion in the small intestine decreases to approximately 44% (Huntington et al., 2006). The low digestibility in the small intestine may indicate that the readily digestible portion of the starch was already digested in the rumen, thereby leaving only the resistant portion to be digested in the small intestine. Low digestibility also may reflect physiological limits to starch digestion in the small intestine.

Starch digestion in the small intestine begins in the lumen of the duodenum by pancreatic α-amylase. Pancreatic α-amylase is excreted into the lumen and begins to hydrolyze starch into maltose and other limit dextrins (Huntington et al., 2006). Maltose and limit dextrins are further hydrolyzed to glucose by the brush border enzymes, maltase and isomaltase (Huntington et al., 2006). Glucose is then absorbed and transported across the luminal membrane. The exact transporter that facilitates the absorption of glucose is not known (Huntington et al., 2006). Sodium-dependent glucose transporter (SGLT1) has been considered the only transporter of glucose from the small intestinal lumen (Harmon and McLeod, 2001); however, other research has questioned the validity of this claim, suggesting that other transporters may be involved (Au et al., 2002). Unlike other species, SGLT1 activity in ruminants is not upregulated in response to increasing supplies of carbohydrate in the small intestine (Bauer et al., 2001; Rodriguez et al., 2004). Regardless of the specific transporter used, it is clear that glucose is transported out of the small intestinal lumen (Kreikemeier et al., 1991).

Several groups have studied the limitations of starch digestion in the small intestine. Ruminants (Kreikemeier et al., 1990a; Walker and Harmon, 1995) are different from non-ruminants (Snook, 1971; Johnson et al., 1977) in that secretion of pancreatic α-amylase is not increased when flow of carbohydrate to the small intestine is increased. In fact, increases in flow of starch to small intestine actually decrease secretion of pancreatic α-amylase (Kreikemeir et al., 1990; Walker and Harmon, 1995; Swanson et al., 2002). Harmon (1992) and Bauer (1996) observed that starch entering the small intestine does not affect brush border enzymes or glucose absorption. These results would suggest that starch digestion is limited by pancreatic α-amylase secretion rather than glucose absorption (Kreikemeier et al., 1991).

Optimizing rate and extent of ruminal fermentation of starch such that metabolic disorders are prevented while at the same time maximizing the amount of starch being digested in the small intestine would lead to the greatest growth and efficiency of feedlot cattle. However, a better understanding of starch flow to the small intestine and capacity of pancreatic α-amylase in ruminant animals are still needed.

Large intestine

Fermentation in the large intestine is the last opportunity to extract energy from the diet. Fermentation in the large intestine is similar to that which occurs in the rumen except that no protozoa inhabit the large intestine. Volatile fatty acids produced during this fermentation can be readily absorbed and used by the host for energy metabolism. Approximately 47% to 89% of starch entering the large intestine can be fermented into volatile fatty acids (Karr et al., 1966; Philippeau et al., 1999; Sindt et al., 2006). However, this only accounts for 2% to 28% of the total starch consumed by the animal (Philippeau et al., 1999; Sindt et al., 2006). Starch not digested in the large intestine will be excreted in the feces. Zinn et al. (2007) summarized fecal starch data from 32 metabolism studies and calculated a mean value of 5.9%, with a range of 0 to 44%. Variation in fecal starch concentrations can be attributed to grain processing methods. Depenbusch et al. (2008) observed lower fecal starch values for cattle fed steam-flaked corn (≤ 5%) compared to cattle fed dry-rolled corn (≈ 20%).

History of Cattle Feeding in the United States

Cattle are not native to North America and were imported into the New England colonies from European countries, West Indies, and Mexico in the 1600's (Bowling, 1942). Prior the 1800's, cattle were predominately fed roughage based diets. Discovery of the fertile Ohio River Valley led to the increased production of corn. It was during this period of time when heavy grain feeding to cattle began (Matsushima, 2006). Soaking the grain prior to feeding was one of the earliest grain processing methods (Georgeson et al., 1894). Georgeson et al. (1894) observed that steers fed "soaked" whole corn gained more weight and were more efficient than steers fed dry corn. In addition, hogs that were fed droppings from the steers fed soaked whole corn gained less weight than the hogs fed the droppings from the steers fed dry corn. Georgeson et al. (1894) suggested that soaking corn increased the starch digestion in the steer and thereby decreasing growth of hogs consuming droppings. The authors advised against soaking grain when temperatures were below freezing and suggested that this practice may be profitable if soaking could be accomplished with the "regular work force" and at a "slight expense". Although current grain processing methods are more advanced than that tested by Georgeson et al. (1894), his comments regarding labor requirements and cost of grain processing methods are still concerns of cattle feeders today.

Cattle feeding migrated to the High Plains in the 1940's due to climatic conditions and the abundance of crops produced via irrigation. It was during this period of time when the concept of steam-flaking corn was first born (Matsushima, 2006). One frigid winter morning in Omaho, NE, Dr. John Matsushima and 3 prominent cattle feeders (Warren H. Monfort, Louis Dinklage, and Earle Brookover) were discussing the most expensive part of their business (i.e., feed cost) over a warm breakfast of corn flakes and milk (Matsushima, 2006). Dr. Matsushima suggested that feeding corn flakes to cattle may decrease the cost of gain of their operations. In 1962, Dr. Matsushima processed the first corn flakes at Colorado State University by steam treating whole corn for 12 minutes at 93°C and subsequently compressing between 2 corrugated steel rollers to produce a flake that was 0.8 mm thick with a final moisture content of 20% (Matsushima, 2006). Results from a feeding study conducted in 1962 demonstrated that cattle fed steam-flaked corn gained 5% more BW and were 7% more efficient than cattle fed dry cracked corn (Matsushima, 2006). Although the production parameters and the specifications of the corn flake have changed slightly over the years, the overall process has remained unchanged over the last 47 yr.

Grain Processing Methods

High-moisture harvesting and storage

High moisture grains are harvested by conventional methods (i.e., combine) at a moisture content that is somewhat greater than the normal harvesting moisture content (i.e., < 14%). Harvested high-moisture grains are then stored in an oxygen limiting environment where they are preserved through fermentation.

High-moisture grains (usually corn or sorghum) are harvested shortly after grain reaches physiological maturity and moisture content is between 25% and 33% (Mader and Rust, 2006). Harvesting grain above or below optimal moisture levels can result in reduced yields (i.e., grain has not reached physiological maturity) or excessive storage losses due to spoilage. Therefore, timing of harvest is very critical to the growth and efficiency of feedlot cattle. Harvested high-moisture grains can be ground or stored whole in an oxygen limiting environment (i.e., upright silo, covered bunker silo, or large storage bags). Mader et al. (1991) demonstrated that cattle fed high-moisture corn stored whole consumed more DM and gained more weight than cattle fed ground high-moisture corn, but G:F was not different. However, Owens et al. (1997) observed no differences in growth or efficiency when high-moisture corn was stored whole or ground. High-moisture harvesting and storage of grain can increase solubility of protein and availability of starch compared with dry-rolled grains (Defoor et al., 2000; Cooper et al., 2002).

Dry processed grain

Dry processed grain fed to feedlot cattle can be produced by using a hammermill or roller mill. The main objectives of dry processing are to break the pericarp layer and reduce particle size of the grain, thereby increasing the surface area exposed to rumen microorganisms. Roller mills are more efficient at producing large particle sizes, whereas hammermills are more efficient at producing fine particle sizes. For this reason, and the fact that they are less costly to operate (McEllhiney, 1986), roller mills constitute the most common method for dry processing grain for feedlot cattle (Richards and Hicks, 2007). Roller mills are advantageous in that they produce a product that is more uniform in particle size and less dusty. Kernels of grain are typically processed by “rolling” or “cracking” them between parallel, corrugated, counter-rotating rolls that rotate at differential speed, which shears whole kernels into smaller pieces. Actual particle sizes of dry-rolled corn are not commonly reported in the literature. McEllhiney (1986) suggested that reference to “meaningless” terms such as fine, medium, and coarse particles sizes should be rejected and replaced with actual measurements of particle size.

Steam-flaking

Steam-flaking is the grain processing method most used by large feedlots (Vasconcelos and Galyean, 2007). The steam-flaking process is defined as the steam treatment of whole grains at atmospheric pressure for a period of time prior to compression between two corrugated steel rollers. As compared to dry processing roller mills, steam-flaking roller mills do not have a differential between the rolls (i.e., 1:1). Thus, little shear is applied to the steam treated grain, rather the grain is flattened between the two rotating corrugated rolls. The combination of heat and water during treatment with steam causes the grain (i.e., starch granules) to swell, and subsequent compression of the grain in the roller mill ruptures starch granules. It is this combination of steps that results in the increased starch availability (Zinn et al., 2002). Steam-flaking grain improves diet digestibility and efficiency of feedlot cattle compared to cattle fed dry processed grains (Huntington, 1997; Zinn et al., 2002; Richards and Hicks, 2007). Cattle fed steam-flaked corn also are more efficient than cattle fed high-moisture corn diets (Mader and Erickson, 2006).

Zinn et al. (2002) suggested 5 main factors that influence the quality of steam-flaked grain: 1) steam chest temperature, 2) steaming time, 3) roll corrugation, 4) roll gap, and 5) roll tension. Flake thickness (mm), flaked density (kg/L), starch solubility (amyloglucosidase-reactive starch), and enzyme reactivity (porcine-pancreatin-amylase reactive starch) are commonly used to monitor quality of flaked grains (Zinn et al., 2002). However, measuring bulk density is the most common method to characterize steam-flaked grains. In addition, dry matter content and particle size also are used to characterize the quality of steam-flaked grains.

Extrusion processing

Extrusion cooking is an old technology and is used by many industries (pet food, fish food, and human food; Riaz, 2000), but has had only limited application in the cattle feeding industry (McLaren and Matsushima, 1971; Gaebe et al., 1998). Extruders can be broken down into 5 distinct parts: main drive motor, drive mechanism (i.e., gear box or belt drive), stationary outer barrel, rotating center screws, and a die. Rossen and Miller (1973) defined extrusion as “a process in which a food material is forced to flow, under one or more varieties of conditions of mixing, heating, and shear, through a die which is designed to form the ingredients.” Extruders are adiabatic, meaning that they generate their own heat due to friction as the feed ingredients are passed between the stationary outer barrel and rotating center screw (Riaz, 2000). Friction and heat generated are results of a number of extruder parameters [i.e., extruder RPM, screw geometry (Figure 1-1), throughput rate of feed ingredients, size of die opening, level of added process water] and properties of feed ingredients (i.e., dry matter content, particle size, viscosity, texture, chemical composition). Extruders are extremely versatile and can have many different functions such as grinding, mixing, shearing, gelatinization, shaping, agglomeration, sterilization, expansion, and dehydration (Riaz, 2000).

Extruders are classified as either a single or twin screw. Single screw extruders require a lower capital investment and operating cost compared with twin screw extruders (Riaz, 2000), but twin screw extruders are more versatile and can handle viscous, oily, sticky, and very wet feed ingredients (Riaz, 2000). In addition, twin screw extruders can accommodate a wider range of raw ingredient particle sizes, have reduced pulsation of product exiting the die, and have greater capacity for mixing than single screw extruders (Raiz, 2000). Twin screw extruders are further classified by rotation of screws (i.e., corotating or counterrotating) and proximity of screws to each other (i.e., intermeshing or nonintermeshing).

The working portion of the twin screw extruder (i.e., stationary barrel and rotating center screws) can be divided into 5 zones, each having a different function: inlet, mixing, cooking, venting, and forming zone. Screw geometry (Figure 1) is different between the separate zones. Screw geometry in the inlet zone is characterized by a wide pitch, wide channel width, and narrow screw root. This screw geometry results in an increased volume capacity inside the extruder, allowing for uninhibited entry of raw ingredients into the extruder screws. The mixing zone will have a more narrow pitch and channel width and can have a wider screw root. In addition, screw flights may have slots in them which will allow leakage of the extruder melt between screw channels, resulting in mixing. Other screw designs can be placed in this section to help with mixing and grinding. The cooking zone will have an even narrower pitch and channel width to promote friction. Reverse conveying screws are typically used at the end of the cooking zone. These reverse conveying screws cause a restriction in product flow toward the extruder exit. This restriction results in 100% fill of screw channels in this region with extruder melt, which results in maximal friction between the stationary extruder barrel and rotating center screw. The venting section is characterized by screw geometry that is similar to that observed in the inlet zone. This allows for release of pressure and temperature of the extruder melt as it expands when leaving the cooking section. Gas (i.e., steam) can be released into the atmosphere or removed under vacuum. Greater removal of steam (i.e., vacuum) in the venting zone will affect expansion and density of the product exiting the extruder die. The forming zone will have a screw geometry with narrower pitch and channel width, which will increase the fill in the screw channels just prior to the extruder die. The die serves as the restriction and ensures the screw channel immediately prior to die is 100% full, which allows a constant flow rate of product exiting the die.

As previously mentioned, very little information is available on extrusion cooking of grains for feedlot cattle. Dr. Matsushima's research group at Colorado State University was the first to explore this grain processing method starting in the late 1960's. After his development of the steam-flaking process, he had shown that steam-flaking grain resulted in improved G:F when compared with grinding or cracking grain. However, the flaking process was not widely adopted at that time by feedlot operators due to its high capital cost. Therefore, he set out to investigate extrusion processing as a less costly alternative that would not require the use of steam (Matsushima et al., 1969). Matsushima et al. (1969) produced extruded corn flakes (i.e., approximately 1 mm thick) by feeding dry corn (85% DM) into a "extruder" consisting of a stator and rotor. The authors noted that the extruded flakes did not hold their form very well during storage and feeding, resulting in a high percentage of "fines" in the feed trough. Matsushima et al. (1969) observed similar intakes and gains between cattle fed flaked corn and extruded corn diets. However, they did note poorer G:F of cattle fed extruded corn diets. In a follow-up study, McLaren and Matsushima (1971) observed similar growth and efficiency between flaked and extruded corn finishing diets. Matsushima's research group concluded that manufacturing flakes using an extruder would result in growth and efficiency similar to that of flakes produced from a "traditional" flaking mill.

Matsushima et al. (1969) also evaluated extrusion processing of sorghum compared with steam-flaked corn, and observed similar intakes and gains for cattle fed extruded sorghum and steam-flaked corn. However, cattle fed extruded sorghum had poorer G:F. In a second study, McLaren and Matsushima (1971) observed poorer intakes, gains, and efficiency for cattle fed extruded sorghum compared with steam-flaked corn. The authors attributed the poor growth and efficiency to the quality of the extruded "flakes" (i.e., large quantity of fines).

Gaebe et al. (1998) conducted an experiment similar to the studies conducted at Colorado State University. They extruded only the grain portion (i.e., corn or sorghum) of the diet and then combined it with the other ingredients prior to feeding. Steers fed extruded grain consumed less DM and gained less BW than steers fed dry-rolled grain. However, G:F was not different between the two grain processing methods. The authors speculated that the combination of highly digestible grain from the extruder and the lack of effective fiber from the dehydrated alfalfa pellets may have led to the significant reductions in DMI and ADG. Total tract starch digestion was increased whereas neutral detergent and acid detergent fiber digestion were decreased for extruded grain diets. These differences in digestion may be explained by the lower ruminal pH of steers fed extruded grain diets, thereby favoring starch digestion and not fiber digestion. Ruminal pH for steers fed extruded grain diets was below 5.0 at 45% of the time points measured over a 24-h period, whereas ruminal pH never dropped below 5.3 for steers fed dry-rolled corn diets (Gaebe et al., 1998). Rate of DM and starch disappearance from Dacron bags were significantly faster for steers fed extruded grain diets than steers fed dry-rolled grain diets (Gaebe et al., 1998). Gaebe et al. (1998) concluded that extruded corn and extruded sorghum should not be used as the sole grain source due to the fermentation rate of these products.

In all three trials, only the grain portion of the diet was extruded and subsequently mixed with the other ingredients prior to feeding to cattle. This combination of ingredients may have encouraged sorting by cattle due to the differences in particle sizes of respective ingredients. Much effort is involved in formulating a well-balanced diet for cattle, but that does not mean that the cattle will eat the correct amounts of ingredients due to selective behavior. Extruding the entire diet into a homogeneous pellet may be beneficial in that this would prevent cattle from selecting individual ingredients.

Feed sorting by cattle

Several researchers have studied the feed sorting behavior of dairy cattle fed a total mixed ration (Leonardi and Armentano, 2003, 2007; Leonardi et al., 2005; DeVries et al., 2005). In addition, Osafo et al. (1997) and Methu et al. (2001) showed that cattle selectively consume the leaf, sheath, and husk when unchopped corn stover was fed in excess. Leonardi and Armentano (2003) observed that cattle selected against longer particles in favor of smaller particles when fed a total mixed ration consisting of 60% concentrate (DM basis). The results show that cattle have the ability to selectively consume portions of the ration. Much effort is placed into formulating diets that meet or exceed the animal’s nutrient requirements for maintenance and productivity. However, we assume that the ration delivered to the cattle is exactly what we formulated and that the cattle consume the appropriate amount of each ingredient.

Realization that cattle can selectively consume portions of the ration has revealed management opportunities for reducing this behavior. Increasing the proportion of dry hay fed to dairy cattle increased this sorting behavior (Leonardi and Armentano, 2003). Leonardi et al. (2005) also observed that cattle sorted against larger particles and observed that adding water to the dry diets decreased this sorting behavior. The cattle fed dry diets consumed less neutral detergent fiber than cattle fed wet diets. Although, ruminal pH, NH_3, total VFA and molar percentage of individual VFA were not different between the two treatments (Leonardi et al., 2005). Leonardi and Armentano (2007) suggested that the sorting behavior may be different between individually fed and group fed cattle. They observed that cattle fed in a free-stall barn sorted to a greater extent than cattle fed individually in a tie-stall barn. Differences in the extent of feed sorting between tie-stall and free-stall fed cattle may reflect differences in feeding behavior. When fed in a group setting, cattle may have a greater propensity to selectively consume portions of the ration compared to cattle fed individually. Hosseinkhani et al. (2008) studied the feeding behavior of cows that had to share a common feeding trough. Competition at the feed trough did not have an effect on DMI or feed sorting behavior (Hosseinkhani et al., 2008), but the rate at which feed was consumed and the frequency of meals consumed were different between group-fed and individually-fed cows. This change in feeding behavior may foster more between-cow variation in the composition of the feed consumed (Hosseinkhani et al., 2008). Devries et al. (2007) studied the effects of forage:concentrate ratio on feed sorting. They observed that feed sorting was more prevalent in low forage diets (i.e., 51% forage) than in high forage diets (62% forage). The authors suggested feed sorting was easier for the cattle as the proportion of concentrate increased. If true, this has implications for finishing feedlot diets which typically contain less than 10% roughage (Vasconcelos and Galyean, 2007).

Delivery of fresh feed to cattle has been shown to have a stimulatory effect on DMI (DeVries and von Keyserlingk, 2005). Feeding behavior, and thus sorting behavior, may be altered by timing of feed delivery. Feeding cattle smaller amounts multiple times a day can decrease sorting behavior of cattle (DeVries et al., 2005). In addition, delivering more feed to cattle than can be consumed will result in higher incidence of sorting and an accumulation of unconsumed feed in the trough (Leonardi and Armentano, 2007).

Effects of diet sorting on growth and efficiency of feedlot cattle have not been addressed. However, increasing the frequency with which feed is delivered to the cattle and formulating diets that are moist and palatable for cattle would likely decrease this behavior. High moisture ingredients such as molasses, corn steep liquor, distiller's solubles, wet corn glutten feed, and wet distiller's grains can be used to "condition" the ration, thereby making it more palatable and decreasing the likelihood of diet sorting. Ensuring adequate bunk space (≈ 24 cm per animal; Horton, 1996) will allow all cattle access to feed at one time and may prevent sorting by the more aggressive cattle. In addition, a feed processing technology (i.e., pelleting, expanding, extruding, etc…) that could form the entire diet into a form that could not be sorted by cattle may have some value for feedlot operations.

Roughages in feedlot finishing diets

Roughages typically are added to finishing diets between 0 and 13.5% (DM basis) with an average of 8.3% during the summer months and 9% during the winter months (Vasconcelos and Galyean, 2007). Corn silage and alfalfa hay are the most widely used roughage sources in finishing feedlot diets (Vasconcelos and Galyean, 2007). Compared to concentrate feeds, roughages have low energy value, high cost per unit of energy, and are susceptible to large inventory losses due to shrink. Reducing the use of roughages may result in financial benefits for feedlot operations. Roughages do provide protein, vitamins, and minerals for maintenance and growth of finishing cattle (NRC, 1996), but are fed primarily for their positive effects on health and maintenance of ruminal motility. Roughages provide tactile stimulation to the rumen by constantly "scratching" the ruminal papilli. This serves to keep the rumen papilli healthy and free of hair and feed impaction. Unhealthy and keratinized papilli have decreased absorptive capacity, thereby reducing growth performance of cattle (Hinders and Owen, 1965). Insertion of plastic pot scrubbers into the rumen has been used effectively to maintain the health of rumen papilli for an extended period of time (Orskov et al., 1979; Loerch 1991). These results show that any item that has a roughage-like effect could be used as a replacement for roughage. This allows the possibility of producing a feed (i.e., pellet) that has a roughage-like effect in the rumen without feeding costly and less digestible roughage.

A balance exists between too much or too little roughage in feedlot diets. Increasing roughage levels usually results in greater DMI and poorer G:F (Woods et al., 1969; Gill et al., 1981; Kreikemeier et al., 1990b). Defoor et al. (2002) demonstrated a linear relationship between neutral detergent fiber (NDF) content of the diet and NEg intake (Kcal/kg $BW^{0.75}$). Intake of NEg increases as the NDF portion of the diet increases. The authors opined that energy density of the diet would be reduced as more NDF (i.e., roughage) was added to the diet. As a result, the animal would have to consume more feed in order to meet its genetic potential for growth (Defoor et al., 2002). Owens et al. (1998) explained that bulk fill in the rumen limits intake of cattle fed forage diets, whereas chemostatic mechanisms control intake of cattle fed concentrate diets. This may explain why DMI is increased as roughage levels are increased. Too little roughage also can be problematic. Low roughage levels can alter fermentation in the rumen, leading to lower ruminal pH and suboptimal DMI.

In addition to providing tactile stimulation to the rumen, roughages stimulate chewing activity. Salivary bicarbonate is secreted during the mastication process. Saliva lubricates the feed which facilitates swallowing and serves to buffer the ruminal pH. Stimulation of chewing is an important function of roughages in feedlot diets. Not all roughages have the same effect on chewing and tactile stimulation. Terms such as effective NDF (eNDF) and physically effective NDF (peNDF) have been used in the dairy industry to help differentiate effectiveness of roughages (Mertens, 1997). Ability of roughage to maintain milk fat percentage is referred to as eNDF (Mertens, 1997). The physical characteristic of roughage that stimulates chewing activity (both eating and ruminating) and provides a floating mat of large particles in the rumen is referred to as peNDF (Mertens, 1997). Effective NDF and peNDF normally are not used by feedlot nutritionists. Crude fiber and NDF are the preferred methods for characterization of roughages used in the formulation of feedlot diets (Vasconcelos and Galyean, 2007). Further development of these concepts and establishment of animal requirements could be valuable to feedlot nutritionists.

Rumination is increased by tactile stimulation of the anterior region of the rumen by the floating mat of roughage (Owens, 1987). Therefore, roughages need to be of sufficient size to form this floating mat in the rumen. Small roughage particles and grains will segregate in the rumen and will not be ruminated (Owens, 1987). Cattle fed roughage diets ruminate more than cattle fed concentrate diets (Owens, 1987). The chewing activity of a feed (both eating and rumination) is a result of its chemical and physical properties (i.e., NDF, particle size, intrinsic fragility, and moisture content; Mertens, 1997). Chewing activity is greater for coarsely chopped particles than for finely chopped particles (Mertens, 1997). In general, corn silage stimulates the greatest chewing activity followed by grass silage, grass hay, alfalfa silage, and alfalfa hay (Mertens, 1997). Non-forage feeds such as grains can stimulate chewing, but not to the same degree as roughages (Mertens, 1997). Increased chewing activity will increase saliva flow and passage rate out of the rumen, which may have detrimental effects on ruminal digestion (Owens, 1987; Kreikemeier et al., 1990b). Stock et al. (1990) proposed that increasing roughage levels may shift the site of starch digestion to the small intestine.

Digestion of roughages in feedlot diets is limited and can lead to increased manure output due to suboptimal conditions in the rumen for fiber digestion. Ruminal pH for feedlot cattle fed finishing diets based on steam-flaked corn are commonly observed below pH 6.0 (Zinn et al., 1995; Sindt et al., 2006; Corona et al., 2006). In vitro studies summarized by Russell and Wilson (1996) suggest a rapid decline in activity of fibrolytic organisms at pH below 6.2. In addition, the optimal pH range for cellulases of ruminal bacteria is rarely below pH 6.0 (Huang et al., 1988; McGavin and Forsberg, 1988; McGavin et al., 1989). Calderon-Cortes and Zinn (1996) observed that fecal excretion of dry matter, organic matter, and acid detergent fiber were greater for steers fed 16% roughage compared with steers fed 8% roughage.

A fine balance exists in feeding roughages to finishing feedlot cattle. Roughages are needed to maintain rumen health and function, but too much roughage will lead to decreased energy density of diet and greater excretion of manure. Therefore, efforts to reduce roughage levels while maintaining rumen health and function would have financial benefits for feedlot operators.

Grain processing and roughage addition both have a profound effect on growth performance and efficiency of feedlot cattle. In addition, both directly affect feed costs and profitability of feedlot operations. We proposed that a new technology of feed processing could be implemented that would increase digestion of starch in the rumen and small intestine while preventing diet selection and providing the opportunity to reduce roughage levels. Extrusion processing was chosen because it would allow us to increase gelatinization of grain and also agglomerate the entire ration into a homogeneous pellet. We hypothesized that roughage levels could be decreased in finishing diets because cattle could not selectively consume portions of the diet. In addition, the large hard pellets may stimulate increased chewing of the ration and may retain their form inside the rumen and provide tactile stimulation to maintain rumen health.

