ABSTRACT
The mechanisms by which reconstitution increases rumen degradation of grain sorghum and relevant studies that have measured effects of reconstitution on growth performance by finishing cattle were reviewed. The growth performance data summarized indicate that reconstitution of sorghum improved feed efficiency by 15% when compared to dry-rolled sorghum with a 7.6% increase in rate of gain. Individual trial responses to reconstitution have varied greatly both for feed efficiency and rate of gain. The extent to which differences in reconstitution techniques have contributed to this inconsistency is not clear, but laboratory trials indicate that the impact could be large. Laboratory data indicate that an aerobic germination period of 1 to 5 d with grain whole prior to anaerobic storage is a critical step in the reconstitution process. This germination period allows initiation of endogenous starch hydrolysis through gibberellin-like hormones that migrate to the aleurone layer and cause protease and amylase enzymes to be released. Endogenous starch hydrolysis ceases under anaerobic conditions, but grain nitrogen becomes increasingly soluble as the duration of both germination and ensiling increase; this increases microbial access to starch granules. Access of starch granules for microbial attack is not readily reflected by enzymatic starch availability measurements.

INTRODUCTION
Cereal grains fed to growing and finishing cattle typically are processed to increase ruminal digestion by increasing the rate of digestion (K_d) in the rumen relative to the rate of passage (K_p) from the rumen. The K_d of cereal grains can be increased by several mechanisms including particle size reduction (e.g., grinding, rolling), solublization of the protein matrix surrounding starch granules of the endosperm (e.g., fermentation during storage), and gelatinization of endosperm starch in concert with physical disruption of the protein matrix surrounding starch granules (e.g., steam flaking, popping, extruding, micronizing). For fermentation, grain can be harvested before it dries in the field (high moisture harvest) or water can be added to dry grain (reconstitution) with this material being allowed to ferment. The harvest window during which grain moisture remains within the range ideal for production of high moisture corn lasts 7 to 14 days; for sorghum grain this period lasts only 2 to 5 days due to direct exposure of the grain in the sorghum head to the environment. Because of this short harvest window, reconstitution has been the preferred method to achieve fermentation with sorghum grain. Traditionally, reconstitution has been defined as the process of rehydrating dry grain (12-15% moisture) to approximately 30% moisture, storing the whole wet grain under oxygen-limiting conditions for approximately 3 weeks for fermentation, and rolling or grinding the fermented grain prior to feeding. Storage time will dictate the extent to which fermentation progresses. The objectives of this paper are to review the mechanisms by which reconstitution increases the K_d of grain sorghum, and to review relevant studies that have measured the effects of reconstitution on growth performance by finishing cattle.

Growth Performance Studies: Prior to 1976
Hinders (1976) reviewed much of the performance data with reconstituted grain sorghum conducted prior to 1976. He differentiated between grain that was reconstituted whole and stored in an oxygen-limited environment versus grain that was rolled or ground prior to storage. Particle size reduction before reconstitution allows the product to be stored in bunker silos. Relative rates of gain and relative feed efficiency for reconstituted grain sorghum relative to dry rolled grain sorghum from the individual studies reported by Hinders (1976) are shown in Figures 1a and 1b; data summarized across studies are in Figure 1c. In most studies, feed efficiency and rate of gain were improved when sorghum was reconstituted in the whole form but the magnitude of improvement varied considerably across trials. Three studies conducted during or prior to 1976 that were not included in this review were those of Schake et al. (1972), Riley et al. (1975), and Bolsen and Riley (1976).
Figure 1. Effects of grain sorghum reconstitution on relative average daily gain (1a) and relative feed efficiency (1b) of individual trials and summarized across trials (1c; Hinders, 1976).

Schake et al. (1972) reconstituted both dry whole and dry-rolled grain sorghum to approximately 30% moisture and evaluated feeding performance relative to a steam-flaked grain sorghum control. Both of the reconstituted grains were stored in oxygen-limiting structures. The whole grain was stored for 14 d prior to initial feeding and was rolled prior to feeding. The reconstituted rolled grain was stored for 30 d prior to initial feeding. Rate of gain was not affected by treatment ($P$-value not reported) but feed efficiency tended to be improved for cattle fed the reconstituted whole grain sorghum rolled versus the reconstituted rolled grain ($P$-value not reported). This study had 75 steers per treatment but only 2 pens/treatment. The studies of Riley et al. (1975) and Bolsen and Riley (1976) reported that there was no difference in cattle performance between those fed reconstituted grain sorghum and those fed dry rolled grain sorghum, but these studies had limited replication. Details of the reconstitution process were not fully described in these studies.

