INTRODUCTION

Several excellent recent reviews of grain processing are referenced at the end of this article. Thus, the focus of this discussion is limited to the implications and the applications of research on steam flaking, citing selected studies that illustrate salient items. The emphasis is on high-concentrate diets fed to growing/finishing cattle.

In this article, steam flaking frequently is compared to dry rolling while recognizing that other processes (i.e., high-moisture or whole corn) often are viable alternatives. Within processing method, grain attributes can vary considerably, such as degree of gelatinization after steam flaking and grain particle size after dry rolling.

For simplicity, “steam flaking” hereafter will be called “flaking.” For this discourse, flaking is considered the process of steaming whole grain at atmospheric pressure, typically for 20 to 40 minutes, and then rolling it to a flake density from 24 to 32 lb/bushel. This causes sufficient disruption of the starch-protein matrix to result in starch digestibility of 80% to 90% in the rumen and 98% to 99% in the total tract. Consequently, one might expect a greater response to flaking with grains that contain more starch; also, response to flaking should be more consistent for grains that are less variable in starch content. The mean and standard deviation for starch content (% of DM) for various cereal grains from DairyOne (2007) were: corn 70.5 ± 5.1; sorghum grain 64.5 ± 14.2; wheat 62.7 ± 9.6; and barley 54.6 ± 9.5%.

GROWTH PERFORMANCE

Flaking Corn

Compared to dry rolling or ensiling, flaking appreciably improves energetic efficiency of corn (Table 1); these differences were summarized in a review of grain processing by Owens et al. (1997). Among criteria for including data in their summary were 1) roughage less than 15% of diet DM, 2) grain more than 55% of diet DM, and 3) a single grain and processing method within a given diet.

<table>
<thead>
<tr>
<th>Process</th>
<th>ADG, lb</th>
<th>DMI, lb/d</th>
<th>F:G</th>
<th>ME, Mcal/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rolled</td>
<td>3.20a</td>
<td>20.8a</td>
<td>6.57a</td>
<td>1.46a</td>
</tr>
<tr>
<td>High Moisture</td>
<td>3.02b</td>
<td>19.2b</td>
<td>6.43a</td>
<td>1.56b</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>3.15a</td>
<td>18.4c</td>
<td>5.87b</td>
<td>1.68c</td>
</tr>
</tbody>
</table>

Owens et al. (1997).

*ADG, average daily gain; DMI, dry matter intake; F:G, feed to gain ratio; ME, metabolizable energy.

When these data are interpreted for feedlot application, variation in efficiency within a processing method can be quite large, particularly with high-moisture or dry-processed corn. Regarding high-moisture corn, Owens et al. (1997) reported that ME values ranged from 1.32 to 1.58 Mcal/lb DM depending on the moisture content and form of processing of the corn.

Summarizing four trials comparing flaked with dry-rolled or -ground corn, Zinn et al. (2002) noted that flaking improved $NE_g$ values from 15.9 to 25.9%.

Some of this large variation in flaking response probably was due to differing efficiencies of dry-processed corn because particle characteristics (size and uniformity) of dry rolled corn can vary widely.

Two recent research reviews (Table 2) indicate that the energetic response to flaking corn, as compared to dry rolling, is considerably greater than summarized in NRC Beef (1996). Zinn et al. (2002) offered two reasons for this difference between research and NRC values, 1) tabular NE values for dry-rolled corn have been overestimated and 2)
tabular NE values for flaked corn have been underestimated, perhaps due to failure to consider the increased digestibility of the non-starch organic matter associated with flaking.

Improvements in growth performance of feedlot cattle that result from flaking corn can be explained largely by increased ruminal, post-ruminal and total-tract digestion of starch (Table 3). Also important is the increased digestibility of non-starch organic matter that appears similar in magnitude to the enhancement in starch digestion (Zinn et al., 1995). A protein matrix encapsulates unprocessed cornstarch granules. Zein normally ferments slowly in the rumen. Flaking denatures zein, and this contributes to the improved digestion of starch and nitrogen.