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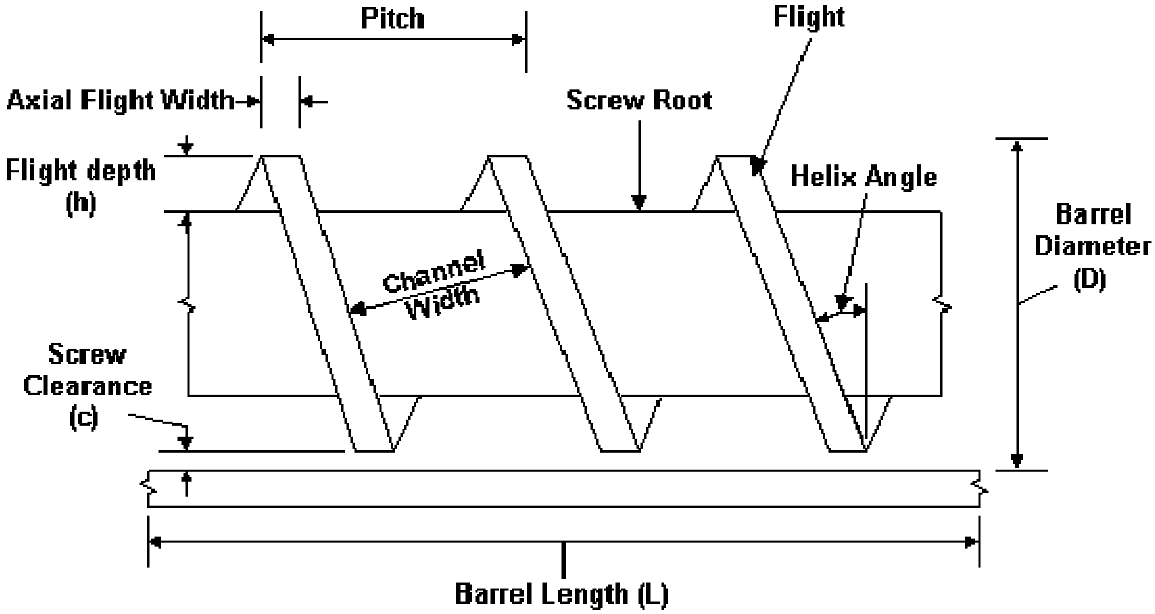
Figure 1-1 Extruder screw terminology



http://www.tangram.co.uk/images/Extrusion%203.gif Accessed July 1, 2009.

CHAPTER 2 - Extrusion processing of feedlot diets I: Evaluation of extruded corn diets

ABSTRACT

Crossbred yearling heifers (n=71; 361 ± 5 kg initial BW) were obtained from a common source and used in a randomized complete block study. Treatments were designed in a 2 × 3 factorial arrangement; factor 1 being level of alfalfa hay (2 or 6% alfalfa hay) and factor 2 being degree of processing (steam-flaked, SFC; low-shear extrusion cooking, LOW; and high-shear extrusion cooking, HIGH). Extruded diets were processed in a 24:1 (length/diameter) corotating, fully intermeshing twin-screw extruder (model BCTG-62, Bühler AG CH-9240, Uzwil, Switzerland). Heifers fed finishing diets containing 2% alfalfa hay consumed less feed ($P = 0.01$) and gained less weight ($P = 0.02$) than heifers fed 6% alfalfa hay; however, G:F was not different ($P = 0.18$). Carcasses from heifers fed finishing diets containing 2% alfalfa hay were lighter ($P = 0.02$) than heifers fed finishing diets containing 6% alfalfa hay; however, dressed yield, LM area, KPH, and 12th rib fat were not different ($P \geq 0.23$). In addition, muscle pH, purge loss during storage, cooking loss, TBARS, Warner-Bratzler shear force, sensory panel characteristics, and retail display life were not different ($P \geq 0.18$) between alfalfa hay levels. Heifers fed SFC finishing diets consumed more ($P < 0.01$) feed than heifers fed either LOW or HIGH. However, ADG was not different ($P \geq 0.46$) between grain processing treatments. Heifers fed LOW and HIGH were more efficient ($P = 0.01$) than heifers fed SFC finishing diet. Carcass weight, dressed yield, LM area, KPH, and 12th rib fat were not different ($P \geq 0.13$) between SFC, LOW, and HIGH. In addition, muscle pH, purge loss during storage, cooking loss, TBARS, Warner-Bratzler shear force, and retail display life were not different ($P \geq 0.23$) between SFC, LOW, and HIGH. Steaks from heifers fed SFC were juicier ($P = 0.01$) than steaks from heifers fed LOW and tended ($P = 0.08$) to be juicer than steaks from heifers fed HIGH. In addition, steaks from heifers fed LOW and HIGH extrudate had a more pronounced ($P = 0.01$) off-flavor compared with SFC. Extrusion processing of feedlot diets improved gain efficiency without having any deleterious effects on meat quality. Reducing alfalfa hay levels from 6 to 2% decreased growth rate and efficiency of feedlot heifers but did not affect carcass characteristics and meat attributes.

Key Words: extrusion, feedlot, growth, meat, roughage

INTRODUCTION

Major advances in grain processing for feedlot cattle have not occurred since the 1950s when steam-flaking was first established (Matsushima, 2006). Extrusion cooking is an old technology and is used by many other industries (pet food, fish food, and human food; Riaz, 2000). Rossen and Miller (1973) defined extrusion as “a process in which a food material is forced to flow, under one or more varieties of conditions of mixing, heating, and shear, through a die which is designed to form the ingredients.” Very little information is available on extrusion cooking of corn for feedlot cattle (McLaren and Matsushima, 1971; Gaebe et al., 1998). In the studies by McLaren and Matsushima (1971) and Gaebe et al. (1998) only the corn portion of the diet was extruded and then mixed with the other dietary ingredients. Gaebe et al. (1998) observed a reduction in DMI but no effects on gain efficiency. The roughage source in that study was dehydrated alfalfa cubes; thus, the large reduction in intake could be due to the roughage type. In our study all ingredients were in a single pellet so the cattle could not segregate the individual feedstuffs (Leonardi and Armentano, 2003; DeVries et al., 2005).

Roughages have a low nutritive value and high cost per unit of energy. Therefore, roughages are not typically fed for their nutritive value, but rather for their physiological effect on rumen epithelial health. This is supported by Loerch (1991), who found that plastic pot scrubbers served as a replacement for roughage. Feeding roughages can help prevent rumenitis, parakeratosis, and liver abscesses (Huntington, 1988). We hypothesized that a large, rigid pellet could act as a roughage source, stimulate saliva production, and provide tactile stimulation in the rumen similar to the plastic pot scrubbers used by Loerch (1991). Therefore, our objective was to compare the effects of extrusion processed diets and traditional steam-flaked corn-based diets at high (6%) and low (2%) alfalfa hay levels.

MATERIALS AND METHODS

Procedures used in this study were approved by the Kansas State University Institutional Animal Care and Use Committee.

Crossbred yearling heifers (n = 71; 361 ± 5 kg initial BW) were obtained from a common source and used in a randomized complete block study. Twenty-two days prior to the start of study, heifers were vaccinated against viral and clostridial diseases with Bovishield-4 and Fortress-7 (Pfizer Animal Health, Exton, PA), treated with Phoenectin pour-on (Phoenix Scientific Inc., St. Joseph, MO), and implanted with Revalor 200 (Intervet Inc., Millsboro, DE). Cattle were offered a common receiving diet [28% steam-flaked corn (SFC), 54% corn silage, 13% alfalfa hay, and 5% supplement; DM basis] from d -22 until d -10. On d -10, steam-flaked corn levels were increased to 36% (DM basis), and corn silage and alfalfa hay levels were decreased to 49 and 10%, respectively. Cattle remained on this diet until d -4, when steam-flaked corn was increased to 49% (DM basis) and corn silage and alfalfa hay were decreased to 36 and 9%, respectively. On d -1, heifers were individually weighed. Animals were sorted from lightest to heaviest weight, with every 6 heifers constituting a weight block (n = 12). Starting with the lightest weight block, heifers were assigned randomly to 1 of 6 pens, and treatments were assigned accordingly. Heifers were housed in individual pens (i.e., one heifer/pen; 1.5 × 7.0 m) with a fence-line feed bunk (1.5 m). The feed bunk and half of the pen were covered by an overhead roof. Heifers were allowed ad libitum access to each of 2 adaptation diets leading to the final finishing diet (Table 2-1). Adaptation diets were fed for 5 d each, and a portion of alfalfa hay was replaced with corn at each step. Diets were fed once daily at 0930 h. Treatments were designed in a 2 × 3 factorial arrangement; factor 1 was level of alfalfa hay (2 or 6%), and the other factor was degree of processing (SFC; low-shear extrusion cooking, LOW; or high-shear extrusion cooking, HIGH).

Steam-flaking

Whole corn was steam treated in a 0.76 × 1.22 × 3.05 m stainless steel steam chest for 45 min. Steam-treated corn was then passed through a 0.46- × 0.61-m flaking mill (pitch = 7 corrugations/cm, 0.80 mm round-bottom vee corrugations; Ferrell-Ross Roll Manufacturing Inc., Hereford, TX) and processed to a bulk density of 360 g/L (28 lb/bushel), with an average particle size of 5,214 ± 811 µm (n = 7). Starch availability (Sindt et al., 2006) of steam-flaked corn was

53.9 ± 7.1 (n = 26). SFC rations were prepared daily by mixing the appropriate amounts of each ingredient in a paddle mixer (model 970131-S5, H.C. Davis Sons Mfg. Co., Inc., Bonner Springs, KS) for 3 min.

Extrusion Processing

Extruded diets were processed in a 24:1 (length/diameter) corotating, fully intermeshing twin-screw extruder (model BCTG-62, Bühler AG CH-9240, Uzwil, Switzerland). Extruder processing conditions are summarized in Table 2-2. Barrel and screw configurations are illustrated in Figure 2-1. Ground corn (2,405 ± 541 µm; n = 7), feed additive premix (616 ± 72 µm; n = 4), and protein supplement (760 ± 161 µm; n = 2) were mixed together in a paddle mixer (model 970131-S5, H.C. Davis Sons Mfg. Co., Inc., Bonner Springs, KS) for 3 min. Corn was processed prior to extrusion processing with a double stack roller mill (23 cm × 46 cm, Rosskamp K roller mill; 6 corrugations per inch for top roll and 10 corrugations per inch for bottom roll). Feed mixture was then dosed into the extruder with a differential dosing unit (model MSDA, Bühler AG, CH-9240, Uzwil, Switzerland) and automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland) at the appropriate rate (Table 2-2). Roughage feeder rates were controlled by a loss-in-weight system with an automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland). Liquid feed rates were controlled by a flow meter (model Promag 53, Endress-Hauser, CH-4153, Reinach, Switzerland) and automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland).

Degree of extrusion processing (i.e., amount of mechanical energy transferred into the feed via extruder, Wh/kg) was altered by changing screw configurations (Figure 1) and independent processing variables (Table 2), resulting in a LOW (73.9 and 80.5 Wh/kg for 2 and 6% alfalfa hay diets, respectively) and HIGH (95.7 and 99.0 Wh/kg for 2 and 6% alfalfa hay diets, respectively) extrudate. Extruded diets were prepared every other day.

Carcass Data Collection

On d 144, cattle were shipped 140 km to a commercial abattoir in Emporia, KS, and carcass data were collected. Carcass weight was obtained at the time of harvest. Longissimus muscle area; subcutaneous fat thickness over the 12th rib; KPH, marbling score, USDA quality grades, and USDA yield grades were determined following a 24-h chill. Final BW was calculated by dividing HCW by a common dress yield of 63.5%.

Boneless strip loins (*Longissimus*; NAMP 180, n = 66) were collected from the right sides of the carcasses approximately 36 h postmortem. Identification tags for 5 boneless strip loins were lost during fabrication and could not be collected for subsequent evaluation of meat quality. Strip loins were kept cool in coolers, transported to the Kansas State University Meat Laboratory, and aged for 20 d at 0°C. After 20 d in the cooler, vacuum packaged boneless strip loins were weighed. Strip loins were then removed from vacuum package, blotted dry with paper towels, and weighed. Vacuum packages were washed in hot, soapy water, air dried, and weighed. Purge loss was calculated by 100- ((dry strip loin / (vacuum packaged boneless strip loin – dried and cleaned vacuum package)) × 100). The pH of each boneless strip loin was determined by inserting the tip of a pH probe (MPI pH probe, glass electrode, Meat Probes Inc., Topeka, KS) into the LM.

Starting at the caudal end of the strip loin, a knife and cutting board were used to cut 4 steaks (2.54-cm thick). The first steak was discarded, and the next 2 steaks were vacuum packaged and frozen for subsequent analysis (i.e., Warner-Bratzler shear force and trained sensory panel evaluation). The fourth steak was immediately evaluated for color stability during a 7-d retail display.

Retail Display Life

On d 22 postmortem, steaks were placed onto polystyrene thermal insulation trays (21 × 15 × 2 cm; Tenneco Packaging Specialty and Consumer Products, Lake Forest, IL) with meat pads (Dri-Loc Meat, Fish & Poultry Pads, Cryovac Sealed Air Corporation, Duncan, SC) and overwrapped with polyvinyl chloride film [MAPAC M (23,250 mL/m^2 per 24 h, 72 ga), Bordon Packaging and Industrial Products, North Andover, MA]. Packaged steaks were then placed into a retail display case (model DMF8, Tyler Refrigeration Corp., Niles, MI) for 8 d. Fluorescent lighting (2153 lux, 3000 K and CRI = 85, Bulb model 32T8/ADV830/Alto, Phillips, Bloomfield, NJ) was kept constant at a temperature of 1.2°C. Each d at 0650 and 1500 h, steaks were rotated to ensure random sample placement in the display case.

Trained visual color panelists (n = 14) evaluated initial color of steaks on d 0 of the display period. Initial color was determined in half-point increments with the scale: 1 = bleached, pale red, 2 = slightly cherry red, 3 = moderately light cherry red, 4 = cherry red, 5 = slightly dark red, 6 = moderately dark red, 7 = dark red, and 8 = very dark red.

Color and surface discoloration of steaks were evaluated by trained panelists (n = 17) on d 0 to 7. Daily color score was determined in half-point increments with the scale: 1 = very bright red, 2 = bright red, 3 = dull red, 4 = slightly dark red, 5 = moderately dark red, 5.5 = borderline acceptability to panelist, 6 = dark red or dark reddish tan, 7 = tannish red, and 8 = tan to brown.

Surface discoloration was determined in whole-point increments with the scale: 1 = none (0%), 2 = slight discoloration (1 to 19%), 3 = small discoloration (20 to 39%), 4 = modest discoloration (40 to 59%), 5 = moderate discoloration (60 to 79%), 6 = extensive discoloration (80 to 99%), and 7 = total discoloration (100%).

Steak color was analyzed instrumentally throughout the 7-d display for International Commission on Illumination L*, a*, and b* values for illuminant A and for reflectance from 400 to 700 nm with 10-nm increments with a Miniscan XE Spectrophotometer (3.18-cm diam. Aperture, Hunter Associates Laboratory, Reston, VA). Hue angle (measurement of true redness; i.e., change from the true red axis; 0° = true red to 90° = true yellow), saturation index (measurement of the vividness of color; i.e., higher values indicate a more vivid color), and 630:580 nm reflectance ratio (greater values of 630:580 nm ratio indicate more redness) were calculated (AMSA, 1991). Each steak was scanned at 3 locations within the LM, and measurements were averaged together to obtain a single value for each time point.

Fatty Acid Oxidation Potential

Fatty acid oxidation potential was determined by using thibarbituric acid reactive substances (TBARS). On d 7 of the display period, the top 1.3 cm of each displayed steak was removed and chopped into 1.3- × 1.3-cm cubes and frozen at -20°C. Pieces were then pulverized in liquid N and combined with 15 mL of 7.2% perchloric acid solution and then 20 mL of cold deionized water to precipitate the protein and malonaldehyde. Samples were filtered through Whatman No. 2 filter paper (Whatman International Ltd., Maidstone, United Kingdom). The filtrate was combined with 5 mL of 0.02 *M* thiobarbituric acid reagent (1.4415 g of thiobarbituric acid and 500 mL of deionized water) and stored in complete darkness for 15 h. Milligrams of malonaldehyde per kilogram of steak were determined by absorbance readings of the sample on a spectrometer at 550 nm.

Sensory Panel Evaluation of Steaks

Sensory panel evaluations of LM steaks were conducted with a 7-member panel trained according to AMSA (1995) guidelines. Before product testing, panelists were oriented to flavor, texture, and aroma attributes of a sample to ensure equivalent scores among panelists. Steaks were thawed and subsequently cooked to an internal temperature of 71°C in a DFG-102 CH-3 Blodgett modified broiler oven (GS Blodgett Company Inc., Burlington, VT). Each steak was turned once when internal temperature reached 58°C. Temperature was monitored by thermocouples attached to a Doric Minitrend 205 (Vas Engineering, San Francisco, CA) temperature monitor. Cooked steaks (2.54-cm thick) were cut into 1.27- × 1.27- × 2.54-cm pieces for evaluation.

Warner-Bratzler Shear Force

Steaks were thawed and subsequently cooked to an internal temperature of 71°C in a DFG-102 CH-3 Blodgett modified broiler oven (GS Blodgett Company Inc., Burlington, VT). Each steak was turned once when internal temperature reached 58°C. Temperature was monitored by thermocouples attached to a Doric Minitrend 205 (Vas Engineering, San Francisco, CA) temperature monitor. Steaks were then cooled to room temperature and stored at 2°C overnight. Twenty-four hours later, eight 1.27-cm cores were removed from each steak parallel to the muscle fibers with a corer (G-R Manufacturing Co., Manhattan, KS) attached to an electric drill (Craftsman 3/8" electric drill, Sears, Hoffman Estates, IL). Each core was then sheared perpendicular to the muscle fibers with a Warner-Bratzler V-shaped blunt blade (G-R Manufacturing Co., Manhattan, KS) attached to a 50-kg load cell of an Instron Universal Testing Machine (model 4201, Instron Corp., Canton, MA) with a crosshead speed of 250 mm/min. Average peak force for the 8 cores was calculated for each steak.

Cooking Loss

Cooking loss of steaks used for Warner-Bratzler shear force was determined by 100-((cooked steak cooled to room temperature/raw steak) × 100).

Statistical Analysis

Growth performance, carcass characteristics, muscle pH, purge loss, cooking loss, TBARS, and Warner-Bratzler shear force were analyzed statistically with MIXED procedure of

SAS (SAS Inst., Inc., Cary, NC). Animal was the experimental unit, and block was used as a random effect. Effects of roughage level, degree of processing, and roughage level × degree of processing were tested by using the *F* test. Sensory panel data were analyzed with the MIXED procedure of SAS with roughage level, degree of processing, and roughage level × degree of processing as the fixed effect and weight block and day sensory panel evaluation served as the random effects. Color stability was analyzed by using MIXED procedure of SAS with day, roughage level, and degree of processing as the fixed effects. Weight block and weight block × roughage level × degree of processing were used as the random effects. Significance level was set at $P \leq 0.05$ and $P \leq 0.10$ was considered to be a tendency.

RESULTS AND DISCUSSION

Finishing Performance

Growth performance of yearling heifers is presented in Table 2-3. Heifers fed finishing diets containing 2% alfalfa hay consumed 7% less feed ($P = 0.01$) than heifers fed 6% alfalfa hay. In addition, live-weight gain and carcass-adjusted weight gain were 13 and 11% lower ($P \leq 0.02$), respectively, for heifers fed 2% alfalfa hay. A roughage × process interaction ($P = 0.01$) was observed for G:F calculated on a live-weight basis. Heifers fed SFC and HIGH containing 6% roughage were 11% more efficient than heifers fed SFC and HIGH containing 2% alfalfa hay, but G:F was not different ($P = 0.29$) for heifers fed LOW containing either 2 or 6% alfalfa hay. When calculated using carcass-adjusted BW, G:F was not different ($P = 0.18$) between alfalfa hay levels.

Heifers fed SFC finishing diets consumed 19% more ($P < 0.01$) feed than heifers fed either LOW or HIGH. Live weight gain and carcass-adjusted gains were not different ($P \geq 0.46$) between grain processing treatments. However, heifers fed LOW and HIGH were 14 to 15% more efficient on a carcass-adjusted basis ($P = 0.01$) than heifers fed the SFC finishing diet. Starch availability (data not shown) was greater ($P \leq 0.02$) for HIGH than for SFC or LOW (54.0, 51.2, and 66.6% for SFC, LOW, and HIGH, respectively).

Low inclusion levels of roughages have been shown to stimulate DMI of cattle fed feedlot diets (Woods et al., 1969; Gill et al., 1981; Kreikemeier et al., 1990). We observed this DMI response in the current study. Increasing alfalfa hay from 2 to 6% stimulated a greater DMI. However, Stock et al. (1990) did not observe the same response when roughage levels were increased from 3 to 6% and concluded that the response to roughage addition differs depending on type of grain fed (i.e., rate and extent of rumen digestion). Diets containing a higher source of fermentable energy may require a greater inclusion level of roughage (Stock et al., 1990). Although no roughage × process interaction was observed in the current data, DMI was not different when either 2 or 6% alfalfa hay was fed in SFC diets. In the highly processed extrudates (i.e., LOW and HIGH), DMI was reduced by nearly 1 kg when alfalfa was reduced from 6 to 2%. Therefore, it is conceivable that higher roughage levels in the highly processed extrudate could have resulted in similar DMI.

Daily weight gain decreased as level of alfalfa hay was decreased from 6 to 2%. Kreikemeier et al. (1990) and Stock et al. (1990) observed a similar reduction in ADG, particularly when roughages were fed below 3 and 5%, respectively. In our study G:F was not different between 2 and 6% alfalfa hay, but Kreikemeier et al. (1990) observed a quadratic increase in G:F when 0, 5, 10, or 15% roughage was fed. In addition, Gill et al. (1981) and Brandt et al. (1987) observed improved G:F with higher inclusion levels of roughage. Stock et al. (1990) observed the opposite with a linear decrease in G:F when 0, 3, 6, and 9% roughage was fed. Stock et al. (1990) explained that the grain source used (i.e., dry-rolled sorghum) had a slow rate of ruminal digestion. Therefore, addition of roughage in this diet was not as crucial because of the lower ruminal digestion rate and actually decreased G:F by diluting dietary energy. This does not explain the results from our study because we did not detect a roughage × grain processing interaction. Our results suggest that decreasing roughage levels to 2% is detrimental to DMI and ADG regardless of grain processing method.

We hypothesized that we would see a roughage × grain processing interaction for G:F and postulated that incorporating the entire ration into a pellet would prevent ingredient selection by cattle (Leonardi and Armentano, 2003; DeVries et al., 2005), resulting in a lower incidence of subacute ruminal acidosis (Stone, 2004) and ultimately leading to improved growth performance. In addition, we hypothesized that the large (approximately 28 × 70 mm), hard, textured pellets could act as a roughage source, stimulate saliva production, and provide tactile stimulation in the rumen similar to the plastic pot scrubbers used by Loerch (1991). However, we did not observe any roughage × grain processing interaction. Heifers used in the current study were fed in individual pens; therefore, ingredient selection may not be as problematic in this system compared with group feeding of animals. Cattle fed in groups would have different and more aggressive feeding behavior than cattle fed individually. Therefore, forming the entire ration into a pellet might be more advantageous for situations in which animals are fed in groups.

Ability of the extrudate to provide “roughage like” effects in the rumen, was likely minimal. The extrudate probably did not retain its form in the rumen for a long enough period of time to provide tactile stimulation. However, visual observations of heifers revealed that the extrudate (i.e., LOW and HIGH) did appear to stimulate a greater degree of mastication compared with SFC. Future attempts to increase the pellet integrity in the rumen could increase tactile stimulation, allowing for lower inclusion levels of roughage.

As expected, we observed a main effect of grain processing for starch availability, but starch availability was similar between SFC and LOW. Therefore, SFC and LOW were similar to each other with the exception of physical form of feed, whereas HIGH had a different form and higher starch availability than SFC. These differences in starch availability do not explain the lower DMI and higher G:F for LOW compared with SFC. Lower DMI is usually indicative of higher degrees of processing (i.e., starch availability; Zinn, 1990; Owens et al., 1997; Corona et al., 2005). Therefore, factors other than starch availability may explain why heifers fed LOW consumed less feed and were more efficient than heifers fed SFC. Rowe et al. (1999) reported that hydration and gelatinization of starch is generally similar between extrusion cooking and steam flaking; however, extrusion cooking increased disruption of the endosperm matrix, resulting in greater separation of starch granules. In the current study, samples analyzed for starch availability were ground through a 1-mm screen, resulting in similar particle sizes and physical disruption of starch granules. In the feed we fed the cattle, separation of starch granules may have been greater for LOW compared with SFC, thereby increasing the rate of rumen fermentation. Disruption of starch granules rather than starch availability (i.e., gelatinization) may explain the reduced DMI for LOW.

Another plausible explanation for the increased DMI for SFC compared with LOW and HIGH is depredation of feed by starlings (This thesis, Chapter 6). Dry matter intakes for LOW and HIGH remained relatively consistent at 7.6 kg/d for the 2% alfalfa treatments and 8.5 kg/d for the 6% alfalfa treatments throughout the duration of the study. However, DMI for SFC was approximately 2 kg less from d 0 through 70 than from d 71 through 143. This drastic increase in DMI halfway through the study corresponds to the arrival of a large flock of starlings at the research facility (This Thesis, Chapter 6). Undoubtedly, feed depredation by starlings artificially increased DMI and decreased G:F during this study. Our best estimate is that feed depredation by starlings increased DMI by 0.8 to 1.0 kg/d and therefore decreased G:F by 10 to 15 g/kg over the entire feeding period for SFC treatments. As a result, we estimate that DMI was 10.8% greater and G:F was 5.5% lower for SFC compared with LOW and HIGH. This is somewhat less than the 19 and 14% improvement for DMI and G:F, respectively, when including feed depredation by starlings. Even though evaluation of feed depredation by starlings was not an objective of this experiment, it is clear that forming the entire ration into a pellet prevents depredation by starlings (This Thesis, Chapter 6).

Carcass Data

Carcass data are summarized in Table 2-4. Carcasses from heifers fed finishing diets containing 2% alfalfa hay were 4% lighter ($P = 0.02$) than carcasses from heifers fed finishing diets containing 6% alfalfa hay. Dressed yield, LM area, KPH, and 12th rib fat were not different ($P \geq 0.23$) for finishing diets containing either 2 or 6% alfalfa hay. Heifers fed 6% alfalfa hay had a higher ($P = 0.01$) incidence of liver abscesses than heifers fed 2% alfalfa hay. Carcass weight, dressed yield, LM area, KPH, 12th rib fat, and liver abscesses were not different ($P \geq 0.13$) between SFC, LOW, and HIGH.

Woods et al. (1969) and Kreikemeier et al. (1990) observed similar carcass weights for cattle fed 5, 10, and 15% roughage, but observed a 2 and 5% reduction in carcass weight when roughage levels were reduced from 5 to 0%, respectively. This is very similar to the 4% reduction in carcass weight we observed in the current study when roughage was reduced from 6 to 2%. Likewise, Woods et al. (1969) and Kreikemeir et al. (1990) observed no differences in dressed yield, LM area, KPH, and 12th rib fat.

Reinhardt et al. (1997) reported that carcass weight decreased as flake density (i.e., degree of grain processing) decreased from 0.361 to 0.283 kg/L. However, Zinn (1990) and Theurer et al. (1999) reported similar carcass weights for cattle fed finishing diets containing grains flaked to different densities. In addition, Barajas and Zinn (1998) noted similar carcass weights between cattle fed dry-rolled and steam-flaked corn. Likewise, Loerch and Fluharty (1998) observed similar carcass weights for cattle fed whole and rolled corn. Our results are supported by the majority of the literature, which suggests that grain processing does not have a significant effect on carcass weights.