Using a body weight-adjusted ME approach in his review of grain processing, Owens et al. (1997) stated that in eight trials directly comparing steam-rolled milo with reconstituted milo, the reconstituted milo had higher body weight-adjusted ME than steam-rolled milo. However, it is not clear from the older literature or in the review of Owens et al. (1997) how closely the
“steam-rolled” grain that was used would compare to steam-flaked grain produced today. Furthermore, many of the earlier studies used only 2 or 3 replications per treatment. In addition, the exact steps involved in reconstituting milo in most of the older literature are not fully described. This makes it difficult to relate performance results to grain handling techniques or physical and chemical characteristics of the processed grain.

**Growth Performance Studies: Since 1976**

Huck et al. (1999) compared growth performance of finishing heifers fed 1) reconstituted grain sorghum rolled prior to reconstituting and ensiling 2) grain sorghum harvested at 25% moisture that was rolled prior to ensiling, and 3) a steam-flaked corn control. The reconstituted grain sorghum was harvested at 14% moisture, rolled, and reconstituted to either 30 or 35% moisture before ensiling. Rate of gain was not affected by processing method, but feed efficiency was superior \( (P < 0.10) \) for the 35% compared with the 30% moisture reconstituted grain sorghum. Feed efficiency was poorer (4%) for the 35% moisture reconstitution treatment relative to the steam-flaked corn control. Consistent with expectations, feed efficiency was poorer (9%; \( P < 0.10 \)) with the 30% moisture reconstituted grain sorghum than with steam flaked corn. Performance of cattle fed the rolled high-moisture grain sorghum was similar to that of cattle fed the 30% moisture reconstituted grain sorghum.

Simpson et al. (1985) evaluated the effects of several reconstitution methods using yearling steers. Their treatments included: 1) dry-rolled grain sorghum, 2) whole grain sorghum soaked in water 21 h that was rolled prior to feeding, 3) whole grain sorghum soaked in water 21 h and exposed to air for 21 h that was rolled prior to feeding, and 4) whole grain sorghum soaked in water 21 h, exposed to air for 21 h, ensiled in air tight polyethylene bags for 5 d and then rolled before feeding. Each grain was fed at 88% of ration dry matter. In the 138 d feeding trial (3 pens/treatment), dry matter intake by cattle fed the reconstituted grain was similar to that of cattle fed the dry rolled grain. Feed efficiency was not different \( (P > 0.12) \) among the treatments with added moisture, but feed efficiency was improved dramatically (15.4%, \( P < 0.12 \)) for steers fed reconstituted grain compared to steers fed dry-rolled grain sorghum.

A meta-analysis using mixed procedures of SAS (SAS Institute, Cary, NC) was conducted on selected growth performance studies published since the review by Hinders (1976) to provide quantitative estimates of the response to reconstituting grain sorghum. Studies included in our analysis must have included at least dry-rolled and reconstituted grain sorghum; fewer studies were available in which both steam-flaked and reconstituted grain sorghum were fed. The data set included the six reconstitution studies summarized by Owens et al. (1997) conducted between 1982 and 1986 as well as data from Simpson et al. (1985). Based on these data (Table 1), the improvement in feed efficiency from reconstituting grain sorghum was surprisingly large (15%). A performance improvement of this magnitude would require reconstituted sorghum to contain an optimistic 0.72 Mcal of NEg/lb if dry-rolled sorghum contained 0.61 Mcal of NEg/lb and was included as 80% of diet dry matter. Perhaps destruction of tannin during the fermentation process as demonstrated by Reichert et al. (1980) may have contributed to the improved feeding value of reconstituted sorghum in these studies. If so, reconstitution should be of less benefit with modern sorghum varieties produced in the US because no modern varieties contain high levels of tannin.

**Table 1. Growth performance by feedlot cattle fed processed grain sorghum**

<table>
<thead>
<tr>
<th>Item</th>
<th>Dry-rolled</th>
<th>Reconstituted</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trials, n</td>
<td>7</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Days on feed, lb</td>
<td>126</td>
<td>126</td>
<td>-</td>
</tr>
<tr>
<td>Initial weight, lb</td>
<td>656</td>
<td>653</td>
<td>-</td>
</tr>
<tr>
<td>Dry matter intake, lb/d</td>
<td>20.0(^a)</td>
<td>18.1(^b)</td>
<td>1.0</td>
</tr>
<tr>
<td>Average daily gain, lb/d</td>
<td>2.62(^a)</td>
<td>2.82(^b)</td>
<td>0.19</td>
</tr>
<tr>
<td>Feed efficiency</td>
<td>7.68(^a)</td>
<td>6.52(^b)</td>
<td>0.3</td>
</tr>
</tbody>
</table>

