INFLUENCE OF STEAMING TIME ON SITE OF DIGESTION OF FLAKED CORN IN STEERS

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ABSTRACT

Four crossbred steers (395 kg) with cannulas in the rumen, proximal duodenum and distal ileum were used to evaluate effects of steaming time of corn on characteristics of digestion. The basal diet contained (DM basis) 12% forage and 75% corn. The corn portion of the diet was provided as either dry-rolled (DR) or steam-flaked (SF), which had been exposed to steam for 34, 47 or 67 min prior to flaking to a mean density of .34 kg/liter. Longer steaming times linearly increased in vitro reactivity of corn starch to amylglucosidase. Steaming time had a quadratic effect (P < .05) on ruminal starch digestion. Ruminal starch digestibility of corn steamed for 47 min was 7% less than for corn steamed for 34 or 67 min. Longer steaming time linearly increased (P < .05) flow of non-ammonia N to the small intestine with the principal increase (5.4%) between 34 and 47 min steaming time. Steaming time did not influence (P > .10) small intestinal or total tract digestibility of OM, starch or N. Compared with DR, SF increased (P < .01) ruminal, small intestinal and total tract digestibility of starch 21.9, 75.1 and 9.2%, respectively.

Although SF resulted in marked improvements in digestibility over DR, steaming times greater than 34 min were not beneficial.

(Key Words: Maize, Starch, Processing, Cattle, Metabolism.)


Introduction

Theurer (1986), summarizing five metabolism trials comparing digestibility of steam-flaked (SF) and dry-rolled (DR) or whole-shelled corn by cattle, observed that total tract, ruminal and postruminal digestibilities of starch in whole-shelled or DR corn averaged 91, 70 and 70%, respectively, whereas corresponding values for SF corn averaged 99, 86 and 93%, respectively. Realizing this potential for improving the nutritive value of corn and other grains (Cole et al., 1976; Galvean et al., 1976; Lee et al., 1982; Ramirez et al., 1985; Zinn, 1987, 1988), many feedlots in the Southwest have included steam-flaking facilities in their feed milling operations. Unfortunately, from the standpoint of feed quality control, the milling specifications or attributes of SF corn that would reflect an optimum or ideal are lacking. As a result, considerable variation exists in the industry in milling practices and measurements for quality assurance. Milling practices that receive the greatest attention are steaming time and flake density. Quality assurance measurements include flake density, moisture uptake and in vitro enzymatic starch digestibility. The objective of this study was to determine the influence of steaming time of corn prior to flaking on characteristics of ruminal, intestinal and total tract digestion of a finishing diet containing 75% corn.

Experimental Procedure

Four crossbred (approximately 25% Brahman blood with the remainder represented by Hereford, Angus, Shorthorn and Charolais breeds in various proportions) steers (395 kg) with “T” cannulas in the rumen, proximal duodenum (6 cm from the pyloric sphincter) and distal ileum (20 cm from the ileal-cecal valve) were used to evaluate effects of steaming time of corn on characteristics of