Zinn (1990) and Loerch and Fluharty (1998) observed similar carcass characteristics with different degrees of grain processing. Theurer et al. (1999) observed a linear decrease in dressing percentage and 12th rib fat thickness as degree of grain processing increased. Similarly, Reinhardt et al. (1997) noted a linear decrease in dressing percentage as flake density decreased. In general, dressing percentage and 12th rib fat thickness increase as degree of grain processing is increased (Owens and Gardner, 2000). It is not clear why we did not observe these same trends in the current study. It is plausible that the sharp reduction in DMI influenced digestive tract fill and fat deposition.

Carcass yield and quality grades are summarized in Table 2-5. Average USDA yield grade, USDA Choice or higher, and marbling score were not different ($P \geq 0.37$) between 2 and 6% alfalfa hay diets. Average USDA yield grade and quality grade were not different ($P \geq 0.47$) between SFC, LOW, and HIGH. However, marbling score was 19% lower ($P = 0.01$) for LOW and HIGH compared with SFC.

Similar to our results, Woods et al. (1969), Kreikemeier et al. (1990), and Stock et al. (1990) did not report any differences in yield and quality grades for cattle fed different levels of roughage. Research from Zinn (1990), Reinhardt et al. (1997), and Theurer et al. (1999) suggests a trend for reduced marbling scores with higher degrees of steam flaking. In addition, Owens and Gardner (2000) suggest that higher degrees of grain processing (i.e., steam flaking) results in lower marbling scores compared with dry-rolled corn.

Meat Quality Attributes

Meat quality attributes are summarized in Table 2-6. Muscle pH, purge loss during storage, cooking loss, TBARS, and Warner-Bratzler shear force were not different ($P \geq 0.18$) between 2 and 6% alfalfa hay.

Muscle pH, cooking loss, TBARS, and Warner-Bratzler shear force were not different ($P \geq 0.23$) between SFC, LOW, and HIGH. However, purge loss from strip loins collected from heifers fed SFC was 24% ($P = 0.06$) and 28% ($P = 0.01$) less than that from loins collected from heifers fed HIGH and LOW, respectively.

Sensory Panel Characteristics

Sensory panel characteristics (Table 2-7) were not different ($P \geq 0.38$) between 2 and 6% alfalfa hay finishing diets.

Steaks from heifers fed SFC were juicier ($P = 0.01$) than steaks from heifers fed LOW and tended ($P = 0.08$) to be juicer than steaks from heifers fed HIGH. In addition, steaks from heifers fed LOW and HIGH extrudate had a more pronounced ($P = 0.01$) off-flavor compared with steaks from heifers fed SFC.

Retail Display Life

Trained color panel evaluation and instrumental color profiles are summarized in Tables 2-8 and 2-9. Initial color of steaks as determined by trained color panelist was bright cherry red and not different ($P \geq 0.59$) between treatments on d 0. Steak color (1 = very bright red and 8 = tan to brown) and discolor (1 = 0% discoloration and 7 = 100% discoloration) were not different ($P \geq 0.21$) between treatments. Steak color became less ($P = 0.04$, quadratic) acceptable to panelist while discoloration of steaks increased ($P = 0.01$, quadratic) during 8-d retail display period.

Redness (a*, positive values = red and negative values = green, respectively), yellowness (b*, positive values = yellow and negative values = blue, respectively), saturation index $[(a^{*2} + b^{*2})^{-1/2}]$, and reflectance ratio of 630 nm:580 nm wavelengths were not different ($P \geq 0.15$) between treatments but decreased quadratically ($P < 0.01$) during the 8-d retail display period. A grain processing method × d interaction ($P \leq 0.03$) was detected for brightness (L*, 0 = black and 100 = white, respectively) and hue angle $[(b^*/a^*)^{\tan^{-1}}]$. L* values for SFC and LOW decreased at a rate faster than L* values for HIGH during the 8-d retail display period. Hue angle for LOW and HIGH increased faster than SFC after d-5 of retail display period.

Overall Conclusions

Extrusion processing of finishing feedlot diets decreased DMI but improved G:F over the conventional steam-flaking process. However, carcass characteristics and meat quality attributes were not different between the different grain processing methods. In summary, extrusion processing improved gain efficiency without having any deleterious effects on meat quality. Reducing alfalfa hay levels from 6 to 2% decreased DMI, ADG, and carcass weight of yearling heifers but did not affect carcass characteristics and meat attributes.

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Table 2-1. Composition of finishing diets containing either 2 or 6% chopped alfalfa hay

Item, %	2% alfalfa hay	6% alfalfa hay
Corn	85.0	81.7
Corn steep liquor	6.6	6.6
Alfalfa hay	2.0	6.0
Limestone	1.7	1.6
Urea	1.2	1.2
Soybean meal	0.6	-
Vitamin/mineral premix[1]	0.7	0.7
Supplement[2]	2.2	2.2
Chemical composition		
DM	79.5	79.7
CP	14.0	14.0
NDF	9.0	10.6
Ca	0.72	0.71
P	0.39	0.39

[1] Formulated to provide the following per kg of total diet DM: 0.1 mg Co; 10 mg Cu; 0.6 mg I; 60 mg Mn; 0.3 mg Se; 60 mg Zn; and 2,200 IU vitamin A.

[2] Formulated to provide 0.5 mg melengestrol acetate (Pfizer Animal Health, Exton, PA), 300 mg monensin (Elanco Animal Health, Greenfield, IN), and 90 mg tylosin (Elanco Animal Health, Greenfield, IN) per heifer daily.

Table 2-2. Extruder processing conditions

	2% alfalfa hay		6% alfalfa hay			*P*-value		
Item	LOW[1]	HIGH[2]	LOW	HIGH	SEM	Shear	Roughage	Shear × Roughage
Corn, kg/h	433	433	338	340	2.4	-	-	-
Corn steep liquor, kg/h	51.6	51.6	42.3	42.4	0.28	-	-	-
Alfalfa hay, kg/h	7.7	7.5	19.9	19.8	0.12	-	-	-
Process water, kg/h	0.0	4.7	0.0	3.6	0.12	-	-	-
Extruder rpm	802	498	802	486	2.29	-	-	-
Die temperature, °C	136	124	140	120	17.0	0.01	0.50	0.01
Die pressure, bar	23.2	18.2	23.5	19.3	0.30	0.01	0.02	0.16
Torque, Nm	388	808	343	703	8.12	0.01	0.01	0.01
Torque, %	26	55	23	48	1.3	0.01	0.01	0.08
Power consumption, kW	32.6	42.2	28.8	35.6	0.46	0.01	0.01	0.01
Specific mechanical energy, Wh/kg	73.9	95.7	80.5	99.0	0.95	0.01	0.01	0.09

[1] LOW = complete feed in the form of a pellet produced by low shear extrusion.

[2] HIGH = complete feed in the form of a pellet produced by high shear extrusion.

Table 2-3. Growth performance of yearling heifers fed finishing diets containing 2 or 6% alfalfa hay with different levels of grain processing

	2% alfalfa hay			6% alfalfa hay				*P*-value		
Item	SFC[1]	LOW[2]	HIGH[3]	SFC	LOW	HIGH	SEM	Roughage	Process	Roughage × Process
No. of heifers	12	12	12	12	11	12	-	-	-	-
Days on feed	143	143	143	143	143	143	-	-	-	-
Initial BW, kg	361	361	361	361	360	361	5.2	0.83	0.97	0.94
Final BW, kg	515	510	499	537	519	537	11.8	0.01	0.48	0.32
DMI, kg/d	10.5	8.2	8.1	10.5	9.2	9.0	0.35	0.01	0.01	0.14
ADG, kg/d	1.08	1.04	0.97	1.23	1.11	1.23	0.06	0.01	0.46	0.30
G:F, g/kg	102.4	127.1	118.6	116.1	120.3	137.1	4.40	0.02	0.01	0.01
Carcass adjusted performance										
Final BW[4]	519	512	499	529	525	532	11.5	0.02	0.66	0.44
ADG, kg/d	1.10	1.05	0.96	1.18	1.15	1.20	0.07	0.02	0.64	0.41
G:F, g/kg	105.0	129.0	118.1	111.6	124.5	133.0	5.14	0.18	0.01	0.18

[1] SFC = steam-flaked corn-based finishing diet.

[2] LOW = complete feed in the form of a pellet produced by low shear extrusion.

[3] HIGH = complete feed in the form of a pellet produced by high shear extrusion.

[4] Carcass adjusted final BW calculated by dividing HCW by a common dress yield of 63.5%.

Table 2-4. Carcass characteristics of yearling heifers fed finishing diets containing 2 or 6% alfalfa hay with different levels of grain processing

	2% alfalfa hay			6% alfalfa hay				*P*-value		
Item	SFC[1]	LOW[2]	HIGH[3]	SFC	LOW	HIGH	SEM	Roughage	Process	Roughage × Process
HCW, kg	329	325	317	336	333	338	7.3	0.02	0.66	0.44
Dressed yield, %	63.9	63.8	63.5	62.7	64.2	62.9	0.49	0.27	0.26	0.26
LM area, cm^2	81.3	85.2	79.4	83.9	83.2	83.9	2.58	0.32	0.60	0.42
KPH, %	2.08	2.04	2.13	2.27	2.14	2.15	0.10	0.23	0.68	0.71
12th rib fat, cm	1.27	0.99	1.12	1.04	1.22	1.14	0.02	0.85	0.94	0.23

[1] SFC = steam-flaked corn based finishing diet.

[2] LOW = complete feed in the form of a pellet produced by low shear extrusion.

[3] HIGH = complete feed in the form of a pellet produced by high shear extrusion.

Table 2-5. Carcass yield and quality grade of yearling heifers fed finishing diets containing 2 or 6% alfalfa hay and with different levels of grain processing

	2% alfalfa hay			6% alfalfa hay				*P*-value		
Item	SFC[1]	LOW[2]	HIGH[3]	SFC	LOW	HIGH	SEM	Roughage	Process	Roughage × Process
USDA yield grade	3.1	2.5	2.7	2.8	2.9	2.9	0.17	0.44	0.47	0.08
USDA Choice or better, %	83.3	58.3	66.7	58.3	63.6	58.3	14.2	0.37	0.69	0.46
Marbling score[4]	Mt^{38}	Sm^{8}	Sm^{30}	Sm^{99}	Sm^{28}	Sm^{15}	26.7	0.61	0.01	0.56

[1] SFC = steam-flaked corn-based finishing diet.

[2] LOW = complete feed in the form of a pellet produced by low shear extrusion.

[3] HIGH = complete feed in the form of a pellet produced by high shear extrusion.

[4] Sm = small marbling classification; Mt = modest marbling classification; superscripts indicate the degree (0 to 99) of marbling within a classification.

Table 2-6. Meat quality attributes of steaks collected from yearling heifers fed finishing diets containing 2 or 6% alfalfa hay with different levels of grain processing

	2% alfalfa hay			6% alfalfa hay				*P*-value		
Item	SFC[1]	LOW[2]	HIGH[3]	SFC	LOW	HIGH	SEM	Roughage	Process	Roughage × Process
Muscle pH	5.49	5.47	5.48	5.47	5.49	5.45	0.015	0.37	0.67	0.33
Purge loss, %	1.5	2.1	1.9	1.7	2.4	2.3	0.24	0.18	0.03	0.83
Cooking loss, %	29.6	26.9	28.9	26.4	22.9	29.8	3.74	0.48	0.48	0.77
TBARS[4]	0.68	1.06	1.02	0.82	0.89	0.92	0.148	0.73	0.23	0.57
Warner-Bratzler shear, kg	3.0	3.3	3.1	3.3	3.3	3.2	0.15	0.35	0.46	0.42

[1] SFC = steam-flaked corn-based finishing diet.

[2] LOW = complete feed in the form of a pellet produced by low shear extrusion.

[3] HIGH = complete feed in the form of a pellet produced by high shear extrusion.

[4] TBARS = thiobarbituric acid reactive substances (measured in milligrams of malonaldehyde per kilogram of steak).

Table 2-7. Sensory panel evaluation of steaks collected from yearling heifers fed finishing diets containing 2 or 6% alfalfa hay with different levels of grain processing

	2% alfalfa hay			6% alfalfa hay				*P*-value		
Item[1]	SFC[2]	LOW[3]	HIGH[4]	SFC	LOW	HIGH	SEM	Roughage	Process	Roughage × Process
Myofibrillar tenderness	6.35	6.01	6.04	6.09	5.99	6.58	0.286	0.71	0.56	0.35
Juiciness	5.76	5.33	5.52	5.57	5.42	5.43	0.123	0.50	0.04	0.47
Flavor intensity	5.82	5.65	5.67	5.75	5.73	5.61	0.073	0.72	0.12	0.53
Connective tissue amount	7.15	6.98	7.15	7.17	7.16	7.10	0.102	0.39	0.50	0.28
Overall tenderness	6.53	6.15	6.22	6.27	6.19	6.21	0.121	0.39	0.09	0.31
Off-flavor intensity	7.67	7.44	7.12	7.36	7.42	7.23	0.103	0.38	0.01	0.11

[1] Scale: 1 = extremely tough, dry, bland flavor, abundant connective tissue, or extremely tough; 8 = extremely tender, juicy, intense flavor, no connective tissue, or tender.

[2] SFC = steam-flaked corn-based finishing diet.

[3] LOW = complete feed in the form of a pellet produced by low shear extrusion.

[4] HIGH = complete feed in the form of a pellet produced by high shear extrusion.

Table 2-8. Trained panel evaluation of color and discoloration of steaks collected from yearling heifers fed finishing diets containing 2 or 6% alfalfa hay with different levels of grain processing

	2% alfalfa hay			6% alfalfa hay			
Item	SFC[1]	LOW[2]	HIGH[3]	SFC	LOW	HIGH	SEM
Initial color[4]	4.01	4.06	4.07	4.14	4.04	3.95	0.124
d 0							
Color[5,7]	2.75	2.62	2.40	2.55	2.54	2.52	0.095
Discolor[6,7]	1.00	1.00	1.00	1.00	1.02	1.00	0.006
d 3							
Color	3.87	3.70	3.47	3.64	3.76	3.62	0.163
Discolor	1.27	1.23	1.11	1.21	1.38	1.29	0.059
d 5							
Color	4.56	4.74	4.44	4.55	4.76	4.45	0.224
Discolor	1.65	1.97	1.64	1.73	1.88	1.89	0.185
d 7							
Color	5.24	5.43	5.66	5.28	5.19	5.20	0.274
Discolor	2.00	2.61	2.73	2.32	2.48	2.48	0.307

[1] SFC = steam-flaked corn-based finishing diet.

[2] LOW = complete feed in the form of a pellet produced by low shear extrusion.

[3] HIGH = complete feed in the form of a pellet produced by high shear extrusion.

[4] Initial color: 1 = bleached, pale red; 4 = bright cherry red; 8 = very dark red.

[5] Color: 1 = very bright red or pinkish red, 5.5 = borderline acceptability to panelist, 8 = tan to brown.

[6] Discolor: 1 = none (0%), 7 = total discoloration (100%).

[7] Quadratic effect of d, $P < 0.05$.

Table 2-9. Instrumental color profiles[1] of steaks collected from yearling heifers fed finishing diets containing 2 or 6% alfalfa hay and with different levels of grain processing

	2% alfalfa hay			6% alfalfa hay			
Item	SFC[2]	LOW[3]	HIGH[4]	SFC	LOW	HIGH	SEM
d 0							
L*[5,6]	49.2	48.8	49.6	49.4	49.6	49.3	0.65
a*[5]	31.9	31.2	30.8	31.4	31.5	31.5	0.32
b*[5]	24.4	23.6	23.4	23.9	24.1	24.0	0.31
Hue angle[5,6]	37.5	37.1	37.2	37.3	37.3	37.4	0.18
Saturation index[5]	40.2	39.1	38.6	39.4	39.7	39.6	0.43
630:580[5]	5.2	5.1	4.9	5.1	5.1	5.2	0.15
d 3							
L*	45.0	45.8	46.2	45.4	46.0	46.2	0.68
a*	28.1	27.7	27.5	27.7	27.1	27.8	0.48
b*	22.2	21.7	21.5	21.8	21.4	21.8	0.35
Hue angle	38.4	38.1	38.1	38.2	38.2	38.1	0.24
Saturation index	35.8	35.2	34.9	35.2	34.5	35.3	0.57
630:580	4.3	4.2	4.1	4.2	4.0	4.1	0.15
d 5							
L*	44.4	44.7	46.0	44.8	45.3	46.9	0.73
a*	26.6	25.5	24.9	26.0	25.5	25.2	0.75
b*	21.1	20.3	19.8	20.7	20.7	19.9	0.47
Hue angle	38.5	38.5	38.5	38.5	39.1	38.4	0.35
Saturation index	33.9	32.6	31.8	33.2	32.9	32.1	0.89
630:580	4.0	3.7	3.5	3.8	3.6	3.5	0.20
d 7							
L*	43.5	44.0	44.5	44.3	44.1	45.6	0.73
a*	25.2	23.4	22.5	24.2	24.1	23.4	1.02
b*	20.7	19.7	19.3	20.0	20.3	19.4	0.52
Hue angle	39.5	40.3	40.8	39.6	40.2	39.9	0.65
Saturation index	32.6	30.6	29.7	31.4	31.4	30.4	1.10
630:580	3.7	3.3	3.0	3.4	3.3	3.2	0.23

[1] L* = brightness (0 = black, 100 = white), a* = redness (positive values = red, negative values = green), b* = yellowness (positive values = yellow, negative values = blue), hue angle = measure of true redness (0° = true red to 90° = true yellow), saturation index = vividness of color (higher values indicate a more vivid color, 630:580 = proportion of oxymyoglobin in the metmyoglobin pigment (lower numbers indicate less oxymyoglobin and more metmyoglobin).

[2] SFC = steam-flaked corn-based finishing diet.

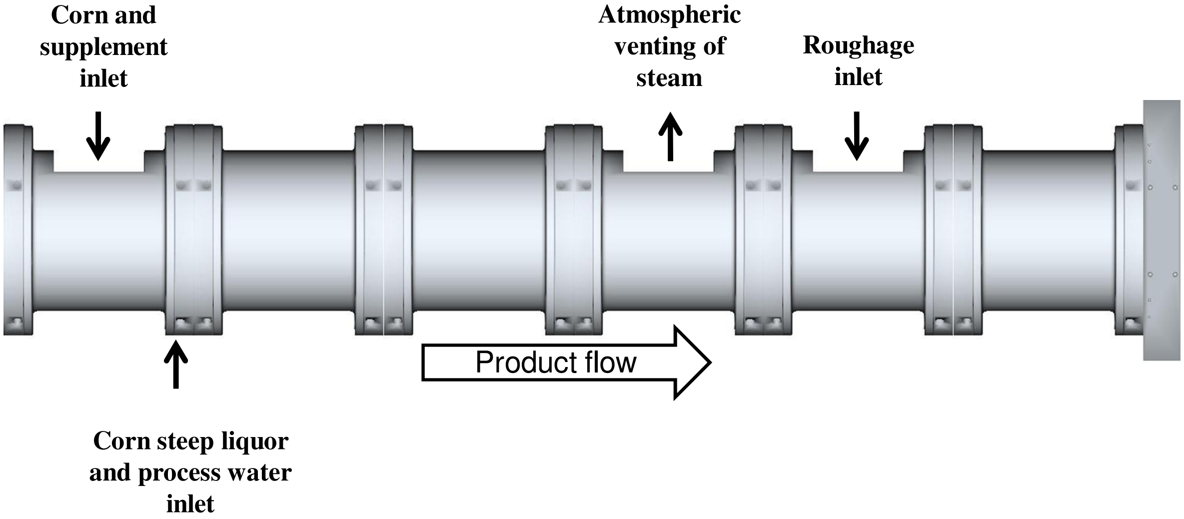
[3] LOW = complete feed in the form of a pellet produced by low shear extrusion.

[4] HIGH = complete feed in the form of a pellet produced by high shear extrusion.

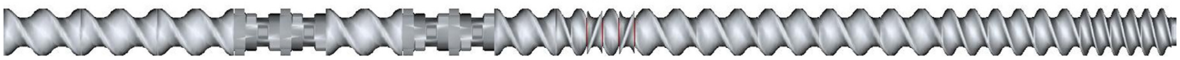
[5] Quadratic effect of d, $P < 0.01$.

[6] Grain processing method × d effect, $P \leq 0.03$.

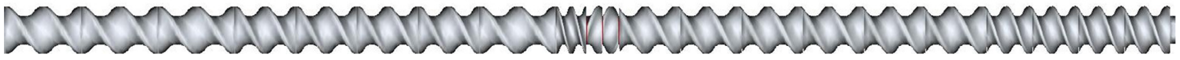
Figure 2-1. Extruder barrel and screw configuration



HIGH shear screw configuration



LOW shear screw configuration



CHAPTER 3 - Extrusion processing of feedlot diets II: Effects of roughage source in extruded corn diets

ABSTRACT

Effects of roughage source were evaluated in steam-flaked and extruded corn diets fed to crossbred yearling heifers (n = 48; 305 ± 3 kg initial BW). Treatments were arranged as a 2 × 2 factorial; factor 1 was grain processing method (steam-flaked or extruded) and factor 2 was roughage source (alfalfa hay or wheat straw). Extruded diets were processed in a 24:1 (length/diameter) corotating, fully intermeshing, twin-screw extruder (model BCTG-62, Bühler AG CH-9240, Uzwil, Switzerland). Final BW, ADG, and G:F were not different ($P \geq 0.13$) between grain processing method and roughage source. In addition, DMI was not different ($P = 0.65$) for grain processing method. However, heifers fed finishing diets containing wheat straw as the roughage source consumed 7% less DM ($P = 0.01$) than heifers fed alfalfa hay. Carcass characteristics and meat quality attributes were not different ($P \geq 0.10$) between grain processing methods and roughage source. A grain processing method and roughage source interaction ($P = 0.04$) was observed by a trained sensory panel for myofibrillar tenderness and overall tenderness. Steaks were more tender for the heifers fed the steam-flaked corn-alfalfa hay diet and extruded corn-wheat straw diet compared with their counterparts. On d 0 of the retail display period, steaks from heifers fed extruded diets had a higher ($P = 0.03$) b* rating (i.e., more yellow) and had a more ($P = 0.04$) vivid color. However, steak color was not different ($P \geq 0.08$) among treatments on the subsequent days and deteriorated ($P = 0.01$, quadratic effect of day) over the 8-d retail display period regardless of treatment. Extruding the entire diet into a homogeneous pellet resulted in similar growth performance, carcass characteristics, and meat attributes as heifers fed steam-flaked corn diets. Reduced intakes of heifers fed wheat straw as the roughage source may be the result of a lower inclusion level rather than a specific effect of roughage type.

Key words: alfalfa hay, corn, extrusion, meat, wheat straw

INTRODUCTION

Alfalfa hay is one of the most common roughage sources fed to feedlot cattle (Vasconcelos and Galyean, 2007). Compared with alfalfa hay, wheat straw has a lower nutritive value (NRC, 1996), but is an excellent source of effective NDF (NRC, 1996) and is a lower cost roughage source. Selective sorting of feed ingredients by cattle fed total mixed rations can be a problem (Leonardi and Armentano, 2003, 2007; Leonardi et al., 2005; DeVries et al., 2005). Due to its physical structure, wheat straw may elicit a greater degree of feed segregation and hence poorer growth performance when compared with alfalfa hay. Increased use of wheat straw as the roughage source by High Plains feedlots may be beneficial and could reduce feed costs without having deleterious effects on beef quality. In addition, use of crop biomass (i.e., wheat straw) that do not require irrigation in the High Plains region will decrease the water requirements per kilogram of beef produced (Beckett and Oltjen, 1993).

Extrusion processing of the entire ration into homogeneous pellets has improved G:F of feedlot cattle fed corn- and alfalfa hay-based diets (This Thesis: Chapter 2). Forming the entire diet into a homogeneous pellet will prevent diet sorting and may permit the use of roughage sources such as wheat straw. The objectives of the current study were to evaluate effects of extrusion processing of corn based finishing diets containing either alfalfa hay or wheat straw as the roughage source on growth performance, carcass characteristics, and meat quality attributes of feedlot heifers.

MATERIALS AND METHODS

Procedures used in this study were approved by the Kansas State University Institutional Animal Care and Use Committee.

Crossbred yearling heifers (n = 48; 305 ± 3 kg initial BW) were obtained from a common source and used in a randomized complete block study. Ten days prior to the start of the study, heifers were vaccinated against viral and clostridial diseases with Bovishield-4 and Fortress-7 (Pfizer Animal Health, Exton, PA), treated with Phoenectin pour-on (Phoenix Scientific Inc., St. Joseph, MO), and implanted with Revalor 200 (Intervet Inc., Millsboro, DE). Heifers were individually weighed on d 0. Animals were sorted from lightest to heaviest weight, with every 4 heifers constituting a weight block (n = 12). Starting with the lightest weight block, heifers were assigned randomly to 1 of 4 pens, and treatments were assigned accordingly. Treatments were arranged in a 2 × 2 factorial; factor 1 was grain processing method (steam-flaked or extruded) and factor 2 was roughage source (alfalfa hay or wheat straw). Heifers were housed in individual pens (i.e., 1 heifer/pen; 1.5 × 7.0 m) with a fence-line feed bunk (1.5 m). The feed bunk and half of the pen were covered by an overhead roof. Heifers were allowed ad libitum access to each of 4 adaptation diets leading to the final finishing diet (Table 3-1). Adaptation diets for the alfalfa hay treatments were fed for 5 d each; a portion of alfalfa hay was replaced with grain at each step. Similarly, adaption diets for the wheat straw treatment were fed for 5 d each but contained a fixed amount of wheat straw (i.e., 2.7%) with the balance of the roughage coming from alfalfa hay. A portion of the alfalfa hay was replaced with grain at each step. Diets were fed once daily at 0930 h.

Steam-flaking

Whole corn was steam treated in a 0.76 × 1.22 × 3.05 m stainless steel steam chest for 45 min. Steam-treated corn was then passed through a 0.46- × 0.61-m flaking mill (pitch = 7 corrugations/cm, 0.80 mm round bottom vee corrugations; Ferrell-Ross Roll Manufacturing Inc., Hereford, TX) and processed to a bulk density of 360 g/L (28 lb/bushel). Steam-flaked corn had an average particle size of 6,054 ± 424 μm (n = 36) and starch availability (Sindt et al., 2006) of 46.2 ± 5.1 (n = 97). Steam-flaked corn rations were prepared daily by mixing the appropriate amounts of each ingredient in a paddle mixer (model 970131-S5, H.C. Davis Sons Mfg. Co., Inc., Bonner Springs, KS) for 3 min.