Table 2. Advantage (%) of flaking corn, compared to dry rolling*

<table>
<thead>
<tr>
<th>Reference</th>
<th>NE\textsubscript{m}</th>
<th>NE\textsubscript{g}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owens et al. (1997)</td>
<td>16.7</td>
<td>22.2</td>
</tr>
<tr>
<td>Zinn et al. (2002)</td>
<td>14.2</td>
<td>17.3</td>
</tr>
<tr>
<td>NRC, Beef (1996)</td>
<td>4.0</td>
<td>4.5</td>
</tr>
</tbody>
</table>

*NE\textsubscript{m}, net energy for maintenance; NE\textsubscript{g}, net energy for gain.

Table 3. Digestibility (%) of starch in corn

<table>
<thead>
<tr>
<th>Process</th>
<th>Rumen, % Intake</th>
<th>Postrumen, % Entering</th>
<th>Total Tract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rolled</td>
<td>61 – 76</td>
<td>68 – 69</td>
<td>89 – 92</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>84 – 85</td>
<td>93 – 94</td>
<td>99</td>
</tr>
</tbody>
</table>


In addition to improving starch utilization, Huntington (1997) reported that flaking corn reduces the variation in starch digestibility throughout the GI tract (Table 4). Thus, one can infer logically that the animal growth response is more consistent with flaking than dry rolling. However, as previously emphasized, dry rolling is a nebulous term due to wide distribution of particle sizes.

Table 4. Digestibility (%) of starch in corn

<table>
<thead>
<tr>
<th>Process</th>
<th>Rumen, % Intake</th>
<th>Postrumen, % Entering</th>
<th>Total Tract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rolled</td>
<td>76 +/- 8</td>
<td>69 +/- 18</td>
<td>92 +/- 3</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>85 +/- 4</td>
<td>93 +/- 4</td>
<td>99 +/- 1</td>
</tr>
</tbody>
</table>

Huntington (1997).

Flaking Sorghum

Compared to dry rolling, flaking also substantially improves energetic efficiency of sorghum grain (Table 5) as summarized in the review by Owens et al. (1997). As with corn, flaking sorghum improves growth performance of feedlot cattle by increasing appreciably the ruminal, post-ruminal and total-tract digestion of starch (Table 6).

Table 5. Least squares means for sorghum processed by various methods

<table>
<thead>
<tr>
<th>Process</th>
<th>ADG, lb</th>
<th>DMI, lb/d</th>
<th>F:G</th>
<th>ME, Mcal/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rolled</td>
<td>3.15</td>
<td>23.1\textsuperscript{a}</td>
<td>7.43\textsuperscript{a}</td>
<td>1.32\textsuperscript{a}</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>3.09</td>
<td>19.1\textsuperscript{b}</td>
<td>6.33\textsuperscript{b}</td>
<td>1.59\textsuperscript{b}</td>
</tr>
</tbody>
</table>

Owens et al. (1997).

*ADG, average daily gain; DMI, dry matter intake; F:G, feed to gain ratio; ME, metabolizable energy. \textsuperscript{ab}(P < 0.05).

Huntington (1997) did not report the degree of trial-to-trial variation in starch digestibility for flaked sorghum, as was noted with corn, presumably due to the small number of trials with sorghum. However, one can deduce that flaking sorghum, as with flaking corn, should reduce the variation in digestion and animal performance.
Table 6. Digestibility (%) of starch in sorghum

<table>
<thead>
<tr>
<th>Process</th>
<th>Rumen, % Intake</th>
<th>Postrumen, % Entering</th>
<th>Total Tract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rolled</td>
<td>60 +/- 12</td>
<td>62 +/- 11</td>
<td>87 +/- 5</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>78</td>
<td>90</td>
<td>98</td>
</tr>
</tbody>
</table>

Huntington (1997).

1Variation around means not reported.

