INTRODUCTION

When feeding grains to feedlot cattle, the goal is to maximize starch digestion while managing acidosis in order to provide optimal economic utilization of the finishing diet. Starch, the main component of grains, is digested primarily in the rumen with some digestion occurring in the small intestine and cecum. The small intestine is the preferred location of starch digestion to occur because digestion in the small intestine is more efficient (20 to 25%; Waldo, 1973) than digestion by the rumen microbes. However the capacity of the small intestine to digest starch may be limited (Karr et al., 1966; White et al., 1971). Starch digestion and acidosis are closely intertwined. Acidosis usually occurs in feedlots with cattle fed high-energy diets. Therefore, the relationship between rate of starch digestion, acidosis, and intake is important in determining whether the level of performance attained equals the level predicted for the cattle and feedstuffs used. Acidosis is one of the most important nutritional disorders in feedlots. In general, acidosis is considered one disorder, but it needs to be separated into acute and subacute types. During acute acidosis, the animal’s life may be threatened or at least some physiological function, usually absorption, may be impaired (Britton and Stock, 1987). In subacute acidosis, the major response observed is a reduction in feed intake with a concomitant reduction in performance (Fulton et al., 1979). Processed grains may differ in site of digestion, rumen versus post-rumen. Processed grains also may differ in their rate and extent of starch digestion in the rumen. In addition, the amount of starch fed (% grain in the diet) has an important effect on acidosis, and consequently, on cattle performance. Thus, it is important to consider rate, extent, site, and amount of starch digestion when determining an appropriate combination of processed grains to be fed.

Combinations of Processed Grains

Grains can be categorized by rate of ruminal fermentation. In general, wheat and barley have the fastest rates of starch digestion whereas corn and grain sorghum generally are the slowest. Any grain processing method that reduces particle size and/or causes gelatinization of the starch granules increases the rate of ruminal breakdown of that starch and increases the possibility of acidosis. Grains harvested at high moisture (greater than 24%), ground and stored in a bunker silo have faster rates of ruminal starch fermentation than the same grains fed after being dry rolled. However, the rate of fermentation also may be affected by moisture level of the incoming grain, particle size, and length of storage. Steam flaking increases the rate of ruminal starch fermentation but the rate also can be affected by grain type, flake density, and flake thickness. With dry processing (rolling or grinding), rate of fermentation may be impacted by grain type, particle size, and the amount of fines. Figure 1 depicts the relative rate of starch digestion in the rumen for various grains and processing methods. This figure was constructed without absolute rates because values within grain processing methods vary and this alters rate of fermentation and the rank order. Processed grains with the fastest rates of starch digestion generally cause the most acidosis. Another factor to consider is that slower fermented grains also will shift the site of digestion from the rumen to the lower tract. Both changes in acidosis and site of digestion can affect efficiency of utilization of the grains fed. Thus, the concept of feeding a combination of processed grains is based on blending two processed grains, one with a rapid rate of starch fermentation with a second processed grain with a slower rate of starch fermentation.
Nebraska Trials, High Moisture Corn – Dry Grain Blends

Nine trials were conducted at the University of Nebraska (Schindler et al., 1978; Stock et al., 1987ab; Stock et al., 1991) to evaluate the complementary effects of feeding a combination of early harvested high moisture corn (HMC) with either dry corn (whole or rolled) or dry-rolled grain sorghum (DRGS). High moisture corn was ground through a tub grinder and stored for a minimum of 90 d in an oxygen limiting structure. Among the trials, the screen size of the grinder varied from 0.75 to 2 in and grain moisture content varied from 23 to 30%. Dry corn and grain sorghum were harvested as dry grain and stored whole. Dry corn was fed either whole or coarsely rolled. Grain sorghum was finely rolled. Cattle were fed high-grain diets consisting of approximately 80% grain, 10% forage (a mixture of corn silage and alfalfa hay), and 10% supplement. Cattle were implanted and fed Rumensin and Tylan. The formulation of the 100% HMC diet was similar among all nine trials.

The complementary effects appeared different when cattle were fed a combination of HMC with dry corn (Figure 2) versus a combination of HMC with DRGS (Figure 3). Cattle fed 100% HMC or 100% dry corn gained and converted feed to gain similarly (Figure 2). However, cattle fed a combination of 67-75% HMC and 33-25% dry corn gained 2.9% faster and 4.3% more efficiently than cattle fed either HMC or dry corn alone. The complementary effect of HMC and dry corn was reduced when the combination consisted of 50% HMC and 50% dry corn. When a combination of 25 to 33% HMC and 75 to 67% dry corn was fed, cattle consumed more feed resulting in faster gains, but the feed/gain ratio was similar to the expected values.