\(^{a,b}\)Means differ \( (P < 0.05) \).
More recent research conducted by Ponce et al. (2006) evaluated the effects of a modified reconstitution process that was applied to corn, not grain sorghum. The objective of their process was to solubilize the protein matrix of dry-rolled corn using a solution of urea and water and to enhance hydrolysis of starch by adding amylase enzyme. Dietary treatments contained 91% concentrate based on 1) dry-rolled corn (DRC), 2) dry-rolled corn treated with urea, amylase, and water (DRT), and 3) steam-flaked corn (SFC). Diets were formulated to contain similar percentages of protein from NPN. Because the DRT grain contained 0.55% added urea, 0.55% urea was added to the remaining diets. In addition, the equivalent of 0.32% urea was added from a steep/molasses blend; the equivalent of 0.1% urea was added to all diets from ammonium sulfate. The DRT diet was prepared each afternoon and held under ambient conditions until being fed the next day.

Steers receiving SFC consumed less DM than steers fed either DRC (5.8%) or DRT (7.3%). Steers receiving DRC tended to gain weight less rapidly on a carcass-adjusted basis (4.7%; \(P < 0.15\)) than steers receiving the DRT diet. Carcass-adjusted feed efficiency was poorest (\(P < 0.10\)) for steers receiving DRC, but efficiency was improved above that for DRC by 3.1% by feeding DRT and an additional 6.3% by feeding SFC. The authors stated that this improvement in feed efficiency from treating the dry-rolled corn with urea, amylase, and water would be conservative because the study was conducted during the cool fall and winter months, and catalytic activity of amylase is dependent on ambient temperature.

**Kernel Characteristics**

At the time most of the reconstitution studies were conducted, the mechanisms by which reconstitution improved growth performance were not clear. Sullins et al. (1971) proposed that softening of the kernel and fermentation changes involving degradation of the protein matrix were involved. Their microscopic analysis revealed that the structure of the endosperm of reconstituted grain was modified and this increased accessibility of the starch granules. Others proposed that lactic acid-producing flora found on grain sorghum were responsible for the benefit attributed to reconstitution (Pflugfelder et al., 1986).

Interestingly, Van der Walt (1956) identified eight species of lactic acid bacteria responsible for the souring of South African sorghum beer. These bacteria produce an exo-polysaccharide shell from sucrose. Pflugfelder et al. (1986) suggested that the ability of these and other slime-producing organisms to convert soluble sugars into an insoluble storage polysaccharide might account, in part, for the effective conservation of dry matter reported during conventional reconstitution.

Between 1971 and 1981, several studies (Sullins et al., 1971; Wagner et al., 1974; Hibberd et al., 1981) indicated that the onset of germination could explain the chemical changes observed in reconstituted grain sorghum. Sullins et al. (1971) detected the release of gibberellin-like hormones that can migrate to the aleurone layer to stimulate the release of protease and amylase enzymes. Girdling the aleurone layer of barley prior to steeping inhibited degradation of the endosperm because the hormone-like substances were unable to move from the embryo to the aleurone layer to activate these enzymes. Grinding or rolling prior to reconstitution destroys this signaling pathway and inhibits much of the autolytic process (Sullins et al., 1971). However, some enzymes present in the particles of ground grain still were activated when water was added; this could result in some enzymatic degradation (Sullins et al., 1971).

Pflugfelder et al. (1986) examined the impact of germination and anaerobic storage on sorghum reconstitution. In their study, grain moisture content was increased to 30-35% by steeping for 16 h in 18°C to 20°C tap water. The steeped grain was allowed to germinate at room temperature under aerobic conditions for 0, 0.5, 1.0, 1.5, or 2.0 d prior to anaerobic storage for 0, 5, 13, or 21 d. The combination of 0 d for germination with 21 d for anaerobic storage simulated conventional reconstitution procedure. Surprisingly, this treatment combination produced little increase in nitrogen solubility above that of untreated controls. Each additional 12 h of germination time resulted in the solubilization of approximately 10% more nitrogen, reaching approximately 50% solubilization for the 2-d germination after 21 d of anaerobic storage; nitrogen continued to be solubilized during anaerobic storage. Starch hydrolysis also was increased with germination periods of 1.5 and 2.0 d, but anaerobic storage did not alter starch hydrolysis. These observations indicate that the endosperm matrix protein could be degraded during both germination and anaerobic storage, but at least 24
h for germination was needed to initiate starch hydrolysis. The authors concluded that short periods of germination prior to anaerobic storage of reconstituted sorghum should greatly accelerate the anaerobic fermentation process and improve digestibility for ruminants. Dry matter loss during the entire process (germination + anaerobic storage) ranged from 2% to 18%.