Huntington (1997) noted that flaking increased ruminal digestibility of starch more for sorghum (19 percentage units) than for corn (13 percentage units). The protein matrix encapsulating raw sorghum starch is even more resistant to microbial degradation than the matrix in corn. Because flaking degrades this matrix, benefits of flaking, in terms of starch digestion and animal performance, are greater for sorghum than for corn. Compared to dry rolling, Owens et al. (1997) reported steam flaking improved ME values for sorghum and corn by 20.5% and 15.1%, respectively.

Although the response (on a percentage basis) to flaking is higher from flaking sorghum, flaked corn remains superior to flaked sorghum in absolute starch digestion throughout the digestive tract (Table 7). These different coefficients are the principle reason that the ME value is 5.3% lower for flaked sorghum than flaked corn (Owens et al., 1997) even though these grains often have a similar starch content.

Theurer et al. (1996) suggested that optimal ruminal starch digestibility for corn and sorghum were near 80% and 85%, respectively, for feedlot cattle on high-grain diets. Research studies summarized in Table 7 suggest that achieving this target is more feasible with corn than sorghum without causing some potential negative consequences of over-processing.

Table 7. Digestibility (%) of starch

<table>
<thead>
<tr>
<th>Process</th>
<th>Rumen, % Intake</th>
<th>Postrumen, % Entering</th>
<th>Total Tract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flaked Corn</td>
<td>84 – 85</td>
<td>93 – 94</td>
<td>99</td>
</tr>
<tr>
<td>Flaked Sorghum</td>
<td>78 – 79</td>
<td>89 – 90</td>
<td>97 – 98</td>
</tr>
</tbody>
</table>

Huntington (1997), Owens and Zinn (2005), Swingle et al. (1999), Theurer et al. (1999).

**Flaking Wheat**

In their review, Owens et al. (1997) reported that flaking wheat, compared to dry rolling, improved body weight-adjusted ME by 13% as compared with improvements in ME of 15% and 21% for flaked corn and flaked sorghum, respectively. Flaking wheat reduced feed intake but had no impact on daily gain (Table 8). In contrast, Zinn (1994) reported that flaking wheat tended to increase dry matter intake and increase daily gain.

Table 8. Least squares means for wheat processed by various methods*

<table>
<thead>
<tr>
<th>Process</th>
<th>ADG, lb</th>
<th>DMI, lb/d</th>
<th>F:G</th>
<th>ME, Mcal/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rolled</td>
<td>3.04</td>
<td>19.8a</td>
<td>6.59a</td>
<td>1.49a</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>3.04</td>
<td>17.9b</td>
<td>5.92b</td>
<td>1.70b</td>
</tr>
</tbody>
</table>

Owens et al. (1997).

*aADG, average daily gain; DMI, dry matter intake; F:G, feed to gain ratio; ME, metabolizable energy.

These differing conclusions probably are due to variation in physical attributes of processed wheat. Dry-rolling wheat creates fine particles; flour can reduce intake and gain and increases the potential for acidosis and bloat. The same appears true for thin, fragile flakes. Conversely, thicker flakes as described by Zinn (1994) improved “diet acceptability” compared to dry rolling; improved acceptability and increased intake may account for much of the improvement in feed efficiency noted from flaking of wheat.

Flaking has far less impact on starch digestion from wheat than from corn or sorghum (Table 9). Yet the improvement in energetic efficiency from flaking wheat approaches that for corn. This supports the
concept that much of the benefit from flaking of wheat is associated with an improved physical form or increased digestibility of non-starch organic matter.

**Table 9.** Digestibility (%) of starch in wheat for feedlot cattle

<table>
<thead>
<tr>
<th>Process</th>
<th>Rumen, % Diet</th>
<th>Postrumen, % Flow</th>
<th>Total Tract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rolled</td>
<td>86.0</td>
<td>84.6</td>
<td>97.9</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>91.6</td>
<td>85.2</td>
<td>98.8</td>
</tr>
</tbody>
</table>

Owens and Zinn (2005).