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Dry-rolled corn was compared with SF corn prepared by exposing the corn to steam for periods of 34, 47 or 67 min prior to flaking to a mean density of 0.34 kg/liter. Under standard conditions of flake density as established for this trial, the 34-min steaming time treatment reflects the minimum steaming time we were capable of obtaining with our steam flaker. Dry-rolled corn was prepared by passing corn through rollers that had been adjusted so that approximately 95% of the kernels were broken (density = 0.54 kg/liter). Steam-flaked corn was prepared as follows. A chest situated directly above the rollers was filled to capacity (441 kg) with corn and brought to a constant temperature at atmospheric pressure of 102°C using steam. The length of time the grain was exposed to the steam was regulated by the rate at which the grain was allowed to pass from the steam chest to the rollers. In each case, the tension of the rollers was adjusted to provide a flake with a density of approximately 0.35 kg/liter. However, with corn held at the highest retention time (67 min), so little grain was being delivered to the rolls per unit time (averaging 6.6 kg/min) that we encountered difficulty in regulating the desired flake density. Consequently, the flake density for that treatment was slightly lower than that for the other two SF corn treatments. The first batch (approximately 441 kg) of SF corn to pass through the rollers was discarded before material was collected for use in this trial. Steaming time (ST, min) was calculated as ST = C/RR - M, where C is the capacity of the steam chest (kg air-dry corn), RR is the removal rate (kg/min) of corn from the chest as measured from beneath the rollers and M is the moisture uptake (kg/min) by the corn during steaming. The SF corn then was allowed to air-dry (5 d) prior to first feeding. Allowing the SF corn to air-dry may result in return of some of the gelatinized starch to an aggregated or insoluble form (retrogradation; French, 1973). Steers were maintained in individual slotted-floor pens (7.6 m²) with ad libitum access to water. Dry matter intake was restricted to 5.34 kg/d (approximately 85% of ad libitum) to avoid feed refusals. Composition of the basal diet is shown in Table 1. Diets were fed at 0800 and 2000 daily. Following a 2-wk diet adjustment period, duodenal, ileal and fecal samples were taken from all steers twice daily for four successive days as follows: d 1, 0750 and 1350; d 2, 0900 and 1500; d 3, 1050 and 1650 and d 4, 1200 and 1800. Individual samples consisted of approximately 500 ml duodenal chyme, 250 ml ileal chyme and 200 g (wet basis) fecal material. Samples from each steer and within each period were composited for analysis. Upon completion of the trial, ruminal fluid was obtained from all steers and composited for isolation of ruminal bacteria via differential centrifugation (Bergen et al., 1968). Samples were subjected to all or part of the following analysis: DM (oven drying at 105°C until no further weight was lost); ash, Kjeldahl N, ammonia N (AOAC, 1975); gross energy (adiabatic bomb calorimeter); purines Zinn and Owens, 1986); chromic oxide (Hill and Anderson, 1958); starch and gelatinized starch. Starch was assayed as follows: 1) a 200-mg ground sample was placed in a 20-ml screw-cap culture tube along with 10 ml H₂O and gently mixed; 2) the tube was capped tightly and incubated at 100°C in a water bath for 3 h (gelatinization step); 3) the tube was allowed to cool and 10 ml buffer (pH 4.5, 9.91 g sodium acetate [anhydrous] plus 7.27 ml glacial acetic acid in 1 liter H₂O), 67 units amyloglucosidase² (1 mg enzyme) and 1 drop toluene were added; 4) the tube again was tightly capped, gently mixed and incubated at 39°C for 2 h in a water bath with shaking; 5) 1 ml of starch hydrolysate solution and 4 ml TCA solution (30 g trichloroacetic acid in 1 liter H₂O) were placed in a 10-ml centrifuge tube and vortexed and incubated at room temperature for 5 min; 6) the tube then was centrifuged at 3,000 × g for 10 min; 7) 4 ml o-

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>%</th>
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<tbody>
<tr>
<td>Alfalfa hay</td>
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<td>6.00</td>
</tr>
<tr>
<td>Corn</td>
<td>74.68</td>
</tr>
<tr>
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<td>2.00</td>
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<td>Chromic oxide</td>
<td>.33</td>
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<tr>
<td>Vitamin A³</td>
<td>+</td>
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</tbody>
</table>

²DM basis.
³Added to provide 2200 IU/kg.

*Table 1. Ingredient composition of basal diet fed to steers.*

1. **Alfalfa hay**
2. **Sudangrass hay**
3. **Corn**
4. **Yellow grease**
5. **Cottonseed meal**
6. **Cane molasses**
7. **Limestone**
8. **Urea**
9. **Trace mineral salt²**
10. **Chromic oxide**
11. **Vitamin A³**

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TABLE 2. INFLUENCE OF STEAMING TIME OF CORN AT ATMOSPHERIC PRESSURE ON MOISTURE CONTENT AND IN VITRO ENZYMATIC STARCH DIGESTIBILITY

<table>
<thead>
<tr>
<th>Item</th>
<th>Dry-rolled corn</th>
<th>Steaming time of steam-flaked corn, min</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>34</td>
<td>47</td>
</tr>
<tr>
<td>Dry matter, % a</td>
<td>88</td>
<td>83</td>
</tr>
<tr>
<td>Bulk density, kg/liter a</td>
<td>.54</td>
<td>.35</td>
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<tr>
<td>In vitro starch reactivity. b Samples were allowed to air-dry prior to analysis.</td>
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<td></td>
</tr>
<tr>
<td>% total starch</td>
<td>3.3</td>
<td>5.2</td>
</tr>
</tbody>
</table>

* Measurements taken on corn as it exited the rollers.