Extrusion Processing

Extruded diets were processed in a 24:1 (length/diameter) corotating, fully intermeshing, twin-screw extruder (model BCTG-62, Bühler AG CH-9240, Uzwil, Switzerland). Extruder processing conditions are summarized in Table 3-2. Barrel and screw configurations are illustrated in Figure 3-1. Corn and supplement were dosed into the extruder with 2 differential dosing units (model MSDA and model MSDE, respectively, Bühler AG, CH-9240, Uzwil, Switzerland) and automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland) at the appropriate rate (Table 3-2). Corn (3,273 ± 355 μm; n = 9) was processed prior to extrusion processing with a double-stack roller mill (23 cm × 46 cm, Rosskamp K roller mill; 2.36 corrugations per cm for top roll and 3.94 corrugations per cm for bottom roll). Roughage feeder rates were controlled by a loss-in-weight system with an automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland). Liquid feed rates were controlled by a flow meter (model Promag 53, Endress-Hauser, CH-4153, Reinach, Switzerland) and automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland). Extruded diets were prepared every other day.

In Vitro Dry Matter Disappearance

Samples from each treatment were randomly selected on 3 different days during the feeding period and used in an IVDMD study. Samples (n = 12; 3 per treatment) were dried for 24 h at 55°C and ground through a 2-mm screen with a Thomas-Wiley laboratory mill (Model 4 Thomas Scientific, Swedesboro, NJ). Laboratory DM was determined for each sample by drying samples in a forced-air convection oven for 16 h at 105°C. Dry weight of polyethylene centrifuge tubes (25 × 100 mm) was recorded, and 0.5 g of sample was added to each tube. Whole ruminal contents were obtained from a ruminally cannulated steer fed a finishing diet (83.4% dry-rolled corn, 5.6% alfalfa hay, 5.5% corn steep liquor, and 5.5% supplement) and strained through 8 layers of cheesecloth. A 30-mL mixture (i.e., 2:1 ratio) of McDougall's buffer (El-Shazly and Hungate, 1965) and strained ruminal fluid was added to each of the tubes and incubated in a reciprocal shaking water bath (model 2872, Thermo Electron Corporation, Marietta, OH) at 39°C for 24 h. Tubes were flushed with CO_2 and sealed with a #5 rubber stopper equipped with a slit rubber policeman. After a 24-h incubation, tubes were removed from the water bath, immediately placed on ice to stop fermentation, and centrifuged (model J2-21 Beckman Centrifuge, Beckman Instruments, Palo Alto, CA) at 30,000 × g for 20 min. Supernatant was removed, and tubes were dried at 100°C for 12 h. Samples were analyzed in duplicate and replicated on 3 different days. Two blanks were prepared for each run by adding McDougall's buffer and ruminal fluid to tubes without substrate. Blank tubes were used to account for the DM in McDougall's buffer and ruminal fluid. Dry matter content was then subtracted from total DM in the treatment tubes.

Starch Availability

Diet samples (n = 8; 2 per treatment) were dried for 24 h at 55°C and then ground through a 2-mm screen with a Thomas-Wiley laboratory mill (Model 4 Thomas Scientific, Swedesboro, NJ). Samples were submitted to a commercial laboratory (SDK Laboratories, Hutchinson, KS) for analysis of starch availability (Xiong et al., 1990).

Carcass Data Collection

On d 133, cattle were shipped 140 km to a commercial abattoir in Emporia, KS, and carcass data were collected upon arrival. Carcass weight was obtained at the time of harvest. Longissimus muscle area, subcutaneous fat thickness over the 12th rib, KPH, marbling score, USDA quality grades, and USDA yield grades were determined following a 24-h chill. Final BW was calculated by dividing HCW by a common dress yield of 63.5%.

Boneless strip loins (*Longissimus*; NAMP 180, n = 43) were collected from the right sides of the carcasses approximately 36 h postmortem. Identification tags for 5 boneless strip loins were lost during fabrication and could not be collected for subsequent evaluation of meat quality. Strip loins were kept cool in coolers, transported to the Kansas State University Meat Laboratory located in Manhattan, KS, and aged for 20 d at 0°C. After 20 d in the cooler, vacuum-packaged boneless strip loins were weighed. Strip loins were then removed from vacuum package, blotted dry with paper towels, and weighed. Vacuum packages were washed in hot, soapy water, air dried, and weighed. Percent purge loss was calculated as 100- [(weight of the dry strip loin / (weight of the vacuum packaged boneless strip loin – weight of the vacuum package)) × 100].

A knife and cutting board were used to cut 4 steaks (2.54-cm thick) starting at the caudal end of the strip loin. The first steak was discarded, and the next 2 steaks were vacuum packaged and frozen for subsequent analysis (i.e., Warner-Bratzler shear force and trained sensory panel evaluation). The fourth steak was immediately evaluated for color stability during an 8-d simulated retail display.

Retail Display Life

On d 20 postmortem, steaks were placed onto polystyrene thermal insulation trays (21 × 15 × 2 cm; Tenneco Packaging Specialty and Consumer Products, Lake Forest, IL) with meat pads (Dri-Loc Meat, Fish & Poultry Pads, Cryovac Sealed Air Corporation, Duncan, SC) and overwrapped with polyvinyl chloride film [MAPAC M (23,250 mL/m^2 per 24 h, 72 ga), Bordon Packaging and Industrial Products, North Andover, MA]. Packaged steaks were placed into a lighted display case (model DMF8, Tyler Refrigeration Corp., Niles, MI) for 8 d. Fluorescent lighting (2153 lux, 3000 K and CRI = 85, Bulb model 32T8/ADV830/Alto, Phillips, Bloomfield, NJ) was kept constant, and display case temperature was maintained at 1.2°C. Each d at 0650 and 1500 h, steaks were rotated to ensure random sample placement in the display case.

Steak color was analyzed instrumentally throughout the 8-d display for International Commission on Illumination L*, a*, and b* values (3.18-cm diam. Aperture, Hunter Associates Laboratory, Reston, VA). Hue angle (measurement of true redness; i.e., change from the true red axis; 0° = true red to 90° = true yellow), saturation index (measurement of the vividness of color; i.e., higher values indicate a more vivid color), and 630:580 nm reflectance ratio (greater values of 630:580 nm ratio indicate more redness) were calculated (AMSA, 1991). Each steak was scanned at 3 locations within the LM, and measurements were averaged to obtain a single value for each time point.

Fatty Acid Oxidation

Fatty acid oxidation was determined by using thiobarbituric acid reactive substances (TBARS). On d 8 of the retail display period, the top 1.3 cm of each displayed steak was removed, chopped into 1.3 × 1.3-cm cubes, and frozen at -20°C. Pieces were then pulverized in liquid N, combined with 15 mL of 7.2% perchloric acid solution, followed by 20 mL of cold deionized water to precipitate the protein and malonaldehyde. Samples were filtered through Whatman No. 2 filter papers (Whatman International Ltd., Maidstone, United Kingdom). The filtrate was combined with 5 mL of 0.02 *M* thiobarbituric acid reagent (1.4415 g of thiobarbituric acid and 500 mL of deionized water) and stored in complete darkness for 15 h. Milligrams of malonaldehyde per kilogram of steak were determined by absorbance readings of the sample on a spectrophotometer at 550 nm.

Sensory Panel Evaluation of Steaks

Sensory panel evaluations of LM steaks were conducted by a 7-member panel trained according to AMSA (1995) guidelines. Before product testing, panelists were oriented to flavor, texture, and aroma attributes of a sample to ensure consistent scores among panelists. Steaks were thawed and subsequently cooked to an internal temperature of 71°C in a DFG-102 CH-3 Blodgett modified broiler oven (GS Blodgett Company Inc., Burlington, VT). Each steak was turned once when internal temperature reached 58°C. Temperature was monitored by thermocouples attached to a Doric Minitrend 205 (Vas Engineering, San Francisco, CA) temperature monitor. Cooked steaks (2.54-cm thick) were cut into 1.27- × 1.27- × 2.54-cm pieces and served to panelist for evaluation. Steaks were evaluated for myofibrillar tenderness, juiciness, flavor intensity, connective tissue amount, overall tenderness, and off-flavor intensity in half-point increments using an 8-point scale (1 = extremely tough, dry, bland flavor, abundant connective tissue, or extremely tough; 8 = extremely tender, juicy, intense flavor, no connective tissue, or tender).

Warner-Bratzler Shear Force

Steaks were thawed and subsequently cooked to an internal temperature of 71°C in a DFG-102 CH-3 Blodgett modified broiler oven (GS Blodgett Company Inc., Burlington, VT). Each steak was turned once when internal temperature reached 58°C. Temperature was monitored by thermocouples attached to a Doric Minitrend 205 (Vas Engineering, San Francisco, CA) temperature monitor. Steaks were then cooled to room temperature and stored at 2°C overnight. Twenty-four hours later, eight 1.27-cm cores were removed from each steak parallel to the muscle fibers with a corer (G-R Manufacturing Co., Manhattan, KS) attached to an electric drill (Craftsman 3/8” electric drill, Sears, Hoffman Estates, IL). Each core was then sheared perpendicular to the muscle fibers with a Warner-Bratzler V-shaped blunt blade (G-R Manufacturing Co., Manhattan, KS) attached to a 50-kg load cell of an Instron Universal Testing Machine (model 4201, Instron Corp., Canton, MA) with a crosshead speed of 250 mm/min. Average peak force for the 8 cores was calculated for each steak.

Cooking Loss

Percentage weight loss during cooking of steaks used for Warner-Bratzler shear force was estimated as 100-[(weight of cooked steak cooled to room temperature / weight of raw steak) × 100].

Statistical Analysis

Growth performance, carcass characteristics, purge loss, cooking loss, TBARS, and Warner-Bratzler shear force were analyzed statistically with the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC). Animal was the experimental unit, and weight block was used as the random effect. Effects of grain processing, roughage source, and interaction were tested with an *F* test. Proportion of carcasses grading USDA Choice or better were analyzed with the binary option of the GLIMMIX procedure. Grain processing, roughage source, and interactions were the fixed effects, and weight block was the random effect. Sensory panel data were analyzed with the MIXED procedure of SAS with grain processing and roughage source as fixed effects and weight block and the day sensory panel were conducted as random effects. Color stability was analyzed with the MIXED procedure of SAS with day effect, grain processing, and roughage source as fixed effects. Weight block and weight block × grain processing × roughage source were used as random effects. Linear and quadratic contrasts were used to compare day effects. In vitro dry matter disappearance was analyzed with the MIXED procedure of SAS. Grain processing, roughage source, and interactions were the fixed effects, and day on which the IVDMD experiment was conducted was the random effect. Significance level was set at $P \leq 0.05$.

RESULTS AND DISCUSSION

Finishing Performance

Growth performance data of yearling heifers are presented in Table 3-3. Final BW, ADG, and G:F were not different ($P \geq 0.13$) among treatments. Dry matter intake was not different ($P = 0.65$) between grain processing methods. Heifers fed alfalfa hay as the roughage source consumed more DM ($P = 0.01$) than heifers fed wheat straw. This difference may be due to roughage level rather than type of roughage fed. Diets were formulated on an equal NDF basis rather than a roughage-equivalent basis. Therefore, grain levels were greater in diets containing wheat straw than in diets containing alfalfa hay. Stock et al. (1990) observed a decrease in DMI when roughage levels were decreased from 9% roughage to no added roughage. Diets that elicit increased fermentation rates of organic acids generally decrease DMI and pH (Allen, 2000). Therefore, the greater DMI observed for heifers fed diets containing alfalfa hay as the roughage source may be a result of energy dilution rather than tactile or physical characteristics of the roughage. This is supported by Depenbusch et al. (This Thesis: Chapter 2), they observed a 7% decrease in DMI when roughage levels were decreased from 6 to 2% in steam-flaked corn and extruded corn diets.

Extrusion processing did not improve G:F of corn-based diets and this contradicts the results of Depenbusch et al. (This Thesis: Chapter 2), who observed a 15% improvement in G:F for heifers fed extruded corn diets compared with heifers fed steam-flaked corn diets. This is difficult to explain considering the IVDMD and starch availability of the finishing diets (Table 3-4). Depenbusch et al. (This Thesis: Chapter 2) found that starch availability was 8% greater for the extruded corn diets when compared with the steam-flaked corn diets (59% vs. 54%, respectively). In the current study, starch availability for the extruded corn diets was 27% greater than the starch availability of the steam-flaked corn diets (54.2% vs. 39.6%, respectively). Greater starch availability of the extruded corn diets in the current study did not elicit improvements in G:F compared to the steam-flaked corn diets.

Specific mechanical energy (SME; Wh/kg) inputs (Table 3-2) were approximately 25% greater for the extruded corn diets fed by Depenbusch et al. (This Thesis: Chapter 2) than for those fed in the current study. SME is a measurement of the amount of mechanical energy (i.e., Wh) used because of shear force and friction when feed is passed between the stationary outer barrel and rotating center screws of the extruder. Higher SME indicates greater shear force, friction, and heat generated, thereby suggesting a higher degree of cooking. However, lower SME in this study actually resulted in higher starch availability and lower G:F than those previously observed in the Depenbusch et al. (This Thesis: Chapter 2). Starch availability values may be skewed and may not represent what happens in vivo because particles were ground through a 2-mm screen and do not represent the large differences in particle size, surface area, bulk density, and structure between extruded diets and steam-flaked diets. It is plausible that the lower SME inputs in the current study resulted in less disruption of starch granules in the extruder barrel because of less friction, thereby decreasing in vivo digestibility compared with the high SME diets fed by Depenbusch et al. (This Thesis: Chapter 2). Another explanation could be structural changes in the extruded pellet produced with the high SME inputs used by Depenbusch et al. (This Thesis: Chapter 2). Pellets produced by Depenbusch et al. (This Thesis: Chapter 2) had a noticeably harder texture and may have resisted hydration and digestion in vivo.

These changes may have slowed the rate of digestion in vivo, resulting in a higher and perhaps more stable pH and leading to more efficient fermentation compared to the current study. Feed made in the current study with lower SME inputs may have resulted in a structure that did not restrict the rate of fermentation in the rumen, thereby causing a rapid reduction in ruminal pH and microbial activity. Potential differences in pellet structure (i.e., starch granules) between this study and that of Depenbusch et al. (This Thesis: Chapter 2) could be due to differences in particle size of the rolled corn processed through the extruder. Particle size of the rolled corn added to the extruder in the Depenbusch et al. (This Thesis: Chapter 2) study was smaller than in the current experiment (2,405 µm vs. 3,273 µm, respectively).

Carcass Data

Carcass data are summarized in Table 3-5. Carcass weight, dressed yield, LM area, KPH, 12th rib fat, and percentage of carcasses grading USDA Choice or better were not different ($P \geq 0.10$) among treatments. These results are supported by Depenbusch et al. (This Thesis: Chapter 2) in that extrusion processing did not affect carcass characteristics when compared with heifers fed steam-flaked corn diets. These results suggest that heifers were finished to the same degree regardless of grain processing method and roughage source.

Meat Quality Attributes

Meat quality attributes of steaks collected from yearling heifers are summarized in Table 3-6. Thiobarbituric acid reactive substances, Warner-Bratzler shear force, purge loss, and cooking loss of steaks were not different ($P \geq 0.10$) among treatments. These results are supported by Depenbusch et al. (This Thesis: Chapter 2) except that they observed a higher purge loss for steaks collected from heifers fed extruded corn diets. This study supports our hypothesis that extrusion processing would not have a deleterious effect on meat quality attributes.

Sensory Panel Characteristics

Sensory panel evaluations of steaks collected from yearling heifers are summarized in Table 3-7. Juiciness, flavor intensity, connective tissue amount, and off-flavor intensity were not different ($P \geq 0.06$) among treatments. A grain processing method × roughage interaction ($P = 0.03$) was observed for myofibrillar tenderness and overall tenderness of steaks. Steaks from heifers fed steam-flaked diets with alfalfa hay as the roughage source were tenderer than steaks collected from heifers fed steam-flaked diets with wheat straw as the roughage source. However, extruded diets containing alfalfa hay as the roughage source were less tender than steaks collected from heifers fed extruded diets containing wheat straw as a roughage source. This is interesting considering that Warner-Bratzler shear force was not different ($P \geq 0.68$) among treatments. Sensory panel tenderness and Warner-Bratzler shear force are expected to be inversely related. Owens and Gardner (1999) suggest that this relationship is not always the case and may be related to others factors that are perceived by humans such as juiciness. Grain processing can alter marbling (Owens and Gardner, 2000), which could alter beef flavor (Owens and Gardner, 1999), but flavor intensity was not different in the current study. Grain-fed beef has a different flavor (Griebenow et al., 1996) and juiciness (Bidner et al., 1981; Davis et al., 1981) compared with forage-fed beef. However, effects of roughage type and roughage level on sensory properties of beef have not been evaluated.

Retail Display Life

Instrumental color profiles of steaks during an 8-d retail display period are summarized in Table 3-8. Brightness (L*, 0 = black and 100 = white), redness (a*, positive values = red and negative values = green), hue angle $[(b^*/a^*)^{\tan^{-1}}]$, and reflectance ratio of 630 nm:580 nm wavelengths were not different ($P \geq 0.07$) among treatments. Yellowness (b*, positive values = yellow and negative values = blue) and saturation index $[(a^{*2} + b^{*2})^{-1/2}]$ were greater for steaks collected from heifers fed extruded corn diets compared with steaks collected from heifers fed steam-flaked corn diets. No treatment by day interaction ($P \geq 0.25$) was observed. However, during the 8-d retail display period, color deteriorated, as evidence by lower values for L*, a*, and b* ($P < 0.01$, quadratic effect of day). Similarly, saturation index and reflectance ratio of 630 nm:580 nm decreased ($P < 0.01$, quadratic effect of day) during the 8-d retail display period. Hue angle increased ($P = 0.01$, quadratic effect of day) for all treatments during the 8-d retail display period. Beef is a perishable food item and can undergo undesirable color changes during retail display (Giddings, 1974, 1977; Ledward, 1985). Owens and Gardner (1999) suggested a relationship between dietary concentrate level and lean color. However, we did not detect a difference in steak color between heifers fed finishing diets containing wheat straw (i.e., 82% concentrate) or alfalfa hay (i.e., 84% concentrate).

Overall Conclusions

A homogeneous pellet created by extrusion processing of a corn-based ration can be fed to feedlot heifers without deleterious effects on growth performance, carcass characteristics, and meat attributes. Extruding the entire ration into pellets did not improve growth performance of heifers when wheat straw was used as the roughage source. It is conceivable that extruding the entire diet into a homogeneous pellet may improve growth performance of cattle fed in a group setting rather than when fed to individually housed animals due to differences in eating behavior.

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Table 3-1. Composition of corn finishing diets

	Corn	
Item	Alfalfa	Straw
Corn	82.2	84.1
Corn steep liquor	6.0	6.0
Alfalfa hay	6.0	-
Wheat straw	-	2.7
Limestone	1.5	1.6
Urea	1.2	1.2
Soybean meal	-	1.3
Vitamin/mineral premix[1]	0.7	0.7
Supplement[2]	2.4	2.4
Chemical composition %		
DM	80.0	84.6
CP	14.0	14.0
NDF	10.0	10.0
Ca	0.70	0.70
P	0.37	0.38

[1] Formulated to provide the following per kg of total diet DM: 0.1 mg Co; 10 mg Cu; 0.6 mg I; 60 mg Mn; 0.3 mg Se; 60 mg Zn; and 2,200 IU vitamin A.

[2] Formulated to provide 0.5 mg melengestrol acetate (Pfizer Animal Health, Exton, PA), 300 mg monensin (Elanco Animal Health, Greenfield, IN), and 90 mg tylosin (Elanco Animal Health) per heifer daily.

Table 3-2. Extruder processing conditions of extruded corn diets containing either alfalfa hay or wheat straw

	Corn			
Item	Alfalfa	Straw	SEM	*P*-value
Corn, kg/h	317.2	324.2	0.21	-
Corn steep liquor, kg/h	39.9	40.1	0.06	-
Roughage[1], kg/h	19.2	8.5	0.35	-
Supplement, kg/h	19.9	25.1	0.09	-
Process water, kg/h	12.9	13.4	0.25	-
Product temperature, °C				
Barrel 3	84.0	84.8	1.56	0.73
Barrel 4	87.9	91.2	0.89	0.01
Die	112.8	112.5	0.60	0.71
Die pressure, bar	9.5	8.6	0.33	0.08
Extruder rpm	501.0	501.1	0.02	0.95
Torque, Nm	521.8	554.0	5.75	0.01
Torque, %	38.8	41.2	0.43	0.01
Power consumption, kWh	27.4	28.9	0.51	0.01
Specific mechanical energy, Wh/kg	67.5	71.2	0.91	0.01

[1] Either chopped alfalfa hay or chopped wheat straw

Table 3-3. Growth performance of yearling heifers fed steam-flaked corn or extruded corn diets containing either alfalfa hay or wheat straw as the roughage source

	Steam-flaked corn		Extruded corn			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
No. of heifers	12	12	12	12	-	-	-	-
Days on feed	133	133	133	133	-	-	-	-
Initial BW, kg	304.7	305.3	305.4	304.0	3.34	0.91	0.90	0.76
Final BW, kg	493.9	480.1	481.2	470.7	8.30	0.22	0.17	0.94
DMI, kg/d	8.4	7.9	8.4	7.8	0.23	0.65	0.01	0.73
ADG, kg/d	1.41	1.31	1.32	1.25	0.059	0.19	0.15	0.82
G:F, g/kg	166.6	164.0	157.2	160.8	4.69	0.13	0.89	0.45
Carcass-adjusted performance								
Final BW[1], kg	478.4	460.7	477.6	478.8	10.4	0.41	0.44	0.38
ADG, kg/d	1.31	1.16	1.30	1.32	0.080	0.39	0.46	0.33
G:F, g/kg	154.8	149.2	153.8	168.6	10.43	0.32	0.61	0.34

[1] Carcass-adjusted final BW calculated by dividing HCW by a common dress yield of 63.5%.

Table 3-4. In vitro dry matter disappearance and starch availability of steam-flaked corn or extruded corn finishing diets containing either alfalfa hay or wheat straw as the roughage source

	Steam-flaked corn		Extruded corn			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
IVDMD, %	60.4	59.9	63.5	62.7	1.09	0.01	0.27	0.75
Starch availability, %[1]	40.9	38.3	55.2	53.2	2.94	0.02	0.50	0.94

[1] Starch availability of complete diet according to enzymatic method described by Xiong et al., 1990.

Table 3-5. Carcass characteristics, yield grade, and quality grade of yearling heifers fed steam-flaked corn or extruded corn diets containing either alfalfa hay or wheat straw as the roughage source

	Steam-flaked corn		Extruded corn			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
HCW, kg	303.8	292.6	303.3	304.0	6.61	0.41	0.44	0.38
Dress yield, %	61.8	61.6	63.1	64.7	1.45	0.17	0.45	0.52
LM area, cm^2	75.3	73.1	72.5	73.3	2.68	0.62	0.80	0.59
KPH, %	2.25	2.25	2.04	2.21	0.123	0.30	0.49	0.49
12th rib fat, cm	1.14	1.02	1.32	1.32	0.145	0.10	0.67	0.64
USDA yield grade	2.67	2.25	2.67	2.83	0.24	0.24	0.61	0.24
USDA Choice or better, %	25.0	33.3	33.3	58.3	14.4	0.16	0.16	0.51
Marbling score[1]	390.8	370.0	376.7	430.8	23.1	0.32	0.48	0.11

[1] Slight = 300-399, Small = 400-499.

Table 3-6. Meat quality attributes of steaks collected from yearling heifers fed steam-flaked corn or extruded corn diets containing either alfalfa hay or wheat straw as the roughage source

	Steam-flaked corn		Extruded corn			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
TBARS[1]	0.75	0.77	0.90	0.78	0.118	0.49	0.68	0.62
Warner-bratzler shear force, kg	3.33	3.36	3.40	3.25	0.216	0.93	0.76	0.68
Purge loss, %	1.47	2.09	1.61	1.50	0.213	0.30	0.25	0.10
Cooking loss, %	23.77	23.53	23.48	24.48	0.745	0.62	0.52	0.38

[1] TBARS = thiobarbituric acid reactive substances (measured in mg of malonaldehyde/kg of steak) following an 8-d simulated retail display.

Table 3-7. Sensory panel evaluations[1] of steaks collected from yearling heifers fed steam-flaked corn or extruded corn diets containing either alfalfa hay or wheat straw as the roughage source

	Steam-flaked corn		Extruded corn			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
Myofibrillar tenderness	6.38	6.04	5.92	6.29	0.161	0.50	0.88	0.04
Juiciness	5.52	5.53	5.24	5.62	0.109	0.28	0.06	0.10
Flavor intensity	5.57	5.40	5.34	5.45	0.102	0.24	0.96	0.09
Connective tissue amount	7.10	6.87	6.91	6.93	0.120	0.55	0.45	0.34
Overall tenderness	6.55	6.18	6.13	6.41	0.151	0.51	0.85	0.04
Off-flavor intensity	7.33	7.42	7.17	7.17	0.153	0.16	0.73	0.76

[1] Scale: 1 = extremely tough, dry, bland flavor, abundant connective tissue, or extremely tough; 8 = extremely tender, juicy, intense flavor, no connective tissue, or tender.