**Flaking Barley**

Owens et al. (1997) reported no improvement in body weight-adjusted ME from flaking barley compared to dry rolling (Table 10) despite sizable improvements from flaking corn (15%), sorghum (21%) and wheat (13%). However, in that review, far fewer studies were available for barley than for the other flaked grains.

Summarizing least squares means from research trials, Owens and Zinn (2005) reported a trend for improved starch digestion by cattle fed flaked barley as compared to those fed dry-rolled barley (Table 11). Flaking enhances the rate of enzymatic starch digestion in barley, particularly when flakes are thin (Zinn, 1993).

**Table 10.** Least squares means for barley processed by various methods*

<table>
<thead>
<tr>
<th>Process</th>
<th>ADG, lb</th>
<th>DMI, lb/d</th>
<th>F:G</th>
<th>ME, Mcal/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rolled</td>
<td>3.20</td>
<td>19.8</td>
<td>6.25</td>
<td>1.62</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>2.93</td>
<td>18.2</td>
<td>6.19</td>
<td>1.61</td>
</tr>
</tbody>
</table>

Owens et al. (1997).

*ADG, average daily gain; DMI, dry matter intake; F:G, feed to gain ratio; ME, metabolizable energy.

**Table 11.** Digestibility (%) of starch in barley for feedlot cattle

<table>
<thead>
<tr>
<th>Process</th>
<th>Rumen, % Diet</th>
<th>Postrumen, % Flow</th>
<th>Total Tract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rolled</td>
<td>86.2</td>
<td>81.6</td>
<td>97.1</td>
</tr>
<tr>
<td>Steam Flaked</td>
<td>89.2</td>
<td>90.5</td>
<td>99.1</td>
</tr>
</tbody>
</table>

Owens and Zinn (2005).

As with wheat, interpretation of the response to flaking of barley is difficult considering the low number of trials. Often not well described were important attributes such as particle size with dry rolling and gelatinization with flaking. Depending on flake thickness, Zinn (1993) observed that flaking of barley increased $\text{NE}_\text{m}$ from 2.8 to 7.0% and $\text{NE}_\text{g}$ from 3.4 to 8.8%.

**Industry Perspectives**

This author surveyed feedlot nutritionists for their perception of the net energy response to steam flaking. For each grain, the question was “Compared to dry rolling, what is the average percentage increase in grain $\text{NE}_\text{g}$ (DM basis) from steam flaking?” Criteria for answers were those used by Owens et al. (1997) including 1) roughage DM < 15% diet, 2) grain of interest > 55% of diet DM, 3) free choice access to feed, 4) single grain source, 5) flaking as only process, and 6) feedlot cattle > 99 days on feed. Results of this survey are summarized in Table 12.

**Table 12.** Increase (%) in grain $\text{NE}_\text{g}$ from steam flaking: Industry survey

<table>
<thead>
<tr>
<th>Grain</th>
<th>No. Responses</th>
<th>Mean, %</th>
<th>Range, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>12</td>
<td>11.6</td>
<td>8 to 14</td>
</tr>
<tr>
<td>Sorghum</td>
<td>11</td>
<td>15.4</td>
<td>8 to 19</td>
</tr>
<tr>
<td>Barley</td>
<td>6</td>
<td>4.5</td>
<td>0 to 5</td>
</tr>
<tr>
<td>Wheat</td>
<td>10</td>
<td>4.5</td>
<td>2 to 10</td>
</tr>
</tbody>
</table>
**Carcass Value**

In an analysis of data from published literature, Owens and Gardner (2000) reported that cattle fed flaked grains had heavier carcass weights than those fed dry-rolled, high-moisture, or whole grains, when averaged across grains (corn, sorghum and wheat). When other attributes were adjusted for carcass weight differences, cattle fed flaked grains had larger longissimus areas and greater subcutaneous fat thickness but lower marbling scores and quality grades than cattle fed dry-rolled grains. The authors suggested that higher subcutaneous fat deposition in cattle fed flaked grains is related to less escape of dietary starch from the rumen.