Cattle fed 100% DRGS (Figure 3) consumed 7.0% more feed, gained 5.6% slower, and were 13.7% less efficient than cattle fed 100% HMC. Cattle fed a combination of 67 to 75% HMC and 33 to 25% DRGS gained as fast and as efficiently as cattle fed 100% HMC; the complementary effect was 2.6% for gain and 4.8% for feed/gain. When cattle were fed a combination of 50% HMC and 50% DRGS, the complementary effect was 3.6% for gain and 4.8% for feed/gain. Cattle fed a combination of HMC and DRGS consistently consumed less feed than expected, although the magnitude of this depression (1.3 to 1.6%) was small.

The slope of the expected gain and feed/gain lines are quite different in Figures 2 and 3. However, the magnitude of the complementary effect of feeding 25 to 33% dry corn or DRGS together with HMC was quite similar.
In a cattle metabolism trial (Stock et al., 1987b), 89% of the starch from a 100% HMC diet was digested in the rumen compared with only 46% for a 100% DRGS diet (Figure 4).

In vitro starch digestion rates were 10.8%/h for HMC and 5.8%/h for DRGS. Thus, both rate and extent of starch digestion were greater for HMC compared with DRGS. Cattle fed a mixture of HMC and DRGS digested more starch in the rumen compared with expected values. The small intestine partially compensated by digesting more starch as the level of DRGS increased. Total tract starch digestion was similar for steers fed HMC alone or in combination with DRGS, but values were greater when DRGS was fed alone (Figure 5).
Observations With Feeding a Blend of HMC and Dry Grain

When HMC is the only grain source in the finishing diet, feed intake generally is reduced as compared with feeding dry grain; the magnitude of the reduction in feed intake appears related to the rate of ruminal starch digestion of the HMC. On the other hand, dry grain, particularly DRGS, is less digested in the rumen and total tract so feed intake increases significantly. Replacing some of the HMC with a slower fermenting grain source such as DRGS, slows the rate of starch digestion in the rumen (less subacute acidosis) compared with feeding HMC alone, but the amount of starch digested in the rumen and total tract is increased when compared with feeding DRGS alone (improved starch utilization). In addition, the processed grain combination increases feed intake compared with feeding HMC alone, but feed intake is lower than for DRGS fed alone. The improvement in feed/gain from feeding a combination of processed grains is the result of reduced acidosis and increased ruminal starch digestion. Therefore, the benefit should be attributed to both grains and not just one single grain – positive associative effect.

Other Combinations of Processed Grains

Table 1 summarizes processed grain trials with different grain combinations. Feeding a combination of a rapidly fermented processed grain, such as dry-rolled
wheat, with a slower fermented processed grain, such as dry-rolled corn (Varner and Woods, 1971; Kreikemeier et al., 1987) or high moisture grain sorghum (Axe et al., 1987) resulted in a complementary effect in gain and feed/gain. Feeding a combination of steam-flaked corn and whole corn (Lee et al., 1982) or a combination of HMC and steam-flaked grain sorghum (Huck et al., 1998) also resulted in complementary effects on gain and feed/gain. However, feeding a combination of two rapidly fermented grains (HMC and dry-rolled wheat or HMC and steam-rolled barley) had no complementary effect on gain or feed/gain (Bock et al., 1991; Duncan et al., 1991), and feeding a combination of two different dry grains (dry-rolled corn and dry-rolled or finely ground grain sorghum) had no complementary effect on gain or feed/gain (Sindt et al., 1989).

Table 1. Complementary effect (%) of processed grain combinations on average daily gain (ADG) and feed/gain