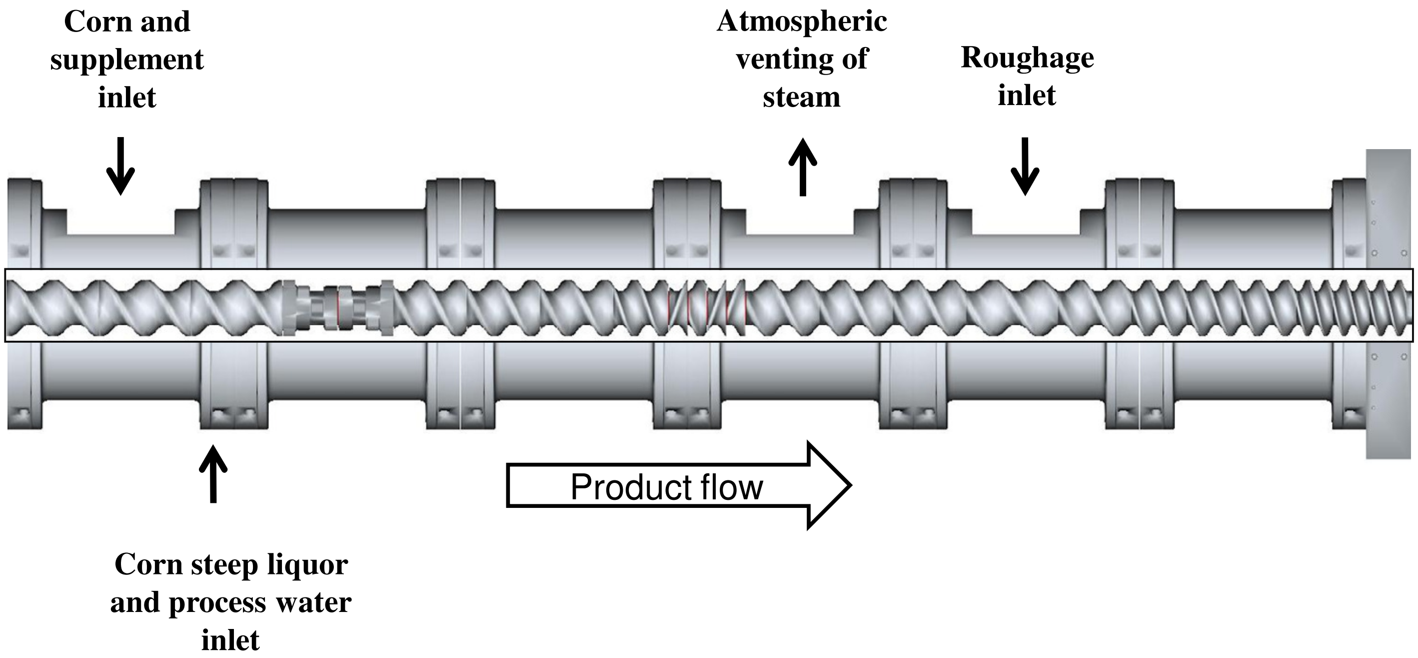
Table 3-8. Instrumental color profiles[1] of steaks collected from yearling heifers fed steam-flaked corn or extruded corn diets containing either alfalfa hay or wheat straw as the roughage source

	Steam-flaked corn		Extruded corn			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
d 0								
L*[2]	48.9	49.1	48.5	49.2	0.61	0.82	0.49	0.75
a*[2]	30.3	30.1	30.7	30.7	0.29	0.07	0.81	0.67
b*[2]	23.1	22.8	23.4	23.8	0.28	0.03	0.78	0.29
Hue angle[2]	37.3	37.2	37.3	37.7	0.21	0.20	0.48	0.27
Saturation index[2]	38.0	37.8	38.6	38.8	0.37	0.04	0.99	0.46
630:580[2]	4.9	4.8	5.1	5.0	0.12	0.09	0.46	0.99
d 3								
L*	47.2	47.9	47.1	47.5	0.59	0.59	0.30	0.76
a*	29.1	28.5	28.2	28.9	0.43	0.63	0.94	0.13
b*	22.2	21.8	21.5	22.4	0.36	0.88	0.53	0.08
Hue angle	37.3	37.4	37.3	37.7	0.19	0.52	0.20	0.32
Saturation index	36.6	35.8	35.5	36.6	0.55	0.72	0.77	0.10
630:580	4.5	4.2	4.3	4.4	0.14	0.92	0.53	0.17
d 5								
L*	44.7	44.6	44.4	44.6	0.77	0.90	0.98	0.84
a*	29.7	28.8	29.6	29.3	0.57	0.76	0.24	0.56
b*	23.7	22.9	23.4	23.5	0.40	0.75	0.35	0.31
Hue angle	38.6	38.6	38.4	38.8	0.22	0.99	0.56	0.37
Saturation index	38.0	36.8	37.7	37.5	0.68	0.75	0.26	0.45
630:580	5.1	4.8	5.1	4.9	0.22	0.92	0.20	0.71
d 7								
L*	44.4	44.1	44.2	44.3	0.76	0.97	0.90	0.79
a*	28.0	27.5	27.8	26.9	0.79	0.57	0.31	0.79
b*	22.4	21.9	22.2	21.8	0.52	0.71	0.42	0.91
Hue angle	38.7	38.6	38.6	39.2	0.30	0.44	0.38	0.27
Saturation index	35.9	35.2	35.6	34.6	0.93	0.62	0.35	0.90
630:580	4.5	4.4	4.5	4.1	0.24	0.45	0.34	0.69

[1] L* = brightness (0 = black, 100 = white), a* = redness (positive values = red, negative values = green), b* = yellowness (positive values = yellow, negative values = blue), hue angle = measure of true redness (0° = true red to 90° = true yellow), saturation index = vividness of color (higher values indicate a more vivid color, 630:580 = proportion of oxymyoglobin in the metmyoglobin pigment (lower numbers indicate less oxymyoglobin and more metmyoglobin).

[2] Quadratic effect of day, $P < 0.01$.

Figure 3-1. Extruder configuration and screw geometry



CHAPTER 4 - Extrusion processing of feedlot diets II: Effects of roughage source in extruded sorghum diets

ABSTRACT

Two experiments were conducted to evaluate the effects of extrusion processing of sorghum based diets on growth performance, carcass characteristics, and meat quality attributes of feedlot cattle. Crossbred yearling heifers (n = 47; 305 ± 3 kg initial BW) were fed individually in Exp. 1. Treatments were arranged as 2 × 2 factorial; factor 1 was grain processing method (steam-flaked or extruded) and factor 2 was roughage source (alfalfa hay or wheat straw). Heifers fed extruded sorghum diets consumed more feed ($P = 0.02$) and were less efficient ($P = 0.01$) than heifers fed steam-flaked sorghum diets. Carcass characteristics, except for USDA yield grade, were not different ($P \geq 0.06$) among treatments. Yield grade was lower and steaks had more connective tissue ($P \leq 0.04$, grain processing method × roughage source) for heifers fed steam-flaked sorghum-wheat straw diets and extruded sorghum-alfalfa hay diets compared with their counterparts. Steak color was not different ($P \geq 0.06$) among treatments during an 8-d retail display, but did deteriorate over time ($P = 0.01$; quadratic effect of day) regardless of treatment. It was concluded from this Exp. that the poor performance of heifers fed extruded sorghum diets may be due to the large particle size of sorghum used in the extrusion process. In Exp. 2, crossbred yearling heifers (n = 83; 328 ± 12 kg initial BW) were used to evaluate extruded pellets produced from fine ground (581µm) or coarse ground (1,264 µm) sorghum. Heifers fed extruded pellets produced from fine ground sorghum consumed less feed ($P = 0.04$) and had a higher G:F ($P = 0.03$) and apparent total tract digestibility for OM ($P = 0.02$) than heifers fed extruded pellets produced from coarse ground sorghum. However, carcass quality grade was lower ($P \leq 0.04$) for heifers fed extruded pellets produced from fine ground sorghum. Results from this study show that grinding sorghum to a smaller particle size prior to extrusion cooking improves G:F of heifers over extruded sorghum diets produced with larger particles of sorghum. Overall, it is clear that steam-flaking sorghum is superior to extrusion cooking of large particles (2,279 µm) of sorghum, but grinding the sorghum to a smaller particle size (581 µm) prior to extrusion cooking may improve the growth performance of cattle fed extruded sorghum diets compared with steam-flaked sorghum diets.

Key words: alfalfa hay, extrusion, meat, particle size, sorghum, wheat straw

INTRODUCTION

Corn is the most common cereal grain fed to feedlot cattle (Vasconcelos and Galyean, 2007) even though the starch content is similar to that of sorghum (Huntington, 1997). Difficulties in processing sorghum grain are one reason why corn is the preferred cereal grain to feed to finishing feedlot cattle in the High Plains. Alfalfa hay is one of the most commonly fed roughage sources used in feedlots (Vasconcelos and Galyean, 2007). Compared with alfalfa hay, wheat straw has lower nutritive value (NRC, 1996), but is an excellent source of effective NDF (NRC, 1996) and costs less than alfalfa hay. Selective sorting of feed ingredients by cattle fed total mixed rations can be a problem (Leonardi and Armentano, 2003, 2007; Leonardi et al., 2005; DeVries et al., 2005). Due to its physical structure, wheat straw may elicit a greater degree of feed segregation and hence poorer growth performance when compared with alfalfa hay. Increased use of sorghum grain and wheat straw by High Plains feedlots could reduce feed costs without having deleterious effects on beef quality. In addition, use of crops (i.e., sorghum) and crop biomass (i.e., wheat straw) that do not require irrigation in the High Plains region will decrease the water requirements per kilogram of beef produced (Beckett and Oltjen, 1993).

Extrusion processing of the entire ration into homogeneous pellets has improved G:F of feedlot cattle fed corn- and alfalfa hay-based diets (Depenbusch et al.; J. Anim. Sci.; companion manuscript). Sorghum grain may respond similarly to extrusion processing, and forming the entire diet into a homogeneous pellet will prevent diet sorting and may permit the use of roughage sources such as wheat straw. Our objectives were to (1) evaluate different roughage sources in extruded sorghum diets on growth performance, carcass characteristics, and meat quality attributes of feedlot heifers and to (2) evaluate different particle sizes of sorghum used in the extrusion process on growth performance, diet digestibility, and carcass characteristics of feedlot heifers.

MATERIALS AND METHODS

Exp. 1

Procedures used in this study were approved by the Kansas State University Institutional Animal Care and Use Committee.

Crossbred yearling heifers (n = 47; 305 ± 4 kg initial BW) were obtained from a common source and used in a randomized complete block study. Ten days prior to the start of the study, heifers were vaccinated against viral and clostridial diseases with Bovishield-4 and Fortress-7 (Pfizer Animal Health, Exton, PA), treated with Phoenectin pour-on (Phoenix Scientific Inc., St. Joseph, MO), and implanted with Revalor 200 (Intervet Inc., Millsboro, DE). Heifers were individually weighed on d 0. Animals were sorted from lightest to heaviest weight, with every 4 heifers constituting a weight block (n = 12). Starting with the lightest weight block, heifers were assigned randomly to 1 of 4 pens, and treatments were assigned accordingly. Treatments were arranged in a 2 × 2 factorial; factor 1 was grain processing method (steam-flaked or extruded) and factor 2 was roughage source (alfalfa hay or wheat straw). One heifer was removed from the study because of lameness. Heifers were housed in individual pens (i.e., 1 heifer/pen; 1.5 × 7.0 m) with a fence-line feed bunk (1.5 m). The feed bunk and half of the pen were covered by an overhead roof. Heifers were allowed ad libitum access to each of 4 adaptation diets leading to the final finishing diet (Table 4-1). Adaptation diets for the alfalfa hay treatments were fed for 5 d each; a portion of alfalfa hay was replaced with grain at each step. Similarly, adaption diets for the wheat straw treatment were fed for 5 d each but contained a fixed amount of wheat straw (i.e., 2.7%) with the balance of the roughage coming from alfalfa hay. A portion of the alfalfa hay was replaced with grain at each step. Diets were fed once daily at 0930 h.

Steam-flaking

Whole sorghum was steam treated for 50 min. Steam-treated sorghum was then passed through a 0.46- × 0.61-m flaking mill (pitch = 7 corrugations/cm, 0.80 mm round bottom vee corrugations; Ferrell-Ross Roll Manufacturing Inc., Hereford, TX) and processed to a bulk density of 335 g/L (26 lb/bushel). Steam-flaked sorghum had an average particle size of 2,466 ± 251 µm (n = 29) and a starch availability (Sindt et al., 2006) of 56.4 ± 9.9 (n = 36). Steam-flaked sorghum rations were prepared daily by mixing the appropriate amounts of each ingredient in a paddle mixer (model 970131-S5, H.C. Davis Sons Mfg. Co., Inc., Bonner Springs, KS) for 3 min.

Extrusion Processing

Extruded diets were processed in a 24:1 (length/diameter) corotating, fully intermeshing, twin-screw extruder (model BCTG-62, Bühler AG CH-9240, Uzwil, Switzerland). Extruder processing conditions are summarized in Table 4-2. Barrel and screw configurations are illustrated in Figure 4-1. Sorghum and supplement were dosed into the extruder with differential dosing units (model MSDA and model MSDE, respectively, Bühler AG, CH-9240, Uzwil, Switzerland) and automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland) at the appropriate rate (Table 4-2). Sorghum (2,279 ± 84 µm; n = 8) were processed prior to extrusion processing with a double-stack roller mill (23 cm × 46 cm, Rosskamp K roller mill; 2.4 corrugations per cm for top roll and 3.9 corrugations per cm for bottom roll). Roughage feeder rates were controlled by a loss-in-weight system with an automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland). Liquid feed rates were controlled by a flow meter (model Promag 53, Endress-Hauser, CH-4153, Reinach, Switzerland) and automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland). Extruded diets were prepared every other day.

In Vitro Dry Matter Disappearance

Samples from each treatment were randomly selected on 3 different days during the feeding period and used in an IVDMD study. Samples (n = 12) were dried for 24 h at 55°C and ground through a 2-mm screen with a Thomas-Wiley laboratory mill (Model 4 Thomas Scientific, Swedesboro, NJ). Laboratory DM was determined for each sample by drying samples in a forced-air convection oven for 16 h at 105°C. Dry weight of polyethylene centrifuge tubes (25 × 100 mm) was recorded, and 0.5 g of sample was added to each tube. Whole ruminal contents were obtained from a ruminally cannulated steer fed a finishing diet (83.4% dry-rolled corn, 5.6% alfalfa hay, 5.5% corn steep liquor, and 5.5% supplement) and strained through 8 layers of cheesecloth. A 30-mL mixture (i.e., 2:1 ratio) of McDougall’s buffer (El-Shazly and Hungate, 1965) and strained ruminal fluid were added to each of the tubes and incubated in a reciprocal shaking water bath (model 2872, Thermo Electron Corporation, Marietta, OH) at 39°C for 24 h. Tubes were flushed with CO_2 and sealed with a #5 rubber stopper equipped with a slit rubber policeman. After a 24-h incubation, tubes were removed from the water bath, immediately placed on ice to stop fermentation, and centrifuged (model J2-21 Beckman Centrifuge, Beckman Instruments, Palo Alto, CA) at 30,000 × g for 20 min. Supernatant was removed, and tubes were dried at 100°C for 12 h. Samples were analyzed in duplicate and replicated on 3 different days. Two blanks were prepared for each run by adding McDougall's buffer and ruminal fluid to tubes without substrate. Blank tubes were used to account for the DM in McDougall's buffer and ruminal fluid. Dry matter weight was then subtracted from total DM in the treatment tubes.

Starch Availability

Diet samples (n = 8; 2 per treatment) were dried for 24 h at 55°C and then ground through a 2-mm screen with a Thomas-Wiley laboratory mill (Model 4 Thomas Scientific, Swedesboro, NJ). Samples were submitted to a commercial laboratory (SDK Laboratories, Hutchinson, KS) for analysis of starch availability (Xiong et al., 1990).

Carcass Data Collection

On d 133, cattle were shipped 182 km to a commercial abattoir in Emporia, KS, and carcass data were collected upon arrival. Carcass weight was obtained at the time of harvest. Longissimus muscle area, subcutaneous fat thickness over the 12th rib, KPH, marbling score, USDA quality grades, and USDA yield grades were determined following a 24-h chill. Final BW was calculated by dividing HCW by a common dress yield of 63.5%.

Boneless strip loins (*Longissimus*; NAMP 180, n = 43) were collected from the right sides of the carcasses approximately 36 h postmortem. Identification tags for 4 boneless strip loins were lost during fabrication and could not be collected for subsequent evaluation of meat quality. Strip loins were kept cool in coolers, transported to the Kansas State University Meat Laboratory located in Manhattan, KS, and aged for 20 d at 0°C. After 20 d in the cooler, vacuum-packaged boneless strip loins were weighed. Strip loins were then removed from vacuum package, blotted dry with paper towels, and weighed. Vacuum packages were washed in hot, soapy water, air dried, and weighed. Percent purge loss was calculated as 100- [(weight of the dry strip loin / (weight of the vacuum packaged boneless strip loin – weight of the vacuum package)) × 100].

A knife and cutting board were used to cut 4 steaks (2.54-cm thick) starting at the caudal end of the strip loin. The first steak was discarded, and the next 2 steaks were vacuum packaged and frozen for subsequent analysis (i.e., Warner-Bratzler shear force and trained sensory panel evaluation). The fourth steak was immediately evaluated for color stability during an 8-d simulated retail display.

Retail Display Life

On d 20 postmortem, steaks were placed onto polystyrene thermal insulation trays (21 × 15 × 2 cm; Tenneco Packaging Specialty and Consumer Products, Lake Forest, IL) with meat pads (Dri-Loc Meat, Fish & Poultry Pads, Cryovac Sealed Air Corporation, Duncan, SC) and overwrapped with polyvinyl chloride film [MAPAC M (23,250 mL/m^2 per 24 h, 72 ga), Bordon Packaging and Industrial Products, North Andover, MA]. Packaged steaks were placed into a lighted display case (model DMF8, Tyler Refrigeration Corp., Niles, MI) for 8 d. Fluorescent lighting (2153 lux, 3000 K and CRI = 85, Bulb model 32T8/ADV830/Alto, Phillips, Bloomfield, NJ) was kept constant, and display case temperature was maintained at 1.2°C. Each d at 0650 and 1500 h, steaks were rotated to ensure random sample placement in the display case.

Steak color was analyzed instrumentally throughout the 8-d display for International Commission on Illumination L*, a*, and b* values (3.18-cm diam. Aperture, Hunter Associates Laboratory, Reston, VA). Hue angle (measurement of true redness; i.e., change from the true red axis; 0° = true red to 90° = true yellow), saturation index (measurement of the vividness of color; i.e., higher values indicate a more vivid color), and 630:580 nm reflectance ratio (greater values of 630:580 nm ratio indicate more redness) were calculated (AMSA, 1991). Each steak was scanned at 3 locations within the LM, and measurements were averaged to obtain a single value for each time point.

Fatty Acid Oxidation

Fatty acid oxidation was determined by using thiobarbituric acid reactive substances (TBARS). On d 8 of the retail display period, the top 1.3 cm of each displayed steak was removed, chopped into 1.3 × 1.3-cm cubes, and frozen at -20°C. Pieces were then pulverized in liquid N, combined with 15 mL of 7.2% perchloric acid solution, followed by 20 mL of cold deionized water to precipitate the protein and malonaldehyde. Samples were filtered through Whatman No. 2 filter papers (Whatman International Ltd., Maidstone, United Kingdom). The filtrate was combined with 5 mL of 0.02 *M* thiobarbituric acid reagent (1.4415 g of thiobarbituric acid and 500 mL of deionized water) and stored in complete darkness for 15 h. Milligrams of malonaldehyde per kg of steak were determined by absorbance readings of the sample on a spectrophotometer at 550 nm.

Sensory Panel Evaluation of Steaks

Sensory panel evaluations of LM steaks were conducted by a 7-member panel trained according to AMSA (1995) guidelines. Before product testing, panelists were oriented to flavor, texture, and aroma attributes of a sample to ensure consistent scores among panelists. Steaks were thawed and subsequently cooked to an internal temperature of 71°C in a DFG-102 CH-3 Blodgett modified broiler oven (GS Blodgett Company Inc., Burlington, VT). Each steak was turned once when internal temperature reached 58°C. Temperature was monitored by thermocouples attached to a Doric Minitrend 205 (Vas Engineering, San Francisco, CA) temperature monitor. Cooked steaks (2.54-cm thick) were cut into 1.27- × 1.27- × 2.54-cm pieces and served to panelist for evaluation. Steaks were evaluated for myofibrillar tenderness, juiciness, flavor intensity, connective tissue amount, overall tenderness, and off-flavor intensity in half-point increments using an 8-point scale (1 = extremely tough, dry, bland flavor, abundant connective tissue, or extremely tough; 8 = extremely tender, juicy, intense flavor, no connective tissue, or tender).

Warner-Bratzler Shear Force

Steaks were thawed and subsequently cooked to an internal temperature of 71°C in a DFG-102 CH-3 Blodgett modified broiler oven (GS Blodgett Company Inc., Burlington, VT). Each steak was turned once when internal temperature reached 58°C. Temperature was monitored by thermocouples attached to a Doric Minitrend 205 (Vas Engineering, San Francisco, CA) temperature monitor. Steaks were then cooled to room temperature and stored at 2°C overnight. Twenty-four hours later, eight 1.27-cm cores were removed from each steak parallel to the muscle fibers with a corer (G-R Manufacturing Co., Manhattan, KS) attached to an electric drill (Craftsman 3/8” electric drill, Sears, Hoffman Estates, IL). Each core was then sheared perpendicular to the muscle fibers with a Warner-Bratzler V-shaped blunt blade (G-R Manufacturing Co., Manhattan, KS) attached to a 50-kg load cell of an Instron Universal Testing

Machine (model 4201, Instron Corp., Canton, MA) with a crosshead speed of 250 mm/min. Average peak force for the 8 cores was calculated for each steak.

Cooking Loss

Percentage weight loss during cooking of steaks used for Warner-Bratzler shear force was estimated as 100-[(weight of cooked steak cooled to room temperature / weight of raw steak) × 100].

Statistical Analysis

Growth performance, carcass characteristics, purge loss, cooking loss, TBARS, and Warner-Bratzler shear force were analyzed statistically with the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC). Animal was the experimental unit, and weight block was used as the random effect. Effects of grain processing, grain source, roughage source, and all interactions were tested with an F test. Proportion of carcasses grading USDA Choice or better were analyzed with the binary option of the GLIMMIX procedure. Grain processing, roughage source, and all interactions were the fixed effects, and weight block was the random effect. Sensory panel data were analyzed with the MIXED procedure of SAS with grain processing, grain source, and roughage source as fixed effects and weight block and the day sensory panel was conducted as random effects. Color stability was analyzed with the MIXED procedure of SAS with day effect, grain processing, grain source, and roughage source as fixed effects. Weight block and weight block × grain processing × grain source × roughage source were used as random effects. Linear and quadratic contrasts were used to compare day effects. In vitro dry matter disappearance was analyzed with the MIXED procedure of SAS. Grain processing, grain source, roughage source, and all interactions were the fixed effects, and day on which the IVDMD experiment was conducted was the random effect. Significance level was set at $P \leq 0.05$.

Exp. 2

Crossbred yearling heifers (n = 83; 328 ± 12 kg initial BW) were obtained from a common source and used in a randomized complete block study. Eighteen days prior to the start of the study, heifers were vaccinated against viral and clostridial diseases with Bovishield-4 and Ultrabac-7 (Pfizer Animal Health, Exton, PA), treated with Phoenectin pour-on (Phoenix

Scientific Inc., St. Joseph, MO), and implanted with Revalor 200 (Intervet Inc., Millsboro, DE). On d -1, heifers were individually weighed, stratified by BW, blocked by BW, and assigned randomly to pens. On d 0, pens of heifers were sorted into respective pens and treatments were assigned randomly to pen. Treatments consisted of extruded sorghum diets produced with a fine and coarse ground sorghum (581 and 1,264 µm, respectively). Heifers were housed in concrete-surfaced pens (36 m^2) with a fence-line feed bunk (3.2 m). The feed bunk and half of the pen were covered by an corrugated steel roof. Heifers were allowed ad libitum access to each of 4 adaptation diets leading to the final finishing diet (Table 4-3). Adaptation diets were fed for 5 d each, and a portion of alfalfa hay was replaced with grain at each step. Heifers were supplemented with zilpaterol hydrochloride (75 mg per animal daily; Zilmax, Intervet, Schering-Plough Corporation, Millsboro, DE) for 21 d at the end of the feeding period, followed by a 3-d withdrawal period immediately prior to harvest. Individual pens of heifers were weighed immediately before being shipped to a commercial abattoir for harvest. Final BW was taken approximately 17 h after last feed delivery.

Extrusion Processing

Extruder processing conditions are summarized in Table 4-4. Barrel and screw configurations are illustrated in Figure 4-1. Extrusion processing methods were similar to that described in Exp. 1. Coarsely ground sorghum (1,264 ± 201 µm; n = 5) was processed with a double-stack roller mill [model N10 × 36, Ferrell-Ross, top roll contained 3.9 corrugations/cm with a 1.5 (inch per foot) spiral and bottom roll contained 6.3 corrugations/cm], and finely ground sorghum (581 ± 125 µm; n = 5) was processed with a hammer mill (model P-24204, Jacobson 40 horsepower).

Apparent Total Tract Diet Digestibility

Apparent DM digestibilities were determined over a 72-h period according to procedures described by Löest et al. (2001). Briefly, on d 116 of the finishing period, heifers were removed from their pens at 0800 h, pen surfaces were thoroughly cleaned, and all unconsumed feed was removed from feed bunks. Heifers were returned to their pens and fed their daily ration. After 24, 48, and 72 h, all feces were collected from each pen, weighed, thoroughly homogenized, and a representative sample (≈2%) was collected. Daily samples from each pen were composited, thoroughly homogenized, and frozen until later analysis. Daily feed refusals (if any) also were collected for each of the sampling days. Diet samples, feed refusals, and feces were analyzed for DM and OM content. Apparent DM and OM digestibility were calculated as: {[1 – (fecal DM output/DMI)] × 100} and {[1 – (fecal OM output/OMI)] × 100}, respectively.

Carcass Data Collection

Heifers were harvested in 2 groups based on weight blocks. On d 122 (3 pens per treatment) and d 182 (3 pens per treatment), heifers were shipped 467 km to a commercial abattoir in Holcomb, Kansas, at which time carcass data were collected by trained personnel. Carcass weight and incidence of liver abscesses were obtained at the time of harvest. Longissimus muscle area, subcutaneous fat thickness over 12th rib, and percentage KPH were obtained following a 48-h chill. In addition, marbling score, quality grades, and yield grades were acquired from USDA grading service personnel. Carcass-adjusted final BW was calculated by dividing carcass weight by a common dressing yield of 63.5%. Actual dressing yield was calculated by HCW/(0.96 × final BW).

Statistical Analysis

Growth performance, apparent total tract digestibility, and carcass characteristics were analyzed by using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit, and block was the random effect. Mean USDA quality grades, USDA yield grades, and liver abscess rates were calculated for each pen and analyzed by using the MIXED procedure of SAS with pen as the experimental unit and block as the random effect. In vitro dry matter disappearance was analyzed using the MIXED procedure of SAS. Treatment was the fixed effect, and day on which the IVDMD experiment was conducted was the random effect. Significance level was set at $P \leq 0.05$.

RESULTS AND DISCUSSION

Exp. 1

Finishing performance

Final BW and ADG were not different ($P \geq 0.16$; Table 4-5) between grain processing methods and roughage source. Heifers fed extruded diets consumed 9% more DM ($P = 0.01$) and were 13% more efficient ($P = 0.01$; live BW basis) than heifers fed steam-flaked sorghum diets.

Increased DMI for heifers fed extruded sorghum diets may indicate less extensive grain processing compared with steam-flaked sorghum diets (Reinhardt et al. 1997; Barajas and Zinn, 1998; Corona et al. 2005). Poorer performance of heifers fed extruded diets compared to those fed steam-flaked sorghum diets may be due to the large particle size (2,279 μm) of cracked sorghum entering the extruder. Whole unprocessed kernels were observed in sorghum going into the extruder. Particle size reduction of sorghum inside the extruder was minimal. This is evident by the whole unprocessed kernels of sorghum visualized in the final extruded pellet. Sorghum can be a difficult cereal to process due to its small physical size. In extruders, a fixed tolerance gap is engineered between the stationary outer barrel and rotating center screws. It is plausible that this gap was of sufficient size to allow whole sorghum kernels to pass through the extruder without any particle size reduction. Processing sorghum prior to feeding to cattle is of particular importance due to its protein matrix surrounding the starch and its negative effect on starch digestion (Rooney and Pflugfelder, 1986). Susceptibility of sorghum to starch digestion may have been limited because of the undisturbed protein matrix in the whole sorghum kernels. Compared with corn, sorghum may need to be preprocessed to a smaller particle size prior to extrusion or extruder parameters (i.e., increased shear force in the extruder) will need to be changed to increase the friction, cooking, and disruption of the protein matrix. Even though we speculated that the degree of grain processing was less for the extruded sorghum diets compared with the steam-flaked sorghum diets, IVDMD and starch availability (Table 4-6) were not different ($P \geq 0.08$) between grain processing methods and roughage source. This is difficult to explain in light of the increased DMI and poorer G:F of heifers fed extruded diets. One plausible explanation for these contradicting data is the fact that finishing diets were ground through a 2-mm screen prior to IVDMD and starch availability analysis. It is unlikely that the heifers fed the extruded sorghum diets reduced the particle size of the sorghum kernel to that same degree by chewing or rumination. Grinding the diets prior to lab analysis may have equalized the samples in respect to starch availability and IVDMD unlike what was observed in vivo for the heifers fed extruded pellets.