When finished cattle are marketed on a carcass basis, value depends on carcass weight, quality grade and/or yield grade. Considering the carcass performance data reported by Owens and Gardner (2000), economic return from flaking is determined far more by carcass weight, and efficiency of carcass growth, than by carcass quality or yield grade.

**MANAGING THE PROCESS**

Zinn et al. (2002) prepared an excellent treatise on processing mechanics and quality standards. Although the focus of that review was flaking of corn, their commentary also is applicable to flaking sorghum. With the objective of improving animal performance, the primary purpose of flaking is optimizing starch digestion by 1) disrupting the protein matrix that encapsulates starch granules, and 2) damaging starch granules that in their native state are densely compacted.

As previously noted, benefits from steam flaking are greater with corn and sorghum than with wheat and barley. The same is true of the challenges with steam flaking. Although there are differences among varieties within a grain, corn and sorghum have more vitreous (hard) endosperm whereas wheat and barley contain a higher percentage of floury (soft) endosperm. In addition, the protein matrices of corn and sorghum inherently are more resistant to degradation than are proteins of wheat and barley.

As outlined by Zinn et al. (2002) the essential mechanics of flaking are 1) hydrate starch with moist heat to create irreversible swelling (gelatinization) of granules and 2) compress starch between rolls at a close tolerance to rupture granules and shear the protein matrix. A proper combination of moisture, heat and pressure is necessary to achieve full benefit from flaking. Implemented alone, hydrating, steaming or rolling has less impact on starch digestion.

**Moisture Addition**

In most feedlots, water (with or without conditioner) is applied to whole grain during transfer of grain from dry storage to holding bins. Adding water after cleaning of grain is preferred because foreign material will wick moisture away from grain. Adequate mixing in a blending auger is essential for uniform uptake of moisture. Inconsistent absorption of water by whole grain causes variation in flake quality and uneven wear of rolls.

Depending on moisture of incoming grain and the target moisture for flakes, 5 to 7% water typically is applied. Steeping time for wetted grain ranges from 30 minutes to 12 hours based on facility design. Steaming further increases grain moisture by 2 to 4% units. The increase in moisture from steaming is influenced by moisture content of grain entering the chest and the time of steaming (retention time). Depending on these variables, flakes will range from 19 to 24% moisture as they exit from the rolls.

The effect of flake moisture on starch digestibility has received limited research attention. The same is true regarding interactions of moisture with density and retention time. With corn, Zinn et al. (2002) suggested that adding 5% moisture was sufficient when retention was about 30 minutes.

Also with corn, Sindt et al. (2006) indicated that adding moisture (up to 10% to whole grain initially at 11%) increased flake moisture and durability but had no effect on enzymatic starch availability. With sorghum, McDonough et al. (1997) reported that higher flake moisture, achieved by adding more water during tempering, improved both the structural integrity of flakes and extent of gelatinization of starch.

Routine measurement of flake moisture is important because it provides insight about the consistency of flakes and composition of ration dry matter. Daily testing of flakes beneath each roll helps achieve consistency among rolls. Flake moisture also can change from rolls to feed bunks depending on how flakes are conveyed (airlift vs. drag) and stored.
Retention Time

Time in steam chests varies among grains and across feedlots. Typical retention times are 30 to 40 min for corn, 40 to 50 min for sorghum and 20 to 30 min for wheat and barley. Zinn et al. (2002) noted that little research was available concerning the minimum retention time for optimal flaking but they suggested that a 30-min steaming was adequate for corn.

Feedlots usually steam for a longer time with sorghum than with corn grain, presumably due to the thicker protein matrix that surrounds starch granules of sorghum. Steaming of wheat and barley is for relatively short periods because the flaking emphasis with these grains is more on physical form than on starch digestion.

Estimating retention time in a steam chest is an important protocol that can be measured using a dye test or measuring the emptying rate of the cabinet. Injecting a food-grade dye at the top of a chest and timing its appearance at the bottom provides insight on retention time and uniformity of flow. Measuring each chest in a feed mill is essential because seemingly identical units can have different retention times. Further, measuring retention is important whenever there is change in grain source or cabinet design.