** Samples were allowed to air-dry prior to analysis.

Results and Discussion

The grade 2 yellow corn (88% DM) used in this trial had the following composition (DM basis): DM, 88%; ash, 1.43%; N, 1.51% and starch, 66.6%. The N content of the corn was slightly lower than the 1.62% N suggested by NRC (1984). The starch content of the corn was similar to the 65.9% starch reported by White et al. (1973).

The influence of steaming time prior to flaking on corn moisture content and starch reactivity to amylglucosidase (a measure of gelatinization or disruption of the starch granule) is shown in Table 2. Moisture uptake by the corn was similar for the 34 and 47 min steaming times, averaging 5%. Increasing the steaming time to 67 min increased moisture uptake by 3 percentage units. Beeson (1972) reported that moisture uptake of 3 percentage units occurs within 12 min of steaming time. Johnson et al. (1968) reported 5 percentage units moisture uptake by corn within 12 min steaming time at atmospheric pressure. These findings are consistent with our experience that the initial 3 to 5 percentage units moisture uptake by corn occurs very quickly following application of steam but that moisture uptake greater than 5 percentage units requires prolonged exposure to steam.

Although moisture uptake by corn did not increase proportionately with steaming time, in vitro starch reactivity did. Reactivity is thought to be a measure of gelatinization or disruption of the starch granule. The comparative DE value of SF corn was determined using the replacement technique. It was assumed that the DE value of SF corn was equal to the DE value of the DR corn it replaced plus the change in DE content of the complete diet brought about by the replacement. Given that the DE value for the DR corn used in the replacement was 3.97 mcavkg (NRC, 1984), and that corn was 75% of the diet, the DE values for SF corn were estimated as follows:

\[
\text{test corn DE} = \left[\frac{(\text{DE test diet} - \text{DE rolled corn diet})}{.75}\right] + 3.97.
\]

The trial was analyzed as a 4 x 4 latin square design experiment (Hicks, 1973). Treatment effects were tested using the following comparisons: 1) DR vs the mean of SF corns, 2) linear effect of steaming time and 3) quadratic effect of steaming time.

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2 Sigma Chemical Company, St. Louis, MO.
3 Stanbio Laboratory, Inc., San Antonio, TX.
The influence of steaming time on site and extent of digestion is shown in Table 3. In general, steaming corn longer than 34 min did not improve the nutritive value of flaked corn. Steaming time had a quadratic effect on ruminal starch digestion. Ruminal starch digestibility of corn steamed for 47 min was slightly lower (7%, \( P < .05 \)) than that of corn steamed for 34 or 67 min. The reason for this effect is not certain. There also was a linear

to reflect gelatinization or irreversible swelling of the starch granules, in which they lose their crystallinity. Irreversible swelling can occur when starch is heated in the presence of moisture to temperatures in excess of 60°C (French, 1973). Reactivity of corn starch to amyloglucosidase increased with steam flaking an average of \( .12\% \) per min of steaming time (reactivity, \( \% = 2.34 + .117 \times \text{steaming time}_{\text{min}} \), \( R^2 = .83 \)).
component \((P < .05)\) in the flow of non-ammonia \(N\) to the small intestine with steaming time. The principal increase \((5.4\%)\) in non-ammonia \(N\) passage to the small intestine occurred between 34 and 47 min steaming time. Otherwise, steaming time did not influence \((P > .10)\) small intestinal or total tract digestibility of OM, starch or \(N\).