Carcass data

Carcass data are summarized in Table 4-7. Carcass weight, dressed yield, LM area, KPH, 12th rib fat, marbling score, and percentage of carcasses grading USDA Choice or better were not different ($P \geq 0.16$) among treatments. A grain processing method × roughage source interaction ($P \leq 0.02$) was observed for USDA yield grade. These results are supported by the tendency ($P = 0.06$) for a grain processing method × roughage source interaction for 12th rib fat thickness. Heifers fed steam-flaked sorghum-wheat straw diets and extruded sorghum-alfalfa hay diets were fatter than their counterparts. Grain processing is generally thought to increase LM area, and 12th rib fat thickness but decrease marbling score and quality grade (Owens and Gardner, 1999). In the current study, different grain processing methods did not affect carcass attributes. The interaction for 12th rib fat and USDA yield grade may reflect a shift in starch digestion from the rumen to the small intestine with more starch escaping the rumen leading to less fat deposition (Owens and Gardner, 1999).

Meat quality attributes

Meat quality attributes of steaks collected from yearling heifers are summarized in Table 4-8. Warner-Bratzler shear force, purge loss, and cooking loss of steaks were not different ($P \geq 0.08$) between grain processing methods and roughage source. Heifers fed steam-flaked sorghum diets had higher ($P = 0.02$) TBARS than heifers fed extruded sorghum diets.

Sensory panel characteristics

Sensory panel evaluations of steaks collected from yearling heifers are summarized in Table 4-9. Juiciness, flavor intensity, and off-flavor intensity were not different ($P \geq 0.30$) among treatments. A grain processing method × roughage source interaction ($P \leq 0.03$) was observed for connective tissue amount. This corresponds with a tendency for a grain processing method × roughage source interaction ($P \leq 0.08$) for myofibrillar and overall tenderness. Steaks from heifers fed steam-flaked diets with alfalfa hay as the roughage source had less connective tissue and were more tender than steaks from heifers fed steam-flaked diets with wheat straw as the roughage source. However, extruded diets containing alfalfa hay as the roughage source had more connective tissue and a lower overall tenderness rating compared with steaks from heifers fed extruded diets containing wheat straw as the roughage source. This is interesting considering that Warner-Bratzler shear force was not different ($P \geq 0.21$) between treatments. Sensory panel tenderness and Warner-Bratzler shear force are expected to be inversely related. Owens and Gardner (1999) suggest that this relationship is not always the case and may be related to others factors that are perceived by humans such as juiciness. Grain processing can alter marbling

(Owens and Gardner, 2000), which could alter beef flavor (Owens and Gardner, 1999), but flavor intensity was not different in the current study. Grain-fed beef has a different flavor (Griebenow et al., 1996) and juiciness (Bidner et al., 1981; Davis et al., 1981) compared with forage-fed beef. However, effects of roughage type and level on sensory properties of beef have not been evaluated. Grain type has been shown to have no influence on sensory properties of beef (Brandt et al., 1992; Mandell et al., 1997).

Retail display life

Instrumental color profiles of steaks during an 8-d retail display period are summarized in Table 4-10. Brightness (L*, 0 = black and 100 = white); redness (a*, positive values = red and negative values = green); and yellowness (b*, positive values = yellow and negative values = blue) were not different ($P \geq 0.06$) among treatments. In addition, calculated hue angle $[(b^*/a^*)^{\tan^{-1}}]$, saturation index $[(a^{*2} + b^{*2})^{-1/2}]$, and reflectance ratio of 630 nm:580 nm wavelengths were not different ($P \geq 0.06$) between treatments. However, during the 8-d retail display period, color deteriorated, as evidence by lower values for L*, a*, and b* ($P < 0.01$, quadratic effect of day), regardless of treatment. Similarly, saturation index and reflectance ratio of 630 nm:580 nm decreased ($P < 0.01$, quadratic effect of day) during the 8-d retail display period. Hue angle increased ($P = 0.01$, quadratic effect of day) for all treatments during the 8-d retail display period. These results support the fact that beef is a perishable food item and can undergo undesirable color changes during retail display (Giddings, 1974, 1977; Ledward, 1985).

Overall Conclusion

In the current Exp., steam-flaking was a superior grain processing method compared with extrusion processing of sorghum based diets. The poorer growth performance associated with the extruded diets may be a result of the large particle size of sorghum (i.e., 2,279 µm) used in the manufacturing process. Extrusion processing of sorghum may require that the kernels be ground to a smaller particle size and thus may elicit equal or possibly superior growth performance as steam-flaking sorghum.

Exp. 2

Finishing performance

Final BW and ADG were not different ($P \geq 0.47$; Table 4-11) between treatments. Heifers fed extruded diets made from fine ground sorghum consumed 9% less ($P = 0.04$) DM and were 15% more efficient ($P = 0.03$) than heifers fed extruded diets made from coarse ground sorghum. In addition, extruded diets made from fine ground sorghum had a higher ($P = 0.02$; Table 4-12) apparent total tract digestibility of OM and tended to have a higher ($P = 0.08$) apparent total tract digestibility of DM than extruded diets made from coarse ground sorghum. Starch availability and IVDMD were not different ($P \geq 0.25$) between treatments.

Results from this experiment suggests that grinding sorghum to a smaller particle size improved G:F and diet digestibility. Unlike the extruded pellets fed in Exp. 1, only minimal amounts of whole kernels of sorghum were observed in the pellets made from coarse ground sorghum. However, particle size of the fine ground sorghum was small enough that no whole kernels were observed in the final extruded pellet. Whole sorghum is resistant to digestion due to its hard and dense peripheral endosperm and the associated protein matrix (Rooney and Pflugfelder, 1986). Therefore, eliminating the whole kernels fed to cattle will improve the nutrient availability of the diet and thereby supporting greater growth and efficiency. This is the likely explanation for the improved G:F of heifers fed fine ground sorghum as compared with coarse ground sorghum. Efforts to optimize the cooking of the sorghum inside the extruder may still require changes to screw geometry (i.e., shape of screw which directly influences retention time and friction inside the extruder) and extruder parameters compared with grains with a less resistant peripheral endosperm (i.e., corn).

Carcass data

Carcass weight, dress yield, LM area, KPH, 12th rib fat, and liver abscesses were not different ($P \geq 0.43$; Table 4-13) between treatments. Heifers fed extruded diets made from coarse ground sorghum had more ($P = 0.04$; Table 4-14) USDA Choice or greater carcasses and fewer ($P = 0.01$) carcasses grading USDA Select than heifers fed extruded diets made from fine ground sorghum. However, marbling score and USDA yield grades were not different ($P \geq 0.45$) between heifers fed extruded diets made from coarse ground or finely ground sorghum. Differences in quality grade between heifers fed extruded diets made from coarse ground or fine ground sorghum may be related to site of starch digestion. Owens and Gardner (2000) reported that grain processing method can influence carcass measurements such as quality grade. Cattle fed steam-flaked corn (i.e., high ruminal digestibility of starch) usually have a lower carcass quality than cattle fed dry-rolled corn finishing diets (i.e., lower ruminal digestibility of starch, Owens and Gardner, 2000). These differences are presumably due to increased starch presented to the small intestine of cattle fed dry-rolled corn. Starch (i.e., glucose) is believed to be a precursor for intramuscular fat deposition (Smith and Crouse, 1984). In the current study, more starch may be presented to the small intestine of heifers fed extruded diets made from coarse ground sorghum compared with fine ground sorghum, resulting in increased accretion of intramuscular adipose.

Overall Conclusion

Sorghum is a difficult grain to process regardless of grain processing method used. Extrusion processing is not an efficient means of reducing particle size of grains. Due to its resistant peripheral endosperm and small physical size, sorghum grain needs to be processed to a small particle size thereby eliminating whole unprocessed kernels in the extruded pellet. Reducing particle size of sorghum prior to extrusion cooking improved G:F and digestibility while reducing the carcasses grading USDA Choice. These results suggests that ruminal digestion was greater for feedlot heifers fed extruded diets made from fine ground sorghum compared with heifers fed diets made from coarse ground sorghum.

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Table 4-1. Composition of sorghum finishing diets containing either alfalfa hay or wheat straw as the roughage source (Exp. 1)

	Sorghum	
Item	Alfalfa	Straw
Sorghum	82.2	84.1
Corn steep liquor	6.0	6.0
Alfalfa hay	6.0	-
Wheat straw	-	2.7
Limestone	1.5	1.6
Urea	1.2	1.2
Soybean meal	-	1.3
Vitamin/mineral premix[1]	0.7	0.7
Supplement[2]	2.4	7.2
Chemical composition %		
DM	80.0	80.0
CP	14.0	14.0
NDF	10.0	10.0
Ca	0.72	0.72
P	0.41	0.41

[1] Formulated to provide the following per kg of total diet DM: 0.1 mg Co; 10 mg Cu; 0.6 mg I; 60 mg Mn; 0.3 mg Se; 60 mg Zn; and 2,200 IU vitamin A.

[2] Formulated to provide 0.5 mg melengestrol acetate (Pfizer Animal Health, Exton, PA), 300 mg monensin (Elanco Animal Health, Greenfield, IN), and 90 mg tylosin (Elanco Animal Health) per heifer daily.

Table 4-2. Extruder processing conditions of extruded sorghum diets containing either alfalfa hay or wheat straw as the roughage source (Exp. 1)

	Sorghum			
Item	Alfalfa	Straw	SEM	*P*-value
Sorghum, kg/h	316.5	324.0	0.21	-
Corn steep liquor, kg/h	40.3	40.3	0.06	-
Roughage, kg/h	20.2	8.5	0.35	-
Supplement, kg/h	20.3	25.2	0.09	-
Process water, kg/h	12.0	12.1	0.25	-
Product temperature, °C				
Barrel 3	80.9	83.0	1.64	0.37
Barrel 4	87.4	89.5	0.88	0.15
Die	113.1	115.2	0.77	0.05
Die pressure, bar	10.5	9.4	0.33	0.02
Extruder rpm	500.9	500.8	0.13	0.86
Torque, Nm	489.8	505.9	7.88	0.15
Torque, %	36.4	37.8	0.59	0.11
Power consumption, kWh	25.7	26.5	0.41	0.15
Specific mechanical energy, Wh/kg	63.1	65.5	1.03	0.21

Table 4-3. Composition of extruded sorghum diets produced with different particle sizes of sorghum (Exp. 2)

	Particle size of sorghum prior to extrusion	
Item	Fine[1]	Coarse[2]
Sorghum	82.2	82.3
Ground alfalfa hay	5.7	5.6
Corn steep liquor	6.2	6.0
Limestone	1.5	1.6
Urea	1.2	1.3
Vitamin/mineral premix[3]	0.7	0.7
Supplement[4]	2.5	2.5
Chemical composition %		
CP	15.8	15.8
NDF	14.0	14.0
Calcium	0.63	0.63
Phosphorus	0.33	0.32
Potassium	0.78	0.78
Crude fat	2.55	2.55

[1] Fine = finely ground sorghum, 581 µm.

[2] Coarse = coarsely ground sorghum, 1,264 µm.

[3] Formulated to provide the following per kg of total diet DM: 0.1 mg Co, 10 mg Cu, 0.6 mg I, 60 mg Mn, 0.3 mg Se, 60 mg Zn, and 2,200 IU vitamin A.

[4] Formulated to provide 0.5 mg melengestrol acetate (Pfizer Animal Health, Exton, PA), 300 mg monensin (Elanco Animal Health, Greenfield, IN), and 90 mg tylosin (Elanco Animal Health) per heifer daily.

Table 4-4. Extruder processing conditions of extruded sorghum diets produced with different particle sizes of sorghum (Exp. 2)

	Particle size of sorghum prior to extrusion			
Item	Fine[1]	Coarse[2]	SEM	*P*-value
Grain feeder, kg/h	435.7	437.4	0.61	-
Corn steep liquor feeder, kg/h	47.1	45.7	4.64	-
Alfalfa hay feeder, kg/h	30.7	30.4	0.93	-
Supplement feeder, kg/h	28.5	28.6	0.10	-
Process water, kg/h	39.7	39.7	0.25	-
Product temperature, °C				
Barrel 3	72.5	61.5	1.29	0.01
Barrel 4	64.7	59.9	0.87	0.01
Die	101.7	89.6	2.46	0.01
Die pressure, bar	8.1	7.4	0.12	0.08
Extruder rpm	500.7	500.7	0.04	0.18
Torque, Nm	565.1	441.0	19.41	0.01
Torque, %	42.0	32.8	1.44	0.01
Power consumption, kW	29.6	23.1	1.02	0.01
Specific mechanical energy, Wh/kg	51.4	40.1	1.94	0.01

[1] Fine = finely ground sorghum, 581 µm.

[2] Coarse = coarsely ground sorghum, 1,264 µm.

Table 4-5. Growth performance of yearling heifers fed steam-flaked sorghum or extruded sorghum diets containing either alfalfa hay or wheat straw as the roughage source (Exp. 1)

	Steam-flaked sorghum		Extruded sorghum			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
No. of heifers	11	12	12	12	-	-	-	-
Days on feed	133	133	133	133	-	-	-	-
Initial BW, kg	305.1	304.9	304.9	304.0	3.61	0.87	0.86	0.93
Final BW, kg	496.0	486.3	486.8	472.1	8.87	0.20	0.18	0.79
DMI, kg/d	8.6	8.5	9.8	8.9	0.31	0.02	0.10	0.22
ADG, kg/d	1.43	1.36	1.37	1.26	0.060	0.18	0.16	0.79
G:F, g/kg	166.4	160.7	140.0	143.5	3.97	0.01	0.78	0.26
Carcass-adjusted performance								
Final BW[1], kg	485.7	483.9	479.0	476.3	8.76	0.37	0.80	0.91
ADG, kg/d	1.36	1.35	1.30	1.30	0.069	0.42	0.86	0.95
G:F, g/kg	158.2	158.8	133.8	146.7	9.75	0.06	0.48	0.48

[1] Carcass-adjusted final BW calculated by dividing HCW by a common dress yield of 63.5%.

Table 4-6. In vitro dry matter disappearance and starch availability or steam-flaked sorghum or extruded sorghum finishing diets containing either alfalfa hay or wheat straw as the roughage source (Exp. 1)

	Steam-flaked sorghum		Extruded sorghum			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
IVDMD, %	57.8	60.2	58.9	58.5	0.81	0.69	0.24	0.08
Starch availability, %[1]	57.2	55.0	58.9	57.3	4.03	0.65	0.67	0.94

[1] Starch availability of complete diet according to enzymatic method described by Xiong et al. (1990).

Table 4-7. Carcass characteristics, yield grade, and quality grade of yearling heifers fed steam-flaked sorghum or extruded sorghum diets containing either alfalfa hay or wheat straw as the roughage source (Exp. 1)

	Steam-flaked sorghum		Extruded sorghum			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
HCW, kg	308.4	307.3	304.2	302.5	5.56	0.37	0.80	0.91
Dress yield, %	62.4	63.6	62.7	64.3	1.45	0.17	0.45	0.52
LM area, cm^2	74.6	73.4	71.0	74.4	2.22	0.57	0.62	0.32
KPH, %	2.36	2.29	2.33	2.25	0.144	0.81	0.60	0.97
12th rib fat, cm	1.11	1.31	1.33	1.01	0.136	0.75	0.63	0.06
USDA yield grade	2.55	2.83	3.00	2.25	0.23	0.70	0.25	0.02
USDA Choice or better, %	36.4	50.0	58.3	33.4	14.4	0.89	0.61	0.16
Marbling score[1]	402.7	420.8	425.0	384.2	20.4	0.73	0.59	0.16

[1] Slight = 300-399, Small = 400-499.

Table 4-8. Meat quality attributes of steaks collected from yearling heifers fed steam-flaked sorghum or extruded sorghum diets containing either alfalfa hay or wheat straw as the roughage source (Exp. 1)

	Steam-flaked sorghum		Extruded sorghum			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
TBARS[1]	0.97	0.92	0.66	0.58	0.140	0.02	0.64	0.93
Warner-bratzler shear force, kg	3.04	3.42	3.44	3.16	0.251	0.78	0.85	0.20
Purge loss, %	2.02	1.40	1.55	1.34	0.253	0.96	0.52	0.08
Cooking loss, %	24.49	23.84	25.30	23.02	0.992	0.95	0.13	0.42

[1] TBARS = thiobarbituric acid reactive substances (measured in mg of malonaldehyde/kg of steak) following an 8-d simulated retail display.

Table 4-9. Sensory panel evaluations[1] of steaks collected from yearling heifers fed steam-flaked sorghum or extruded sorghum diets containing either alfalfa hay or wheat straw as the roughage source (Exp. 1)

	Steam-flaked sorghum		Extruded sorghum			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
Myofibrillar tenderness	6.40	6.18	6.01	6.45	0.206	0.82	0.68	0.07
Juiciness	5.34	5.37	5.45	5.33	0.121	0.81	0.69	0.45
Flavor intensity	5.34	5.50	5.32	5.33	0.098	0.30	0.36	0.46
Connective tissue amount	7.21	6.93	6.84	7.07	0.131	0.31	0.99	0.04
Overall tenderness	6.55	6.28	6.17	6.51	0.197	0.71	0.84	0.08
Off-flavor intensity	7.26	7.26	7.21	7.44	0.117	0.57	0.33	0.34

[1] Scale: 1 = extremely tough, dry, bland flavor, abundant connective tissue, or extremely tough; 8 = extremely tender, juicy, intense flavor, no connective tissue, or tender.

Table 4-10. Instrumental color profiles[1] of steaks collected from yearling heifers fed steam-flaked sorghum or extruded sorghum diets containing either alfalfa hay or wheat straw as the roughage source (Exp. 1)

	Steam-flaked sorghum		Extruded sorghum			*P*-value		
Item	Alfalfa	Straw	Alfalfa	Straw	SEM	Process	Roughage	Process × Roughage
d 0								
L*[2]	49.4	48.6	49.3	48.9	0.86	1.06	0.91	0.84
a*[2]	30.0	30.2	30.4	28.6	0.49	0.62	0.26	0.09
b*[2]	23.0	23.2	23.4	21.7	0.48	0.61	0.33	0.10
Hue angle[2]	37.4	37.5	37.6	37.0	0.27	0.32	0.65	0.30
Saturation index[2]	37.8	38.1	38.3	35.9	0.66	0.85	0.28	0.09
630:580[2]	4.9	5.0	4.9	4.6	0.15	0.17	0.28	0.16
d 3								
L*	46.9	47.7	47.9	46.7	0.66	0.71	0.99	0.18
a*	29.0	29.1	29.4	28.5	0.41	0.37	0.85	0.15
b*	22.1	22.3	22.7	21.6	0.34	0.32	0.95	0.06
Hue angle	37.4	37.4	37.7	37.2	0.21	0.24	0.92	0.21
Saturation index	36.4	36.6	37.2	35.8	0.51	0.47	0.89	0.09
630:580	4.5	4.4	4.5	4.4	0.14	0.14	0.95	0.95
d 5								
L*	45.2	44.5	45.1	45.0	0.89	1.00	0.83	0.76
a*	28.6	29.1	30.2	28.4	0.58	0.58	0.47	0.06
b*	22.9	23.1	24.0	22.5	0.44	0.47	0.65	0.09
Hue angle	38.7	38.4	38.4	38.3	0.24	0.27	0.51	0.64
Saturation index	36.7	37.2	38.6	36.2	0.71	0.73	0.52	0.06
630:580	4.7	4.9	5.2	4.8	0.21	0.21	0.31	0.12
d 7								
L*	44.4	44.1	44.6	44.6	0.91	1.03	0.72	0.87
a*	26.6	26.9	28.1	27.1	0.87	0.95	0.38	0.50
b*	21.4	21.6	22.4	21.6	0.57	0.62	0.45	0.40
Hue angle	38.9	38.8	38.9	38.5	0.37	0.42	0.68	0.75
Saturation index	34.1	34.5	35.9	34.7	1.02	1.11	0.39	0.46
630:580	4.1	4.2	4.6	4.4	0.25	0.26	0.16	0.49

[1] L* = brightness (0 = black, 100 = white), a* = redness (positive values = red, negative values = green), b* = yellowness (positive values = yellow, negative values = blue), hue angle = measure of true redness (0° = true red to 90° = true yellow), saturation index = vividness of color (higher values indicate a more vivid color, 630:580 = proportion of oxymyoglobin in the metmyoglobin pigment (lower numbers indicate less oxymyoglobin and more metmyoglobin).

[2] Quadratic effect of d, $P < 0.01$.

Table 4-11. Growth performance or yearling heifers fed extruded sorghum diets produced with different particle sizes of sorghum (Exp. 2)

	Particle size of sorghum prior to extrusion			
Item	Fine[1]	Coarse[2]	SEM	*P*-value
No. of pens (heifers)	6 (41)	6 (42)	-	-
Days on feed	169	169	-	-
Initial BW, kg	328	329	12.5	0.25
Final BW, kg	488	483	9.5	0.60
DMI, kg/d	7.4	8.1	0.39	0.04
ADG, kg/d	0.95	0.91	0.07	0.52
G:F, g/kg	130.4	111.8	6.85	0.03
Carcass-adjusted performance				
Final BW[3], kg	490	481	10.3	0.54
ADG, kg/d	0.96	0.90	0.07	0.47
G:F, g/kg	131.8	111.4	7.81	0.03

[1] Fine = finely ground sorghum, 581 µm.

[2] Coarse = coarsely ground sorghum, 1,264 µm.

[3] Carcass adjusted final BW calculated by dividing HCW by a common dress yield of 63.5%.

Table 4-12. Apparent total tract digestibility, IVDMD, and starch availability of extruded sorghum diets produced with different particle sizes of sorghum fed to yearling heifers (Exp. 2)

	Particle size of sorghum prior to extrusion			
Item	Fine[1]	Coarse[2]	SEM	*P*-value
Apparent total tract digestibility, %				
DM	76.3	72.0	2.25	0.08
OM	79.6	74.5	2.00	0.02
IVDMD, %	66.8	63.4	3.25	0.25
Starch availability, %[3]	34.0	34.5	1.89	0.86

[1] Fine = finely ground sorghum, 581 µm.

[2] Coarse = coarsely ground sorghum, 1,264 µm.

[3] Starch availability determined by procedures described by Xiong et al. (1990).

Table 4-13. Carcass characteristics of yearling heifers fed extruded sorghum diets produced with different particle sizes of sorghum (Exp. 2)

	Particle size of sorghum prior to extrusion			
Item	Fine[1]	Coarse[2]	SEM	*P*-value
HCW, kg	311	306	6.6	0.54
Dress yield, %	63.7	63.3	0.03	0.83
LM area, cm^2	87.1	86.5	2.26	0.71
KPH, %	2.12	2.12	0.17	0.98
12th rib fat, cm	1.22	1.14	0.13	0.63
Liver abscess, %	9.5	4.8	4.20	0.43

[1] Fine = finely ground sorghum, 581 µm.

[2] Coarse = coarsely ground sorghum, 1,264 µm.

Table 4-14. USDA yield and quality grades of yearling heifers fed extruded sorghum diets produced with different particle sizes of sorghum (Exp. 2)

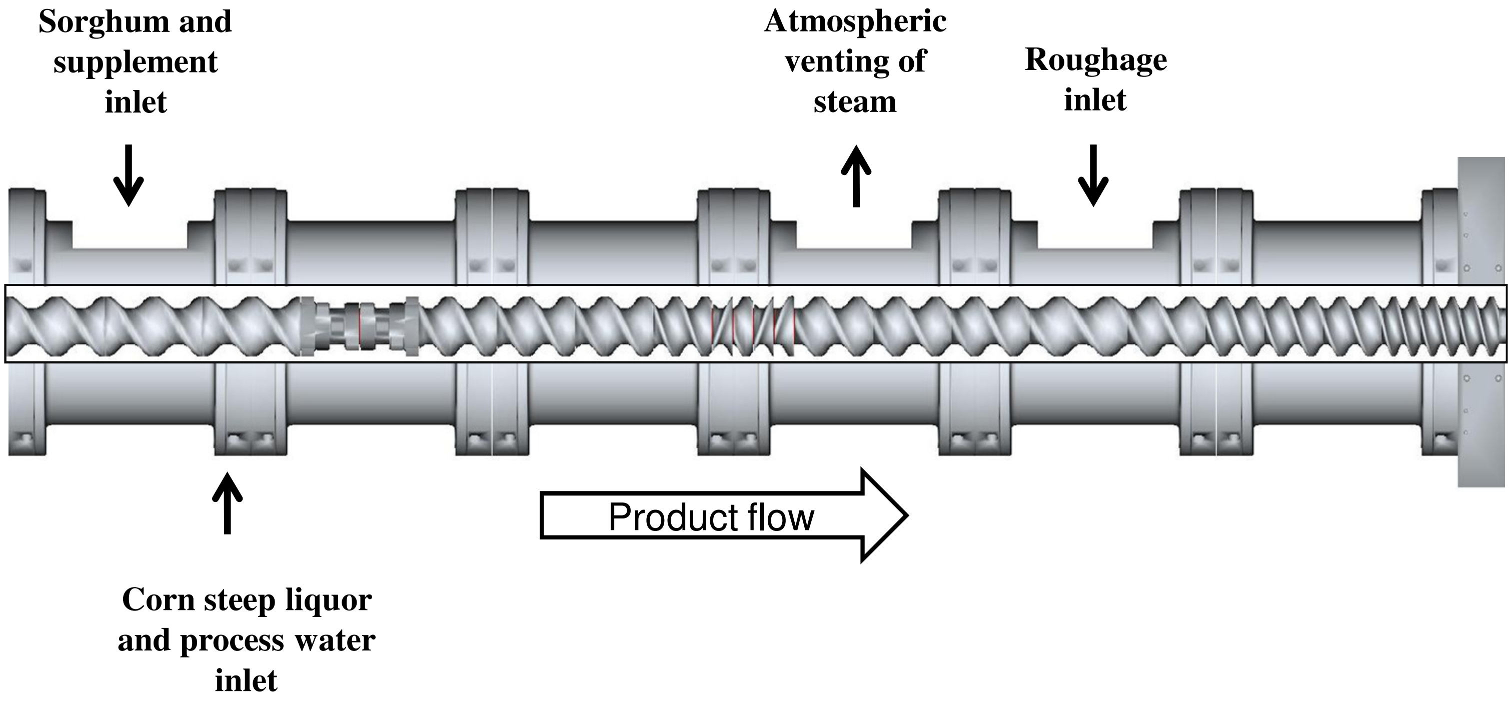
	Particle size of sorghum prior to extrusion			
Item	Fine[1]	Coarse[2]	SEM	*P*-value
Marbling score[3]	426	427	19.85	0.95
USDA quality grade, %				
Choice or greater	49.2	73.8	2.10	0.04
Select	48.4	16.7	9.41	0.01
Standard	2.4	9.5	2.80	0.07
USDA yield grade				
YG 1, %	11.9	11.9	5.94	0.99
YG 2, %	58.3	50.0	7.91	0.45
YG 3, %	27.0	33.3	8.54	0.54
YG 4 and 5, %	2.8	4.8	4.60	0.76
Average	2.2	2.3	0.16	0.54

[1] Fine = finely ground sorghum, 581 µm.