Flake Thickness (Density)

The most important variable affecting extent of processing is flake thickness, measured indirectly in feedlot mills as density (bushel weight). In studies summarized by Owen and Zinn (2005), flaking corn to lower densities for feedlot cattle increased starch digestion at all sites, particularly the small intestine. Results with varying density of sorghum have been similar, with one notable exception. Lower density with sorghum failed to increase starch digestion in the small intestine (Swingle, et al., 1999; Theurer, et al., 1999; Xiong et al., 1991). These data suggest that the protein matrix in sorghum remains as an impediment to small-intestinal starch digestion.

Owens et al. (1997) summarized the influence of flake thickness on cattle performance for corn, sorghum and barley. Flakes of medium thickness (23 to 29 lb) tended to result in superior cattle performance, compared the thinner (< 23 lb) or thicker (> 29 lb) flakes. They reported flake weights as “dry” densities. One must be cautious extrapolating data in their review to feedlots because roll operators often weigh flakes hot and moist.

Consistency within a mill (among operators, across rolls and over time) is essential. As noted, flakes weigh more when hot and moist than when cool and dry. Intact flakes weigh less than fines. Differences in weighing protocol can easily result in 2- to 3-lb difference in bushel weight.

Regarding optimum density, one size does not fit all; it varies among feedlots and even among rolls within a mill. Flaking to a similar density does not necessarily assure that flakes are similar in terms of starch availability.

Other Considerations

McDonough et al. (2004) reported that accelerated aging of corn and sorghum at 50°C for up to 15 days increased hardness index of the grain by 12 to 15%. During aging, floury endosperm became more corneous. As the grain hardened, strong associations between starch and protein developed, causing the endosperm to fracture through endosperm cells instead of along cell walls. These observations suggest that flaking is more beneficial, and extensive flaking more useful, for grain stored long periods than for grain freshly harvested. As a practical matter, optimum flake weight probably differs by period of time grain is stored and conditions during storage.

When flaked grains are stored in warm, moist conditions, gelatinized starch molecules can reassociate to form retrograde starch. Retrograde starch is “enzyme resistant” when incubated in the presence of starch-digesting enzymes such as amylglucosidase. However, the capacity of rumen microbes to ferment or solublize enzyme-resistant retrograde starch is unclear. Ward and Galyean (1999) compared flaked-corn samples collected beneath rolls to samples collected as flakes exited storage bins. Bin samples were much lower in enzymatic starch availability, compared to roll samples. However, sampling site did not affect rate or extent of in vitro dry matter disappearance (IVDMD). In a study with similar design, McMeniman et al.
(2007) also reported lower starch availability in bin samples compared to roll samples. In contrast to the findings of Ward and Galyean (1999), these authors reported rate and extent of IVDMD were lower for bin samples. Whether retrograde starch impacts feedlot performance is unknown, but the subject merits further study.

OPTIMUM PROCESSING

Owens and Zinn (2005) and Zinn (1990) indicated that net energy reached a maximum when flake density of corn resulted in 99% total tract digestion of starch. Theurer et al. (1996a) suggested that optimum processing resulted in 80% and 85% ruminal starch digestion for corn and sorghum, respectively.

Processing beyond this optimum tends to increase rate more than extent of starch digestion, thereby increasing risk. Illustrated in Table 13, risk includes increased acidosis, reduced DMI, and poorer efficiency (Reinhardt et al., 1997). Other consequences of over-processing are an increased incidence of bloat, laminitis and feed aversion.

Table 13. Degree of processing and performance of cattle fed sorghum

<table>
<thead>
<tr>
<th>Item*</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28</td>
</tr>
<tr>
<td>Retention time, min</td>
<td>50</td>
</tr>
<tr>
<td>Gelatinization, %</td>
<td>58.7</td>
</tr>
<tr>
<td>pH*hours</td>
<td></td>
</tr>
<tr>
<td>Below 5.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Below 5.5</td>
<td>18.2</td>
</tr>
<tr>
<td>DMI, lb/d</td>
<td>19.0</td>
</tr>
<tr>
<td>F:G</td>
<td>5.92</td>
</tr>
</tbody>
</table>

Reinhardt et al. (1997).