Although steaming corn for periods of greater than 34 min appeared to have minimal effects on characteristics of digestion, SF generally improved digestibility of corn over than obtained with DR. As shown in Table 3, ruminal starch digestion was increased \((P < .01)\) from 68.3\% for DR corn to an average of 83.3\% for SF corn. These values are in good agreement with the average values of 70 and 86\% ruminal starch digestibility of DR and SF corn, respectively, as summarized by Theurer \((1986)\). The 22\% greater ruminal starch digestibility with SF explains most of the 15\% greater \((P < .05)\) ruminal OM digestion of SF vs DR corn-based diets.

There were no treatment effects \((P > .10)\) on ruminal escape of feed \(N\). This result is consistent with two previous trials \((Zinn, 1987, 1988)\) comparing DR and SF corn. Prigge et al. \((1978)\) observed that \(N\) solubility was lower for SF, but they found no relationship between \(N\) solubility and ruminal escape of feed \(N\).

Non-ammonia \(N\) flow to the small intestine was greater \((18.4\%, P < .01)\) for SF than for DR corn-based diets. This increase was largely a result of increased microbial synthesis \((P < .01)\), a consequence of increased ruminal digestibility of the SF corn-based diets. However, as has been noted in previous studies \((Prigge et al., 1978; Zinn, 1988)\), ruminal microbial efficiency \((N\) synthesis per unit OM fermented) also tended to be greater \((P > .10)\) for SF than for DR corn-based diets.

Small intestinal digestion of starch flowing to the abomasum was 75.1\% greater \((P < .01)\) for SF than for DR corn-based diets. This observation is consistent with other studies \((Theurer, 1986; Zinn, 1987, 1988)\) and serves to emphasize the importance of physical characteristics of feed particles as a limitation to small intestinal starch utilization. Small intestinal OM digestibility also was 25.9\% greater \((P < .05)\) for SF than for DR corn-based diets. The majority \((80.3\%)\) of this improvement in OM digestibility in the small intestine can be accounted for by the increased starch digestibility.

Apparent small intestinal \(N\) digestibility was increased 10.8\% \((P < .01)\) for SF vs DR corn-based diets. Expected small intestinal \(N\) digestibility \((intestinal\ digestible\ \(N\), \(g/d\ = .68 \times\) ruminal escape feed \(N\) + .73 \times\) microbial \(N\) – 3; Zinn and Owens, 1981) was 103 and 94\% of that observed, respectively, for the DR and SF corn-based diets. This comparison suggests that the apparent improvement in intestinal \(N\) digestibility probably was more related to increased intestinal digestibility as a result of steam flaking than to an abnormally low digestibility for the DR corn-based diet.

Total tract digestibility of starch was 9.2\% greater \((P < .01)\) for SF than for DR corn-based diets. This increase in starch digestibility can account for 94.5\% of the increase \((6.1\%, P < .05)\) in total tract digestibility of OM. The DE value of the diet was 5.8\% greater \((P < .05)\) for SF than for corn-based diets. Assuming a DE value of 3.97 Mcal/kg for DR corn \((NRC, 1984)\), the DE value of SF corn was 4.22 Mcal/kg. Thus, SF increased the DE value of corn 6.3\% over that expected with DR. This is less than the 11.1\% improvement in DE observed in a previous study \((Zinn, 1988)\). Net energy values of the DR and SF corn can be estimated from DE using the following equations: \(\text{NE}_m = -.661 + .736\text{DE}\) and \(\text{NE}_g = -.410 + .877\text{NE}_m\) \((adapted from NRC, 1984)\). In this manner, the \(\text{NE}_m\) and \(\text{NE}_g\) values for SF corn were 2.45 and 1.74 Mcal/kg, respectively. These estimates, although slightly higher than tabular values for SF corn \((2.38 and 1.64\ Mcal/kg,\ respectively, for \(\text{NE}_m\) and \(\text{NE}_g; NRC, 1984)\) are lower than estimates obtained in previous studies \((Zinn, 1987, 1988)\).

Implications

Prolonged steaming did not increase the nutritive value of steam-flaked corn. Assessments of in vivo starch digestibility were not useful measures of nutritive value of steam-flaked corn. Total tract starch digestibility was essentially complete \((99.5\%)\) for steam-flaked corn at a steaming time of 34 min. Because feed intake was restricted in this trial, generalization of these conclusions to field conditions requires caution.

Literature Cited