[2] Coarse = coarsely ground sorghum, 1,264 µm.

[3] Marbling score: 400 = small.

Figure 4-1. Extruder configuration and screw geometry



CHAPTER 5 - Extrusion processing of feedlot diets IV: Optimal level of process water in extruded corn diets

Abstract

Crossbred yearling heifers (n = 195; 328 ± 12 kg initial BW) were used in a randomized complete block study. Five extruded corn and alfalfa hay diets were manufactured with different levels of process water added to the extruder (4, 6, 8, 10, and 12%, respectively). Extruded diets were processed in a 24:1 (length/diameter) corotating, fully intermeshing, twin-screw extruder (model BCTG-62, Bühler AG CH-9240, Uzwil, Switzerland). Increasing the amount of water added to the extruder decreased ($P = 0.01$) process temperatures and pressure inside the extruder barrel. Motor torque, power consumption, and electricity usage per kg of feed produced all were lower ($P \leq 0.04$; quadratic) as levels of process water was increased from 4% to 12%. Dry matter intake was not different ($P \geq 0.62$) among treatments. Final BW, ADG, and G:F (live-weight basis) decreased ($P \leq 0.06$; linear) as amount of process water increased. Carcass-adjusted BW, ADG, G:F, starch availability, and apparent total tract digestibility were not different ($P \geq 0.14$) among treatments. However, IVDMD improved ($P = 0.05$; linear) as process water was increased. Carcass weight, dress yield, LM area, KPH, 12th rib fat, and marbling score were not different ($P \geq 0.14$) among treatments. A cubic effect ($P \leq 0.03$) of water addition was observed for carcasses grading USDA select and standard and a quadratic effect was observed for USDA yield grade 2 carcasses. A quadratic effect of water level was not observed for growth performance, thus suggesting that the optimal level is at or below 4% water. It was clear from this study that increasing the amount of process water reduced electrical usage but, had a negative effect on growth performance of feedlot cattle.

Key words: cattle, corn, extrusion, feedlot, growth, mechanical energy

INTRODUCTION

Feed related costs, including grain processing, represent the majority of the total cost of gain for feedlot cattle. Grain processing is essential to maximizing growth rate and efficiency of feedlot cattle. Improving energy availability should be the main goal of grain processing (Owens et al., 1997). Various grain processing methods have been used to improve digestibility of grains (Rowe et al., 1999). Extrusion cooking is an old technology used by many industries (e.g., pet food, fish food, and human food; Riaz, 2000). Less information is available on extrusion cooking of feed for feedlot cattle (McLaren and Matsushima, 1971; Gaebe et al., 1998; Depenbusch et al.; companion manuscripts). Extrusion processing makes it possible to cook or "gelatinize" the starch portion of the grain, mix it with other ingredients, and agglomerate them into a homogenous pellet that cattle cannot segregate. Results from studies by Depenbusch et al. (J. Anim. Sci. companion manuscripts) in which they fed extruded corn diets to finishing feedlot diets have been mixed. Improvements in G:F have ranged from 0% to 15% compared with steam-flaked corn diets. Extrusion cooking is a continuous process where the product is heated through the friction generated as the product is sheared between the stationary outer barrel and rotating center screws. Increased friction inside the extruder will increase torque and electrical usage of the main drive motor of the extruder. We have speculated that the amount of energy used in the extrusion process may be related to growth performance of cattle. Therefore, our objective for the current study was to compare different amounts of mechanical energy (shear) used to manufacture diets by altering the levels of process water added to the extruder.

MATERIALS AND METHODS

Procedures used in this study were approved by the Kansas State University Institutional Animal Care and Use Committee.

Crossbred yearling heifers (n = 195; 328 ± 12 kg initial BW) were obtained from a common source and used in a randomized complete block study. Eighteen days prior to the start of the study, heifers were vaccinated against viral and clostridial diseases with Bovishield-4 and Ultrabac-7 (Pfizer Animal Health, Exton, PA), treated with Phoenectin pour-on (Phoenix Scientific Inc., St. Joseph, MO), and implanted with Revalor 200 (Intervet Inc., Millsboro, DE). On d -1, heifers were individually weighed, stratified by BW, blocked by BW, and assigned randomly to pens. On d 0, pens of heifers were sorted into respective pens and treatments were assigned randomly to pen. Five extruded corn diets were manufactured with 4, 6, 8, 10, or 12% water. Fourteen heifers were removed from the study (6 gave birth to a calf, 3 were removed because of lameness, 2 died from bloat, 1 died from respiratory disease, 1 died from peritonitis, and 1 died from unknown causes). Both heifers that died from bloat were in the 4% added water treatment. Heifers were housed in concrete-surfaced pens (36 m^2) with a fence-line feed bunk (3.2 m). The feed bunk and half of the pen were covered by an corrugated steel roof. Heifers were allowed ad libitum access to each of 4 adaptation diets leading to the final finishing diet (Table 5-1). Adaptation diets were fed for 5 d each, and a portion of alfalfa hay was replaced with corn at each step. Heifers were supplemented with zilpaterol hydrochloride (75 mg per animal daily; Zilmax, Intervet, Schering-Plough Corporation, Millsboro, DE) for 21 d of the feeding period, followed by a 3-d withdrawal period prior to harvest. Individual pens of heifers were weighed immediately before being shipped to a commercial abattoir for harvest. Final BW was taken approximately 17 h after last feed delivery.

Extrusion Processing

Extruded diets were processed in a 24:1 (length/diameter) corotating, fully intermeshing, twin-screw extruder (model BCTG-62, Bühler AG CH-9240, Uzwil, Switzerland). Extruder processing conditions are summarized in Table 5-2. Barrel and screw configurations are illustrated in Figure 5-1. Corn and supplement were dosed into the extruder with 2 differential dosing units (model MSDA and model MSDE, respectively, Bühler AG) and an automated control system (model BCTB-II, Bühler AG) at the appropriate rate (Table 5-2). Cracked corn (3,207 ± 465 μm; n = 9) was processed prior to extrusion processing with a double-stack roller mill (23 cm × 46 cm, Rosskamp K roller mill; 2.4 corrugations/cm for top roll and 3.9 corrugations/cm for bottom roll). Roughage feeder rates were controlled by a loss-in-weight system with an automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland). Liquid feed rates were controlled by a flow meter (model Promag 53, Endress-Hauser, CH-4153, Reinach, Switzerland) and an automated control system (model BCTB-II, Bühler AG, CH-9240, Uzwil, Switzerland). Extruded diets were prepared every other day.

In Vitro Dry Matter Disappearance

Samples from each treatment were randomly selected on 3 different days during the feeding period and used in an IVDMD study. Samples (n = 15; 3 per treatment) were dried for 24 h at 55°C and ground through a 2-mm screen with a Thomas-Wiley laboratory mill (Model 4, Thomas Scientific; Swedesboro, NJ). Laboratory DM was determined for each sample by drying the sample in a forced-air convection oven for 16 h at 105°C. The dry weight of polyethylene centrifuge tubes (25 × 100 mm) was recorded, and 0.5 g of sample was added to each tube. Whole ruminal contents were obtained from a ruminally cannulated steer fed a finishing diet (83.4% dry-rolled corn, 5.6% alfalfa hay, 5.5% corn steep liquor, and 5.5% supplement), and contents were strained through 8 layers of cheesecloth. A 30-mL mixture (i.e., 2:1 ratio) of McDougall's buffer (El-Shazly and Hungate, 1965) and strained ruminal fluid was added to each tube, and tubes were incubated in a reciprocal shaking water bath (model 2872, Thermo Electron Corporation, Marietta, OH) at 39°C for 24 h. Tubes were flushed with CO_2 and sealed with a #5 rubber stopper equipped with a slit rubber policeman. Following a 24-h incubation, tubes were removed from the water bath, immediately placed on ice to stop fermentation, and centrifuged (model J2-21 Beckman Centrifuge, Beckman Instruments, Palo Alto, CA) at 30,000 × g for 20 min. The supernatant was removed, and tubes were dried at 100°C for 12 h. Samples were analyzed in duplicate and replicated on 3 different d. Two blanks were prepared for each run by adding McDougall's buffer and ruminal fluid to tubes without substrate. Blank tubes were used to account for the DM in McDougall's buffer and ruminal fluid and were subtracted from the total DM in the treatment tubes.

Apparent Total Tract Diet Digestibility

Apparent DM digestibilities were determined over a 72-h period according to procedures described by Löest et al. (2001). Briefly, on d 116 of the finishing period, heifers were removed from their pens at 0800 h, pen surfaces were thoroughly cleaned, and all unconsumed feed was removed from feed bunks. Heifers were returned to their pens and fed their daily ration. After 24, 48, and 72 h, all feces were collected from each pen, weighed, thoroughly homogenized, and a representative sample (≈2%) was collected. Daily samples from each pen were composited, thoroughly homogenized, and frozen until later analysis. Daily feed refusals (if any) also were collected for each of the sampling days. Diet samples, feed refusals, and feces were analyzed for DM and OM content. Apparent DM and OM digestibility were calculated as: {[1 – (fecal DM output/DMI)] × 100} and {[1 – (fecal OM output/OMI)] × 100}, respectively.

Carcass Data Collection

Heifers were harvested in 2 groups based on weight blocks. On d 122 (3 pens per treatment) and d 182 (3 pens per treatment), heifers were shipped 467 km to a commercial abattoir in Holcomb, Kansas, at which time carcass data were collected by trained personnel. Carcass weight and incidence of liver abscesses were obtained at the time of harvest. Longissimus muscle area, subcutaneous fat thickness over 12th rib, and percentage KPH were obtained following a 48-h chill. In addition, marbling score, quality grades, and yield grades were acquired from USDA grading service personnel. Carcass-adjusted final BW was calculated by dividing carcass weight by a common dressing yield of 63.5%. Actual dressing yield was calculated by HCW/ 0.96 × final BW).

Starch Availability

Diet samples (n = 10; 2 per treatment) were dried for 24 h at 55°C and then ground through a 2-mm screen with a Thomas-Wiley laboratory mill (Model 4, Thomas Scientific). Samples were then submitted to a commercial laboratory (SDK Laboratories, Hutchinson, KS) for analysis of starch availability according to procedures described by Xiong et al. (1990).

Statistical Analysis

Growth performance, apparent total tract digestibility, and carcass characteristics were analyzed by using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit, and block was the random effect. Mean USDA quality grades, USDA yield grades, and liver abscess rates were calculated for each pen and analyzed by using the MIXED procedure of SAS with pen as the experimental unit and block as the random effect. In vitro dry matter disappearance was analyzed using the MIXED procedure of SAS. Treatment was the fixed effect, and day on which the IVDMD experiment was conducted was the random effect. Contrasts were used to compare linear, quadratic, and cubic effects of added water in extruded corn diets. Significance level was set at $P \leq 0.05$.

RESULTS AND DISCUSSION

Extruder Processing Conditions

Extruder processing parameters are summarized in Table 5-2. Product temperature decreased inside barrel 3 ($P = 0.01$; linear), barrel 4 ($P = 0.01$; quadratic), and at the die ($P = 0.01$; linear) as process water was increased from 4% to 12%. Pressure inside the extruder also decreased ($P = 0.01$; quadratic) as process water was increased. Torque (i.e., Nm and %) of main drive motor, power consumption of main drive motor (kWh), and specific mechanical energy (Wh/kg) decreased ($P \leq 0.04$; quadratic) as process water was increased.

Gelatinization “is the collapse (disruption) of molecular orders within the starch granule along with concomitant and irreversible changes in properties such as granular swelling, crystallite melting, loss of birefringence, viscosity development, and starch solubilization” according to Atwell et al. (1988). Collapse of starch structure (i.e., molecular order) occurs when starch is heated in the presence of moisture. A ratio of 1.5 parts of water per 1 part starch is needed for complete gelatinization (Lund, 1984). Gelatinization can occur at lower water levels, but will require greater heat or mechanical energy (Rooney and Pflugfelder, 1986). In the current study, water addition acted as a lubricant and decreased friction (i.e., temperature and pressure) inside the extruder. Extrusion cooking is a continuous process where the product is heated through the friction generated as the product is sheared between the stationary outer barrel and rotating center screws. Mechanical energy through the rotating screw is transferred into the feed (i.e., starch gelatinization) during the extrusion process. Presumably a decrease in friction (i.e., temperature and pressure) would be related to lower starch availability. However, starch availability was not different ($P \geq 0.14$; Table 5-3) among different water levels in the current study. Not only were the starch availability values not different they were extremely low compared to what was expected. In other research (Depenbusch et al., J. Anim. Sci.; companion manuscripts), we observed starch availabilities ranging from 50 to 70%. In addition, starch availability was related to specific mechanical energy inputs used in the production process (Depenbusch et al., J. Anim. Sci.; companion manuscripts). This relationship did not exist in the current study. Increased specific mechanical energy inputs did not result in an equal improvement in starch availability. The precise reason for these discrepancies is not clear. Retrogradation of the starch could explain the unusually low starch availability values. Retrogradation is the process in which gelatinized starch molecules begin to associate in an ordered structure (Atwell et al., 1988). Retrogradation begins when 2 or more starch chains begin to realign, and under favorable conditions progresses until a crystalline order appears. Zinn et al. (2002) suggests retrogradation of starch granules is directly proportional to degree of dispersion of the starch molecules. Retrogradation results in structural changes of the starch granules that decrease porosity of the internal starch matrix, resulting in reduced starch availability (Zinn et al., 2002). Factors affecting retrogradation of starch molecules include structure of amylopectin, amylose content, and presence of lipids (Yao et al., 2002). Jacobson and BeMiller (1998) suggest other factors also influence rate and extent of retrogradation, including temperature, starch-water concentration, and method of cooking (time, temperature, amount of shear). It is conceivable that retrogradation of the starch occurred thereby reducing starch availability and erasing any potential differences in starch availability among treatments.

Finishing Performance

Dry matter intake was not different ($P \geq 0.62$; Table 5-4) for extruded corn diets produced with different levels of water. Average daily gain and G:F (i.e., live-weight basis) decreased ($P \leq 0.06$) as process water increased from 4% to 12%. However, on a carcass-adjusted basis, ADG and G:F were not different ($P \geq 0.18$) among different levels of process water.

Our hypothesis was that 4% water would result in a highly processed product and lead to severe reductions in DMI and growth rate and that 12% water would also result in poor animal growth performance because of reduced friction and a lesser degree of grain processing. Therefore, we expected to observe a quadratic response of G:F to added water levels. Addition of water to the extruder had the desired effect on specific mechanical energy in that it was greatest at 4% added water and lowest at 12% added water. These results translated into a linear decrease in G:F when calculated on a live-weight basis. Therefore, the optimal water level was not between 4 and 12%, and suggest the optimal level is less than or equal to 4% water.

Apparent total tract digestibility for OM and DM were not different ($P \geq 0.53$) among water levels. As previously mentioned, starch availability was not different ($P \geq 0.14$) among water levels. However, IVDMD increased linearly ($P = 0.05$; Table 5-3) with added levels of water. In vitro dry matter disappearance is an indicator of ruminal digestion and suggests that adding water improved ruminal digestion. It is not clear why IVDMD increased with higher water levels and why starch availability did not respond in a similar manner. Time between production of feed and lab analysis (i.e., IVDMD and starch availability) were similar and thus discrepancies between the results of these two methods is not explained by differences in starch retrogradation. Perhaps there was some differences in hydration rate of the ground feed samples between different water levels which led to the differences in IVDMD.

Carcass Characteristics

Carcass weight, dress yield, LM area, KPH, and 12th rib fat were not different ($P \geq 0.08$; Table 5-5) among treatments. These results suggest that water addition to the extrusion process does not affect the composition of gain of feedlot cattle. Increasing water levels in extruded corn diets had a cubic effect ($P = 0.05$) on liver abscesses. A cubic effect ($P \leq 0.03$; Table 5-6) of water level was observed for USDA Select and Standard carcasses. Percentage of carcasses grading USDA yield grade 2 were lowest ($P = 0.05$; quadratic) for 4 and 12% water and highest for 8% water. A biological explanation of the cubic and quadratic effects of water level on carcass quality and yield grades is not clear.

Overall Conclusion

Overall carcass characteristics were not different among heifers fed extruded corn diets produced with different levels of water. Therefore, water levels can be used to optimize energetic efficiency of the feed manufacturing process and growth performance without having deleterious effects on carcass quality. Growth performance of feedlot heifers is related to the amount of mechanical energy used in the manufacturing process. Higher energy inputs (i.e., specific mechanical energy) result in better growth performance compared with feed manufactured with lower energy inputs. The optimal level of water addition in the extruder was not determined in the current study, suggesting that we should have tested lower levels of water.

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Table 5-1. Composition of extruded corn finishing diets produced with different levels of processing water

	Water added during extrusion process, %				
Item	4	6	8	10	12
Corn	82.1	81.9	82.0	82.3	82.1
Ground alfalfa hay	5.7	5.7	5.7	5.7	5.7
Corn steep liquor	6.1	6.3	6.2	6.1	6.1
Limestone	1.6	1.6	1.6	1.5	1.6
Urea	1.3	1.3	1.3	1.2	1.3
Vitamin/mineral premix[1]	0.7	0.7	0.7	0.7	0.7
Supplement[2]	2.5	2.5	2.5	2.5	2.5
Chemical composition %					
CP	14.5	14.5	14.5	14.4	14.5
NDF	10.5	10.4	10.5	10.5	10.5
Calcium	0.62	0.62	0.62	0.61	0.62
Phosphorus	0.32	0.33	0.33	0.32	0.32
Potassium	0.67	0.67	0.67	0.66	0.67
Crude fat	3.53	3.52	3.53	3.54	3.53

[1] Formulated to provide the following per kg of total diet DM: 0.1 mg Co, 10 mg Cu, 0.6 mg I, 60 mg Mn, 0.3 mg Se, 60 mg Zn, and 2,200 IU vitamin A.

[2] Formulated to provide 0.5 mg melengestrol acetate (Pfizer Animal Health, Exton, PA), 300 mg monensin (Elanco Animal Health, Greenfield, IN), and 90 mg tylosin (Elanco Animal Health) per heifer daily.

Table 5-2. Extruder processing conditions of extruded corn diets produced with different levels of process water

	Water added during extrusion process, %						*P*-values		
Item	4	6	8	10	12	SEM	Linear	Quadratic	Cubic
Corn, kg/h	435.2	436.2	437.0	438.9	438.8	1.01	-	-	-
Corn steep liquor, kg/h	45.9	47.2	46.6	45.7	46.5	2.07	-	-	-
Alfalfa hay, kg/h	30.3	30.3	30.7	30.2	30.5	0.46	-	-	-
Supplement, kg/h	28.5	28.5	28.5	28.1	28.7	0.07	-	-	-
Process water, kg/h	19.9	29.7	39.7	49.7	59.5	0.16	-	-	-
Product temperature, °C									
Barrel 3	74.4	71.6	67.2	64.8	60.3	1.19	0.01	0.78	0.87
Barrel 4	78.5	69.7	64.1	60.8	57.9	0.89	0.01	0.01	0.29
Die	110.2	102.9	92.2	83.1	75.6	1.81	0.01	0.83	0.38
Die pressure, bar	9.1	8.2	7.7	6.3	4.2	0.29	0.01	0.01	0.20
Extruder rpm	500.5	500.7	500.4	500.8	500.9	0.14	0.05	0.33	0.65
Torque, Nm	697.5	588.2	498.5	435.6	377.4	16.42	0.01	0.04	0.78
Torque, %	51.9	43.8	37.1	32.4	28.1	1.22	0.01	0.04	0.78
Power consumption, kWh	36.6	30.8	26.1	22.8	19.8	0.86	0.01	0.03	0.78
Specific mechanical energy, Wh/kg	65.9	54.2	45.2	38.8	33.1	1.65	0.01	0.02	0.74

Table 5-3. Apparent total tract digestibility, IVDMD, and starch availability of extruded corn diets produced with different levels of process water

	Water added during extrusion process, %						*P*-values		
Item	4	6	8	10	12	SEM	Linear	Quadratic	Cubic
Apparent total tract digestibility, %									
DM	80.4	77.5	80.8	77.3	79.5	2.25	0.71	0.61	0.91
OM	83.1	80.5	83.4	80.3	82.5	2.00	0.79	0.53	0.95
IVDMD, %	65.1	65.3	64.7	67.5	70.8	3.25	0.05	0.22	0.85
Starch availability, %[1]	37.1	33.9	33.8	36.7	35.8	1.89	0.89	0.14	0.86

[1] Starch availability of complete diet according to enzymatic method described by Xiong et al. (1990).

Table 5-4. Growth performance of yearling heifers fed extruded corn diets produced with different levels of process water

	Water added during extrusion process, %						*P*-values		
Item	4	6	8	10	12	SEM	Linear	Quadratic	Cubic
No. of pens (heifers)	6 (37)	6 (41)	6 (39)	6 (37)	6 (41)	-	-	-	-
Days on feed	169	169	169	169	169	-	-	-	-
Initial BW, kg	328	328	329	328	328	12.5	0.71	0.63	0.53
Final BW, kg	489	493	485	481	472	9.5	0.05	0.40	0.83
DMI, kg/d	7.2	7.2	7.1	7.3	7.3	0.39	0.62	0.90	0.84
ADG, kg/d	0.96	0.98	0.93	0.91	0.84	0.07	0.06	0.39	0.79
G:F, g/kg	133.9	137.0	130.5	123.1	114.4	6.85	0.01	0.25	0.65
Carcass-adjusted performance									
Final BW[1], kg	501	489	483	492	483	10.3	0.27	0.54	0.42
ADG, kg/d	1.02	0.97	0.92	0.97	0.93	0.07	0.31	0.59	0.57
G:F, g/kg	141.0	135.6	129.5	132.0	128.9	7.81	0.18	0.59	0.80

[1] Carcass-adjusted final BW calculated by dividing HCW by a common dress yield of 63.5%.

Table 5-5. Carcass characteristics of yearling heifers fed extruded corn diets produced with different levels of process water

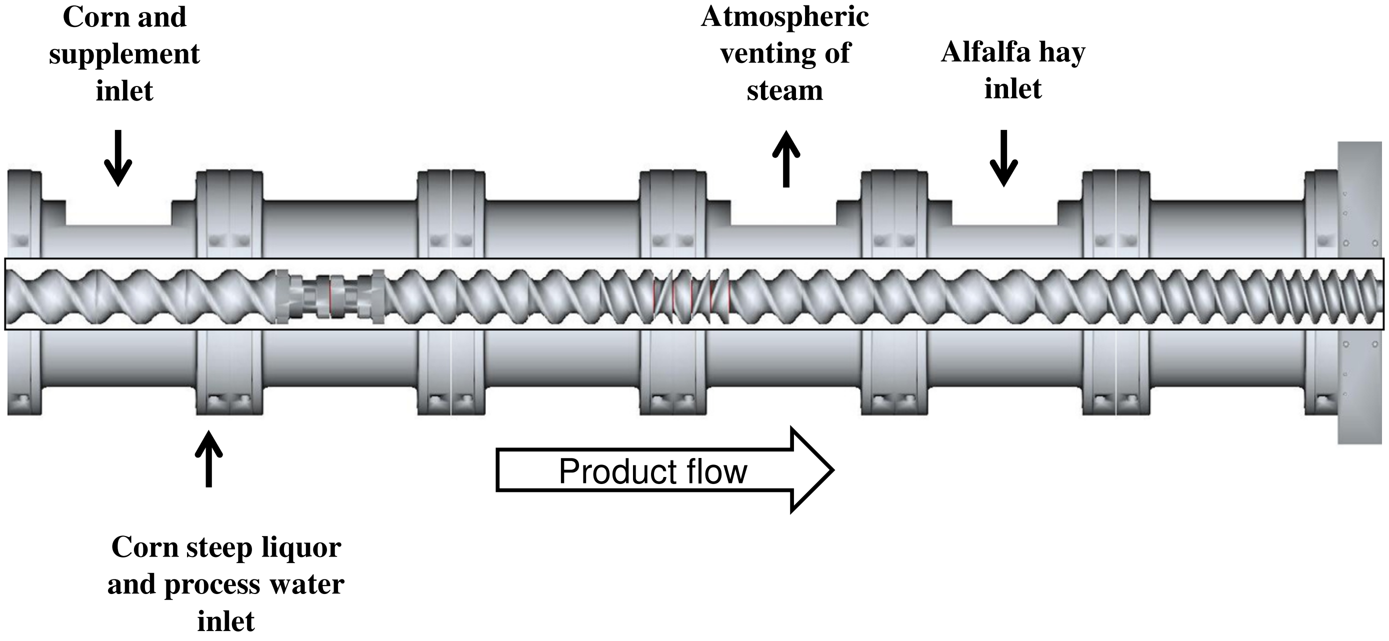
	Water added during extrusion process, %						*P*-values		
Item	4	6	8	10	12	SEM	Linear	Quadratic	Cubic
HCW, kg	318	311	307	313	307	6.6	0.27	0.54	0.42
Dress yield, %	64.9	63.1	63.1	64.9	65.3	0.03	0.46	0.14	0.33
LM area, cm^2	85.2	86.5	89.0	85.2	85.2	2.26	0.87	0.68	0.67
KPH, %	2.12	2.11	2.11	2.09	2.13	0.17	0.99	0.73	0.81
12th rib fat, cm	1.22	1.30	1.30	1.35	1.19	0.13	0.96	0.23	0.78
Liver abscess, %	13.7	19.0	7.9	8.1	19.0	4.20	0.99	0.17	0.05

Table 5-6. USDA yield and quality grade of yearling heifers fed extruded corn diets produced with different levels of process water

	Water added during extrusion process, %						*P*-values		
Item	4	6	8	10	12	SEM	Linear	Quadratic	Cubic
Marbling score[1]	403	428	418	403	418	19.85	0.93	0.68	0.21
USDA quality grade, %									
Choice or greater	49.1	68.3	59.9	47.9	44.8	2.10	0.26	0.12	0.16
Select	48.5	24.2	40.1	52.1	48.1	9.41	0.29	0.22	0.03
Standard	2.4	7.5	0	0	7.1	2.80	0.82	0.26	0.02
USDA yield grade									
YG 1, %	22.6	12.3	15.5	15.1	21.5	5.94	0.98	0.12	0.67
YG 2, %	31.1	36.9	52.3	43.2	31.8	7.91	0.76	0.05	0.63
YG 3, %	31.3	43.6	27.0	31.8	44.3	8.54	0.53	0.42	0.12
YG 4 and 5, %	15.0	7.2	5.2	9.9	2.4	4.60	0.18	0.57	0.12
Average	2.4	2.5	2.2	2.4	2.3	0.16	0.38	0.92	0.75

[1] Marbling score: 400 = small, 500 = modest.