*DMI, dry matter intake; F:G, feed to gain ratio.

It is a practical challenge to determine the density (thickness) at which optimum processing is achieved. Zinn et al. (2002) reported strong relationships of density to solubility ($r^2 = 0.87$) and enzyme reactivity ($r^2 = 0.79$). However, a considerable lag time exists between the production of flakes and their laboratory evaluation. Further, relationships of density to ruminal ($r^2 = 0.22$) and total tract ($r^2 = 0.52$) starch digestion were not so strong.

Fecal starch, perhaps a more suitable measure of starch digestion, explained 91 to 94% of variation in total-tract starch digestion, and 68% of variation in ruminal starch digestion for corn in feedlot cattle (Zinn et al., 2002; Owens and Zinn, 2005). Numerous studies with corn, sorghum and barley have shown that fecal starch as a percentage of fecal DM is less for cattle fed flaked grain than for cattle fed dry-rolled grain. Further, among flaked grains, lower flake density typically reduces fecal starch.

Owens and Zinn (2005) suggested that optimum processing of flaked corn occurred in feedlot cattle when fecal starch was 4% to 5% of DM. Despite encouraging research, most feedlots do not routinely monitor fecal starch. Thus, we know very little about inherent variation in fecal starch, either among individuals within a pen or pens within a feedlot.

OTHER FACTORS

Compiling data from studies directly comparing starch digestibility to animal performance, Theurer et al. (1996a) reported that ruminal and small-intestinal starch digestibility accounted for 54% and 35%, respectively, of variation in feed efficiency. These data confirm the importance of grain processing and also illustrate that factors besides grain processing can significantly influence performance. Some of these factors have been studied in research trials; others are apparent from experience at feedlots. Some remain speculative.

Roughages

Roughage (forage NDF) contributes little digestible energy to high-concentrate diets. On the other hand, roughage aids in mixing the diet, stimulating saliva production, diluting acids, and encouraging rumination. Unfortunately, we do not understand all the complex interactions between roughage and grain processing.
Owens et al. (1997) reported that alfalfa was superior to corn silage in body weight-adjusted ME response for flaked corn, sorghum and wheat. Owens and Zinn (2005) indicated that optimum forage NDF range was 5% to 9% for cattle fed growing/finishing diets and suggested that values outside this range compromise energy intake and daily gain. Theurer et al. (1999b) noted that at a constant forage NDF, there were no interactions among dry roughage sources and response to flaking sorghum grain to various densities.

Based on intuition and experience, this author believes there is an important inverse relationship between level of forage NDF and extent of grain processing. Specifically, the more extensively that flaked grain is processed, the higher the level of roughage necessary to sustain DM intake and minimize digestive disorders.

In addition to level of roughage, physical form also is important. Coarser processing results in less ration fines, stimulates chewing and rumination, and these help to maintain intake and minimize acidosis.

Concentrates

Associative effects among concentrates are important in determining benefit from flaking and optimum degree of processing. One example is combining high-moisture corn with flaked corn or sorghum. Rate of ruminal starch digestion is faster with high-moisture corn than flaked grain. Thus the presence of high-moisture corn might justify flaking more conservatively.

Another example is incorporating wet ethanol by-products. When finishing diets contain large amounts of corn wet distillers grains (CWDG), research suggests that the advantage of steam-flaked corn over dry-processed or high-moisture corn is reduced (Vander Pol et al., 2006; Corrigan et al., 2007). However, rather than diminishing the energetic efficiency of flaked corn, added CWDG appears to improve relative values of dry-processed and high-moisture corn.