More recently, Balogun et al. (2005) studied the effect of aerobic and anaerobic treatments on laboratory characteristics of grain sorghum. Samples of grain were either dry-rolled or soaked whole. Soaked grain was 1) rolled after soaking, 2) stored anaerobically for 21 d and then rolled, 3) stored aerobically for 5 d to allow germination and then rolled, or 4) stored aerobically for 5 d to allow germination and finally stored anaerobically for 16 days and then rolled. As occurred in the study of Pflugfelder et al. (1986), treatments that involved aerobic storage to allow germination significantly increased the solubility of nitrogen and carbohydrate as well as extent of fermentation and degradation of the reconstituted grain. The combination of aerobic and anaerobic treatments increased fermentability and degradability of reconstituted grain. Balogun et al. (2005) concluded that incorporating an aerobic phase that allows germination to occur prior to anaerobic storage could take advantage of the activity of both endogenous and microbial enzymes to improve the digestibility of grain sorghum. Work by McNeill et al. (1971) indicates that reconstitution of sorghum will increase the extent of ruminal starch digestion (Table 2) compared to dry-rolling primarily due to greater accessibility of starch because reconstitution did not alter in vitro starch availability (Table 3; McNeill et al., 1975). Ruminal protein digestion of reconstituted sorghum also is markedly higher than for dry-rolled sorghum (Table 4; Potter et al., 1971).

Table 2. Ruminal, post ruminal, and total tract digestion of starch from reconstituted grain sorghum (McNeill et al., 1971)

<table>
<thead>
<tr>
<th>Item</th>
<th>Dry Ground</th>
<th>Reconstituted</th>
<th>Steam Flaked</th>
<th>Micronized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruminal Digestion, %</td>
<td>42.03</td>
<td>66.67</td>
<td>83.41</td>
<td>42.99</td>
</tr>
<tr>
<td>Post Ruminal Digestion, %</td>
<td>94.42</td>
<td>98.42</td>
<td>98.42</td>
<td>95.00</td>
</tr>
<tr>
<td>Total Digestion, %</td>
<td>96.76</td>
<td>99.47</td>
<td>99.74</td>
<td>97.14</td>
</tr>
</tbody>
</table>

Table 3. Susceptibility of processed sorghum grain to amyloglucosidase (McNeill et al., 1975)

<table>
<thead>
<tr>
<th>Item</th>
<th>Glucose release, mg/g dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Ground</td>
<td>118.6</td>
</tr>
<tr>
<td>Reconstituted</td>
<td>139.3</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>615.5</td>
</tr>
<tr>
<td>Micronized</td>
<td>232.7</td>
</tr>
</tbody>
</table>

These data provide one plausible explanation for performance benefits sometimes observed from reconstituting grain sorghum; however, the extent of germination in most studies is unclear. Disparity in procedures probably explains the variability in response associated with reconstitution.

SUMMARY

Addition of 15 to 18 percentage points of moisture to field-dried, unprocessed (whole) sorghum grain generally requires multiple additions of small increments of water on more than one occasion or other modifications to achieve uniform moisture distribution before ensiling. [For corn grain, water uptake is much faster if water is hot rather than cold.] In contrast, water absorption by ground or rolled sorghum grain occurs within minutes. Germination requires an intact seed plus oxygen and warmth and is an important factor for improving feeding value in the reconstitution process. Germination could be initiated before ensiling and continue until oxygen within the storage structure is depleted if environmental conditions are favorable. Germination for 24 hours will initiate endogenous starch hydrolysis, but this process ceases under anaerobic conditions. Nevertheless, grain nitrogen becomes increasingly soluble as the length of either germination or ensiling increases; this increases...
accessibility of starch granules to ruminal microbes. Growth performance data indicates that reconstitution of sorghum can improve feed efficiency by 15% when compared dry-rolled sorghum, but confirmation of these data is needed using current sorghum grain varieties and production practices.

LITERATURE CITED

QUESTIONS AND ANSWERS
Q: Mike, why was urea added when you reconstituted your grain?
A: We were hoping for some urea hydrolysis and ammoniation of the grain. Based on starch availability measurements, we did not get any benefit from the amylase enzyme. We did see a slight improvement in performance with the urea treatment, likely from slightly greater starch accessibility. In addition, we conducted this study in the wintertime to determine if under those ambient conditions we would see any benefit from the added enzyme.

Q: Mike, what are the logistical challenges for reconstituting grains at a commercial feedyard to increase the feeding value of dry grain?
A: Size will impact the logistics. Bob Lake pointed out the extensive nature of their effort involved with ensiling high-moisture corn. The key factors with reconstitution are hydrating the grain and then allowing sufficient time for enzymatic or bacterial activity. The logistics of reconstituting a large quantity of grain in a short time and storing it for a sufficient time under the favorable ambient conditions to get the optimum response would present a huge logistical challenge for a large feedlot.