Figure 5-1. Extruder configuration and screw geometry



CHAPTER 6 - Feed depredation by European starlings

Abstract

During much of the year, inconspicuous flocks of starlings feed on seeds, fruits, and insects. However, during the winter months, several hundred to more than one million starlings form large feeding flocks. Starlings can eat nearly one kilogram of feed per month, half of which comes directly from the feed bunk. In the first study, we evaluated feed selection and predation by starlings on five commonly fed finishing diets. Four diets evaluated were in traditional meal-type form; one diet was in pellet form. Diets were placed in a section of the feed bunk that was made unavailable to the cattle by a secured wire-mesh cattle panel. Of the original 13.6 kg of steam-flaked corn (82%) and alfalfa hay (6%) diet placed in the feed bunk, only 1.9 kg ($P < 0.05$) of residual feed was recovered after starlings returned to their evening roost. Starlings preferentially selected the steam-flaked corn thereby concentrating the crude protein and crude fiber contents ($P < 0.05$) in the residual feed. Similar trends for feed disappearance were observed for the dry-rolled corn (85%) and alfalfa hay (6%) diet; steam-flaked corn (78%) and corn silage (12%) diet; and steam-flaked corn (66%), alfalfa hay (6%), and distiller's grain (25%) diet. However, crude protein content was not different between fresh and residual feed for the dry-rolled corn and alfalfa hay diet and for the steam-flaked corn and corn silage diet. Quantity and chemical composition between fresh and residual feed of the extruded corn and alfalfa hay diet was not different ($P > 0.05$). Starling infestation can increase amount of feed delivered to cattle; however, forming the total mixed ration into a extruded pellet can prevent starling predation. Given the option, starlings will preferentially select the grain portion of the diet thereby creating variations in ration composition. In a second study, amount of feed delivered increased 36% for cattle fed the traditional meal-type diet (i.e., 82% steam-flaked corn and 6% alfalfa hay) compared with cattle fed the same diet in a extruded pellet form during a period of severe starling infestation. Following seasonal dispersal of starlings in late February, feed deliveries of the traditional meal diet decreased to pre-starling levels, and feed deliveries of extruded diet remained unchanged.

Key words: cattle, European starling, feedlots, predation

Study area

This study was conducted at a research cattle feeding facility located near Manhattan, Kansas. The research feedlot contains more than 200 pens of various sizes and has a onetime capacity of 1,200 animals. A small portion of the pens are fully enclosed, but the majority of the pens are partially or completely open to the environment. One-third of the pens are dirt surfaced; remaining pens are concrete surfaced. The surrounding area (i.e., within 1.5 km of research feedlot) contains native grass, cropland, timber, and residential areas. In addition, there is a swine (160-sow capacity) and dairy (200-cow capacity) research operation within 0.2 km of the feedlot. The starlings' roost was in mature eastern red cedar trees (*Juniperus virginiana*) located 2.4 km from the feedlot. Starlings arrived at the feedlot around 0750 and left for the roost site around 1650 hr.

Figure 6-1 shows maximum and minimum daily temperatures during the study period. Average high temperature was 8.8 °C and average low temperature was -3.2 °C. During the same period of time, 15.2 cm of moisture fell in the form of snow or rain. Temperature and moisture measurements were taken at a weather station located 3.5 km southeast of the study area.

Introduction

European starlings (*Sturnus vulgaris*) were first introduced to the United States in the late 1800s (Linz et al. 2007). It is believed that starlings were imported from Europe and released in New York City's Central Park so that all birds mentioned in Shakespeare's works would inhabit the new country. For the next fifty years, the starling population grew exponentially; by 1942, the starling population had spread to the west Coast (Cabe 1993). Nearly one-third (i.e., 200 million) of the world's starling population inhabits the North American continent (Feare 1984). Starlings inhabiting the High Plains are not considered migratory and remain in the same general area throughout the year (Dolbeer 1982). However, starlings from northern climates can escape snow covered feeding grounds by migrating up to 1,500 km (Linz et al. 2007). During much of the year, small, inconspicuous flocks of starlings feed on seeds, fruits, and insects (Tinbergen 1981). However, during the winter months, large flocks of several hundred to one million starlings will share common feeding and roosting sites. These large flocks prefer to roost in coniferous trees, which provide protection from wind and other adverse weather conditions (Clergeau and Quenot 2007). Bray et al. (1975) documented an average distance of 18 km between roost and feedings sites which is consistent with the range of 8 to 40 km previously cited by other researchers (Wynne-Edwards 1929, Boyd 1932, Marples 1932, and Guarino 1968). Confinement cattle feeding operations (i.e., feedlots and dairies) have been associated with large populations of starlings during the winter months (Feare and Swannack 1978, Feare and Wadsworth 1981, and Lee 1988). Large flocks of starlings are attracted to the continuous supply of fresh feed in the troughs. Previous research has documented that an 85 g starling can eat nearly one kg of feed in a 30-day period (Besser et al. 1968). One report from a California feedlot estimated a $900 to $1,000 daily loss of feed due to a flock of 750,000 starlings. The objective of our two-experiment study was to evaluate starling predation on several meal-type rations compared with a pelleted ration containing similar ingredients.

Methods

Experiment 1

Finishing diets used in this study were formulated using feed ingredients (Table 6-1) commonly found in the High Plains region of the United States. Four different mixtures of a meal-type diet and one extruded mixture of similar ingredients (Table 6-2) were used. The first diet contained 84.7% dry-rolled corn and 6% alfalfa hay. The next two diets were based on steam-flaked corn; one contained 6% alfalfa hay, and the other contained 12% corn silage. The fourth meal-type diet was based on steam-flaked corn and contained 6% alfalfa hay and 25% corn dried distiller's grains with solubles. The extruded pellet diet was the same mixture of ingredients as the 81.7% steam-flaked corn and 6% alfalfa hay diet. Dry-rolled corn was processed to a mean geometric particle size of 4,072 µm (*n* = 23) using a single stack roller mill, and steam-flaked corn was processed to a flake density of 360 g/L with a mean geometric particle size of 5,724 µm (*n* = 159). The extruded diet was processed using a co-rotating, fully intermeshing, twin-screw extruder (Model BCTG-62, 25:1 (i.e., Length:Diameter), Bühler AG, Uzwil, Switzerland). All ingredients, including the corn and alfalfa hay, were agglomerated using the extruder and forced through a die to form a complete pelleted feed.

Thirty individual feeding sites were constructed by dividing a concrete fence-line feed trough (Pappas Concrete Inc., Holcomb, KS) into 76.2-cm sections. Each ration (13.6 kg) was placed into 30 different feeding sites (6 feeding sites/ration) prior to arrival of the starlings (0750 hr). Feeding sites were constructed by adhering a 5.1-cm-thick by 15.2-cm-tall piece of wood to the bottom of the feed trough. A two gauge wire mesh cattle panel was secured on the pen side of the feed trough to prevent disturbance of the feed by cattle. The feed aliquots were available to the starling flock for the entire day (i.e., 10 hr). After starlings left the feedlot and returned to their evening roost (1650 hr), we weighed and sampled the residual feed in the trough. Samples of fresh and residual feed were analyzed for crude protein, crude fat, and crude fiber.

Photographic images of feed predation by starlings were acquired by securing a digital scouting camera (Cuddeback Expert, 3.0 megapixel, Non Typical Inc., Park Falls, WI) approximately 2.5 m above the feed trough. The scouting camera was programmed to take a picture every hour from 0600 until 1900. In addition, the motion sensor was utilized with a 15 min delay.

Experiment 2

Twenty-six crossbred yearling heifers were housed in individual pens (1.5 m x 7 m) containing a fence-line feed trough (1.5 m) and a water fountain. Half of the pen and the feed trough were covered by an overhead roof. Heifers were randomly assigned to either the 81.7% steam-flaked corn and 6% alfalfa hay diet or to the extruded diet containing the same proportion of ingredients (Table 6-2). Cattle were fed respective diets once daily at 0800 hr. The amount of feed delivered to each pen was adjusted daily so that only trace amounts of unconsumed feed remained in the feed trough 22 hr after delivery. Daily feed delivered to the cattle was monitored for 142 days (19 October 2006 to 11 March 2007).

Statistical analysis

Feed disappearance due to starlings was analyzed as a randomized complete block design using the mixed procedure of SAS (Version 9.1; Cary, NC). Individual feeding sites were grouped into six different blocks. Within each block, diets were randomly assigned to one of the five homogeneous feeding sites. Feeding site served as the experimental unit. The experiment was replicated on seven consecutive days.

Seven randomly selected samples of residual feed and two randomly selected samples of fresh feed per diet were analyzed as a completely randomized design using the mixed procedure of SAS (Version 9.1; Cary, NC).

Results and Discussion

Experiment 1

Table 6-3 shows the amount of feed delivered, residual feed recovered, and percentage of feed consumed by starlings over a 10-hr period. The steam-flaked corn and alfalfa hay ration exhibited the greatest loss (86%) of feed by the starlings, whereas 78.7% of the steam-flaked corn, alfalfa hay, and corn dried distiller's grain ration and 76.2% of the steam-flaked corn and corn silage ration were consumed by starlings over the same period of time. Of the meal-type diets, the dry-rolled corn and alfalfa hay ration was the least affected (65.5%) by starling predation. Starlings did not consume any of the extruded ration. Figure 6-2 is a photograph of the feeding sites before (Figure 6-2a) and during the predation (Figure 6-2b) of starlings. No starlings were perched in the third feeding site containing the extruded ration, but the other feeding sites contained a large number of starlings. Distribution and density of starlings remained fairly constant throughout the day.

Nutrient analysis of fresh and residual feed is summarized in (Table 6-4). Concentrations of crude protein and crude fiber were greatest in residual samples of the meal-type rations compared with fresh ration samples, implying that starlings were selectively choosing the corn portion of the ration and leaving the roughage portion.

Nutritionists and feedlot managers strive to provide consistent, quality ration from day to day and hour to hour. Data from Table 6-4 and Figure 6-3 show distinct changes in chemical and physical composition of the ration over a 10-hr period due to starling predation. When transitioning young cattle from a predominately forage diet (i.e., cattle grazing native pasture) to a high-grain diet (i.e., energy dense diet formulated for maximal growth), normal practice is to adapt cattle from a ration similar to the residual feed portrayed in Figure 6-3b to the high-grain ration portrayed in Figure 6-3a. However, this adaptation process usually requires two to five transition diets with each diet being fed for four to eleven days (Vasconcelos and Galyean 2007) to avoid digestive tract disturbances, which lead to acute and subacute acidosis (Owens et al., 1998) and, ultimately, death. In the present study with starling predation, this change in ration quality happened in hours, not days. However, our research feedlot has a onetime capacity of 1,200 animals, whereas large, commercial feedlots can have a onetime capacity of 20,000 to 100,000 animals. Therefore, the roughly 30,000 starlings observed at our feedlot were significantly more concentrated than if these same birds were dispersed over a large, commercial feedlot. But clearly, starlings preferentially choose the grain portion of the ration, which will ultimately lead to changes in physical and chemical composition. Severity of these changes is largely determined by number of starlings present and size of the feedlot.

Experiment 2

Figure 6-4 illustrates daily feed deliveries of the meal-type ration (i.e., 81.7% steam-flaked corn and 6% alfalfa hay) and extruded ration over a 144-day period. For the first 79 days, feed deliveries mirrored each other with cattle fed the meal-type ration consuming, on average, around 11.5 kg feed per day. However, on 8 January 2007, feed deliveries started to diverge. From 8 January 2007, to 23 February 2007, feed delivery of the meal-type ration linearly increased 33% from 11.5 to 17.2 kg of feed per day, whereas feed deliveries of the extruded ration remained fairly stable. This divergence corresponds closely to the arrival (early January) of wintering starlings. Interestingly, delivery of the meal-type ration linearly decreased from 25 February 2007, to pre-starling levels on 11 March 2007, after the wintering flock dispersed.

This 33% increase in the meal-type feed delivered to the trough is directly attributed to feed predation of the European starlings. We believe that if starlings had not been present, cattle fed the meal-type ration would have continued consuming feed at a rate of about 11.5 kg per day. With this in mind, we calculated the difference between the actual amount of feed delivered to the cattle and the hypothetical amount of feed delivered (i.e., 11.5 kg per day). Under these assumptions, this difference in feed delivered is the sum of the feed consumed by the starlings. Therefore, on average, starlings consumed 179 kg of feed per pen during the course of 47 days. Multipling that by 13 pens results in 2,327 kg of total feed consumed by starlings. Most if not all of this feed consumed by starlings is the steam-flaked corn portion of the diet. Assuming all 2,327 kg of feed consumed by starlings was steam-flaked corn, the total cost would be $563, or $43 per heifer (i.e., $541 for whole corn and $22 for grain processing cost associated with steam-flaking).

Implications

Starling predation not only results in loss of expensive feed but can also negatively affect animal performance because of changes in chemical and physical composition of the ration.

Forming feed into large pellets that starlings cannot consume could be a possible means of preventing bird predation.

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Figure 6-1. Maximum and minimum daily temperature from 1 January 2007 to 30 March 2007.

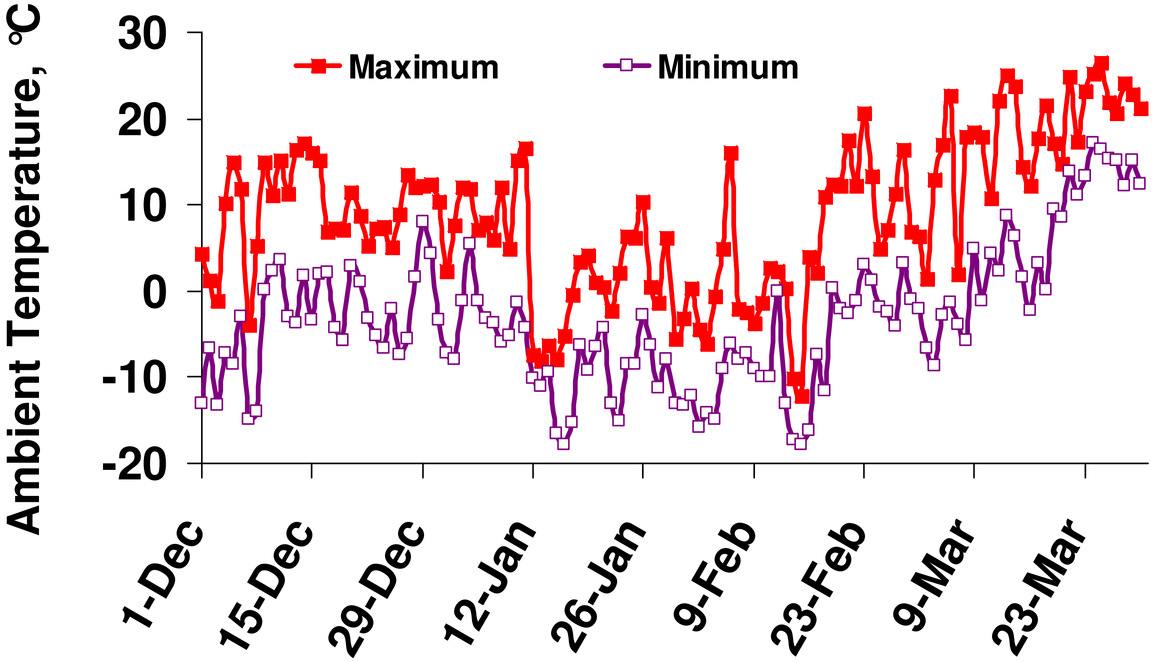


Table 6-1. Nutrient content of individual feed ingredients used in experimental diets

Ingredient, %	**Crude Protein**	**Crude Fat**	**Crude Fiber**
Steam-flaked corn	9.7	4.3[a]	9.0[a]
Dry-rolled corn	10.1	4.3[a]	9.0[a]
Alfalfa hay	14.5	2.4[a]	59.4
Corn silage	8.8	2.6[a]	49.7
Dried corn distiller's grains	29.6	10.0	31.8
Corn steep liquor	32.0	-	-
Urea	291.0[a]	-	-
Soybean meal, dehulled	54.0[a]	1.6[a]	7.8[a]
Supplement	-	-	-

[a] Nutrient content based on 1996 Nutrient requirements of beef cattle (National Research Council).

Table 6-2. Composition of total mixed rations, % (dry matter basis)

Ingredient	DRC[a] with alfalfa hay	SFC[b] with alfalfa hay	SFC with corn silage	SFC with dried distiller's grains	Extruded pellets[c]
Steam-flaked corn	-	81.7	77.8	65.7	-
Dry-rolled corn	84.7	-	-	-	81.7
Alfalfa hay	6.0	6.0	-	6.0	6.0
Corn silage	-	-	12.0	-	-
Corn dried distiller's grains	-	-	-	25.0	-
Corn steep liquor	6.0	6.6	-	-	6.6
Urea	0.4	1.2	1.1	0.4	1.2
Soybean meal	-	-	4.6	-	-
Supplement	2.9	4.5	4.5	2.9	4.5

[a] DRC = Dry-rolled corn.

[b] SFC = Steam-flaked corn.

[c] Composition identical to the SFC diet. Ingredients were agglomerated together to form a pellet via extrusion processing.

Table 6-3. Feed consumed by European starlings during a 10-hr exposure period (i.e., 0800 to 1600 hr)

Item	DRC[a] with alfalfa hay	SFC[b] with alfalfa hay	SFC with corn silage	SFC with distillers grains	Extruded pellets[c]	SEM[d]	*P*-value
Feed delivered, kg	13.6	13.6	13.6	13.6	13.6	-	-
Residual feed, kg	4.7^{ae}	1.9^{b}	3.3^{c}	2.9^{c}	13.6^{d}	0.6	0.01
Feed disappearance, %	65.5^{ae}	86.0^{b}	76.2^{c}	78.7^{c}	0^{d}	4.3	0.01

[a] DRC = Dry-rolled corn finishing diet.

[b] SFC = Steam-flaked corn finishing diet.

[c] Composition identical to the SFC diet.

[d] SEM = Standard error of the mean.

[e] Means within row with unlike letters are different ($P < 0.05$).

Table 6-4. Nutrient content of total mixed rations before (Fresh) and after (Residual) 10-hr exposure period (i.e., 0800 to 1600 hr) to European starlings

Treatment	Crude Protein	Crude Fat	Crude Fiber
Dry-rolled corn with alfalfa hay			
Fresh (*n* = 2)	12.9 ± 1.6[a]	4.4 ± 0.7	15.1 ± 5.7
Residual (*n* = 7)	15.9 ± 0.9	3.6 ± 0.4	27.3 ± 3.0**
Steam-flaked corn with alfalfa hay			
Fresh (*n* = 2)	15.7 ± 1.6	3.7 ± 0.7	14.7 ± 5.7
Residual (*n* = 7)	19.5 ± 0.9*	3.4 ± 0.4	37.0 ± 3.0*
Steam-flaked corn with corn silage			
Fresh (*n* = 2)	13.9 ± 1.6	5.1 ± 0.7	18.9 ± 5.7
Residual (*n* = 7)	16.0 ± 0.9	4.4 ± 0.4	41.3 ± 3.0*
Steam-flaked corn with dried distiller's grains			
Fresh (*n* = 2)	16.0 ± 1.6	5.3 ± 0.7	21.8 ± 5.7
Residual (*n* = 7)	21.9 ± 0.9*	7.3 ± 0.4*	36.4 ± 3.0*
Extruded pellets[b]			
Fresh (*n* = 2)	15.2 ± 1.6	2.2 ± 0.7	14.0 ± 5.7
Residual (*n* = 7)	15.0 ± 0.9	2.5 ± 0.4	13.0 ± 3.0

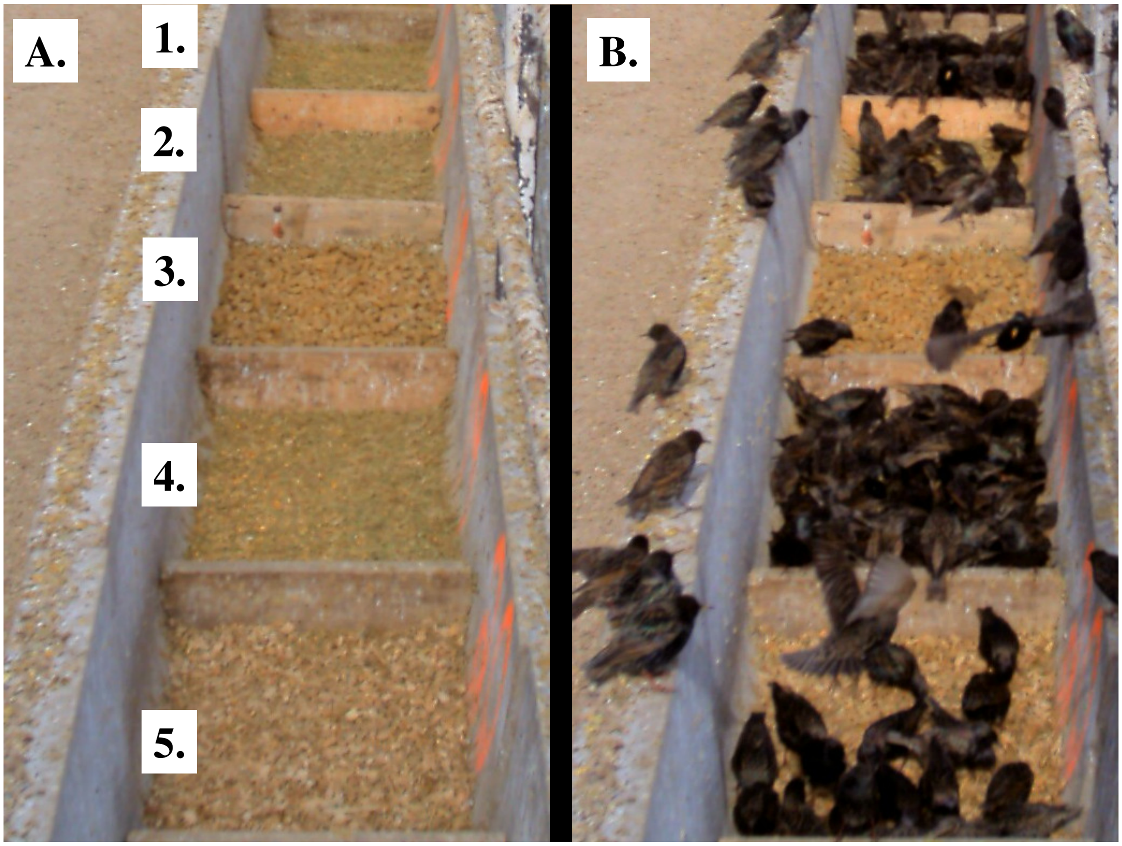
[a] Standard error of the mean.

[b] Composition is identical to the steam-flaked corn and alfalfa hay diet.

**Nutrient content of residual feed different than fresh feed ($P < 0.10$).

*Nutrient content of residual feed different than fresh feed ($P < 0.05$).

Figure 6-2. Plate A, photographed at 0800 hr, and illustrates feeding sites before arrival of European starlings. Plate B illustrate preference by European starlings at the identical feeding locations



1. Steam-flaked corn, alfalfa hay, and distiller's grains.
2. Steam-flaked corn and alfalfa hay.
3. Extruded pellets.
4. Dry-rolled corn and alfalfa hay.
5. Steam-flaked corn and corn silage.

Figure 6-3. Steam-flaked corn and alfalfa hay diet before and after 10-hr exposure period (i.e., 0800 to 1600 hr) to European starlings

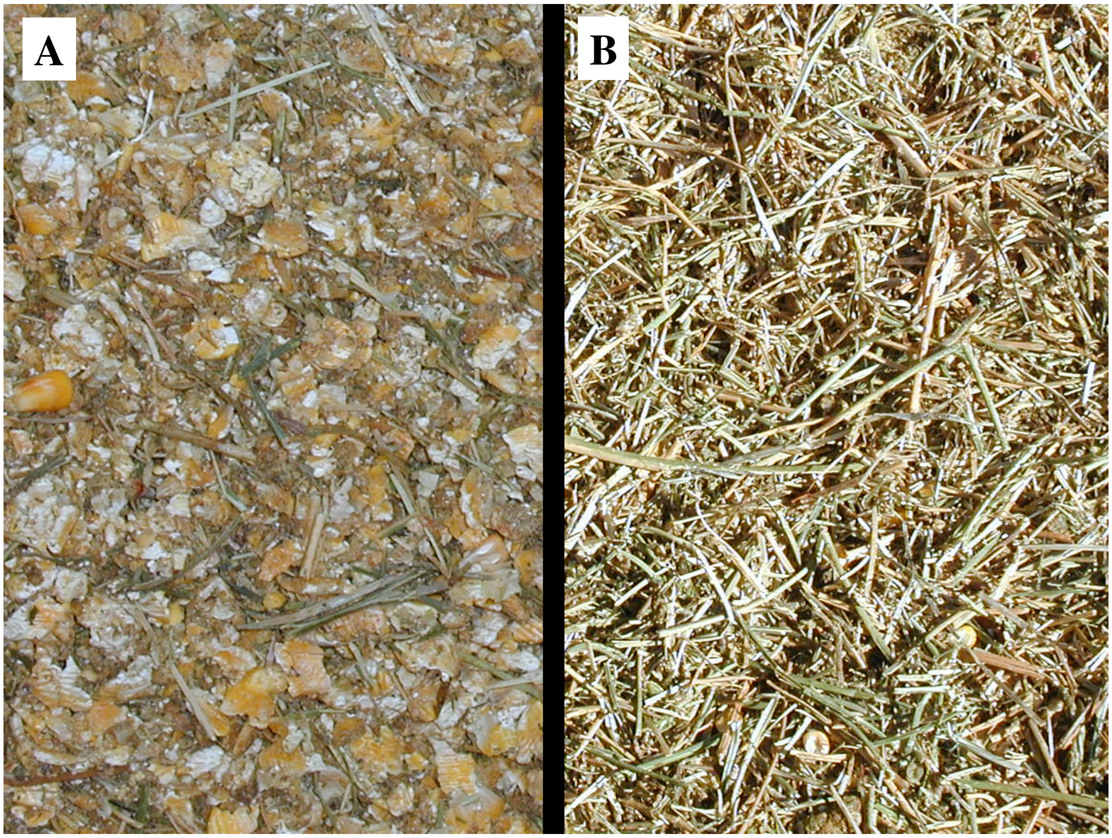


Figure 6-4. Differences in feed delivered to pens of cattle fed between October and March. The sharp increase after January 1 is attributed to arrival of large numbers of European starlings. Birds dispersed by 1 March.