Bunk Management

Pritchard and Bruns (2003) authored an excellent treatise on bunk management. Appropriately, they stated “the causes of variable results in bunk management research can be ambiguous.” The same is true for practices in feedlots. Evaluating results is difficult, partly because daily variation in feed intake by a pen provides little insight about animal-to-animal differences within a pen.

Emphasized by Pritchard and Bruns (2003), the primary considerations in bunk management are 1) controlling intake and 2) minimizing metabolic disorders. Because these also are important factors in grain processing, bunk management and steam flaking are inherently associated.

However, studies of this association are limited. One can presume that if bunk management minimizes intake variation, then it facilitates more extensive processing of grain. Conversely, practices that induce or fail to control intake variation require more conservative grain processing.

Defined by differences in providing access to feed, bunk management programs include ad libitum, clean bunk, and restricted (or limited) feeding. Often debated, merits and drawbacks of each program have not been studied sufficiently.

What is known or surmised is that the bunk management program affects a) level and variation of intake, b) rate and efficiency of growth, c) incidence of binging or aversion, and d) frequency of digestive disorders. Grain processing will affect these same parameters. In this common context, there is an inextricable link between flaking grain and managing bunks.

Feed Additives

Monensin fed in high-grain diets increases average rumen pH, reduces feed intake variation, increases meal frequency while diminishing meal size, and reduces bloat. Monensin also interacts with the bunk management program to affect rumen pH and eating behavior (Erickson et al., 2003). Unfortunately, the relationship between monensin and grain processing has received only very cursory examination in research studies.

In finishing rations devoid of monensin, such as those fed in “natural” programs, typical diet formulas include a higher amount of roughage to control acidosis and minimize bloat. When such rations contain flaked grain, particularly corn or sorghum, another means for managing digestive disorders is to process grain conservatively. When reducing ruminal
starch fermentation, potential tradeoffs are less total-tract digestion and subsequent loss of efficiency. In terms of animal performance, cost effectiveness of this exchange is unclear.

A similar conundrum exists between extent of grain processing and feeding antibiotics such as tylosin. Tylosin greatly reduces the incidence of liver abscesses and their negative impact on performance of cattle fed high-grain rations (Nagaraja and Chengappa, 1998). In the absence of tylosin, higher roughage levels in finishing rations will reduce the incidence of abscesses. It is unknown whether more conservative processing of flaked grain results in a similar benefit.

Environment

Eng (personal communication, 2006) stated that: “improvements from steam flaking are greater in more temperate and more stable climates.” Climate, season, weather, and breed type all can affect level and pattern of consumption. Therefore, it seems reasonable that these factors can influence not only the response to flaking, but also the optimum degree of processing. Framed in a practical context, flaking for a Brahman calf in the Southwest is different from flaking for a Continental yearling in the Midwest.

SUMMARY

Compared to all other methods of grain processing, flaking improves growth performance of cattle fed growing-finishing rations. Flaking improves energetic efficiency of corn and sorghum more than barley and wheat. For corn and sorghum, most of the benefit from flaking is due to improved ruminal and total tract digestion of starch. For barley and wheat, the principle advantage from flaking is higher feed intake, due to improved physical attributes of the grain.

Optimum processing usually maximizes net energy intake. For optimum results, flaking needs to be more extensive for corn and sorghum than barley and wheat. Inadequate processing corn and sorghum will compromise efficiency due to poor starch digestion. In contrast, excessive processing will reduce intake and gain, harm efficiency, and increase the prevalence of digestive and metabolic disorders.

Variables affecting steam flaking include grain type and variety, processing conditions, other diet ingredients, bunk management, feed additives, environment, and cattle type. Regarding processing conditions, flake thickness (density) has more impact than any other variable. Also important are retention time in the steam chest and moisture content at rolling. Laboratory evaluation provides only limited insight about processing. Fecal starch is a valuable tool, but it is not used widely. Other useful criteria include DM intake and digestive disorders. Compared to other methods of processing, flaking requires a greater investment in equipment, energy and labor. Costs of steam flaking to compare with its benefits are addressed elsewhere in this publication.

LITERATURE CITED