<table>
<thead>
<tr>
<th>Processed Grain Types</th>
<th>Reference</th>
<th>ADG</th>
<th>Feed/gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry-rolled wheat and dry-rolled corn</td>
<td>Varner and Woods, 1971</td>
<td>+4.1</td>
<td>+0.7</td>
</tr>
<tr>
<td>Steam-flaked corn and whole corn</td>
<td>Lee et al., 1982</td>
<td>+5.3</td>
<td>+0.5</td>
</tr>
<tr>
<td>Steam-flaked corn and whole corn</td>
<td>Lee et al., 1982</td>
<td>+2.5</td>
<td>+0.1</td>
</tr>
<tr>
<td>Dry-rolled or dry ground corn and whole corn</td>
<td>Turgeon et al., 1983</td>
<td>+7.1</td>
<td>+5.5</td>
</tr>
<tr>
<td>Dry-rolled wheat and high moisture grain sorghum</td>
<td>Axe et al., 1987</td>
<td>+5.4</td>
<td>+5.7</td>
</tr>
<tr>
<td>Dry-rolled wheat and dry-rolled corn</td>
<td>Kreikemeier et al., 1987</td>
<td>+4.2</td>
<td>+3.9</td>
</tr>
<tr>
<td>Dry-rolled corn and dry-rolled or dry ground grain sorghum</td>
<td>Sindt et al., 1989</td>
<td>-0.8</td>
<td>+2.0</td>
</tr>
<tr>
<td>High moisture corn and dry-rolled wheat</td>
<td>Bock et al., 1991</td>
<td>-3.8</td>
<td>-3.3</td>
</tr>
<tr>
<td>High moisture corn and steam-rolled wheat</td>
<td>Bock et al., 1991</td>
<td>+2.9</td>
<td>+3.1</td>
</tr>
<tr>
<td>Steam-rolled barley and dry-rolled corn</td>
<td>Duncan et al., 1991</td>
<td>+2.6</td>
<td>+2.9</td>
</tr>
<tr>
<td>Steam-rolled barley and high moisture corn</td>
<td>Duncan et al., 1991</td>
<td>-4.3</td>
<td>-5.8</td>
</tr>
<tr>
<td>Dry-rolled barley and whole corn</td>
<td>Pritchard and Robbins, 1991</td>
<td>-0.03</td>
<td>-2.3</td>
</tr>
<tr>
<td>Steam-flaked grain sorghum and high moisture corn</td>
<td>Huck et al., 1998</td>
<td>+6.2</td>
<td>+4.9</td>
</tr>
<tr>
<td>Steam-flaked grain sorghum and dry-rolled corn</td>
<td>Huck et al., 1998</td>
<td>+6.4</td>
<td>+5.0</td>
</tr>
<tr>
<td>Steam-flaked grain sorghum and steam-flaked corn</td>
<td>Huck et al., 1998</td>
<td>+4.3</td>
<td>+1.4</td>
</tr>
<tr>
<td>Steam-flaked corn and steam-flaked grain sorghum</td>
<td>Duff et al., 2002</td>
<td>-1.0</td>
<td>-1.9</td>
</tr>
</tbody>
</table>
Interestingly, cattle fed a combination of whole and finely ground corn or whole and rolled corn gained faster and more efficiently than cattle fed either whole, ground, or rolled corn (Turgeon et al., 1983). These complementary responses are greater than one would predict based on differences in rate and extent of ruminal starch digestion.

In two trials, feeding a combination of steam-flaked corn and steam-flaked grain sorghum was evaluated. A complementary effect with gain was observed in one trial (Huck et al., 1998), but no complementary effect with gain or feed/gain was observed in the second trial (Duff et al., 2002).

Several trials demonstrated a 2 to 3% complementary effect in gain and feed/gain when two grains were combined, but this small difference may be due to random variation. Comparing different trials is difficult because the formulation of diets, processing methods, and experimental protocols differ.

**Future - Blends with other feed ingredients**

With the increased availability of wet milling (corn gluten feed) and dry milling (distillers grains) feed byproducts, the benefit from feeding a combination of rapidly and slowly fermented grains may be altered. One of the advantages of feeding wet corn gluten feed is its effect to reduce subacute acidosis in the feedlot. Thereby, one might hypothesize that some of the benefit of feeding a slowly fermented processed grain with a rapidly fermented processed grain could be negated by including 20 to 30% (DM basis) wet corn gluten feed in the diet. In the review of Owens et al. (1997), feeding HMC and steam-flaked corn improved efficiency 1.4% and 11.4% compared with feeding dry-rolled corn. However, when HMC, steam-flaked corn, and dry-rolled corn were fed in diets containing 25 to 30% (DM basis) wet corn gluten feed, HMC and steam-flaked corn improved feed efficiency 8.1% and 14.6%, respectively, compared with feeding dry-rolled corn (Erickson; elsewhere in this publication). Thus it appears that feeding wet corn gluten feed allows higher levels of highly processed grains to be fed without increasing the incidence or severity of acidosis.

With the abundance of the wet and dry milling feed byproducts, the need to feed high amounts of grain also can be reduced. The University of Nebraska has fed combinations of wet corn gluten feed and wet distillers grains at levels that replaced up to 75% of the grain in the diet. Feeding diets composed with different grain byproducts (gluten feed, distillers grains, midds, beet pulp) may be the combinations of the future.

**CONCLUSIONS**

Feeding combinations of rapidly digested grains (high moisture corn, dry-rolled wheat) with more slowly digested grains (whole corn, dry-rolled corn or dry-rolled grain sorghum) resulted in a positive complementary effect in gain and feed/gain in the feedlot. This improvement in performance can be explained partially by a reduction in subacute acidosis as compared with feeding the rapidly fermented grain alone and partially by an increase in ruminal and total tract digestion as compared with feeding the slowly fermented grain alone.

**LITERATURE CITED**


