Effects of Corn Processing on *In Vitro* and *In Situ* Digestion of Corn Grain in Holstein Steers**

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ABSTRACT : This study was conducted to determine effects of whole (intact), coarsely-ground (4 mm), finely-ground (1 mm), steam-flaked and steam-flaked-ground (1 mm) corns on *in vitro* and *in situ* DM digestibilities and also *in vitro* fermentation characteristics. After 48 h incubation, *in vitro* dry matter digestibilities of whole, steam-flaked, coarsely-ground, steam-flaked-ground, and finely-ground corns were 6.79, 61.68, 76.48, 85.72 and 90.31%, respectively. Steam-flaked-ground corn showed the highest digestibility until 24 h incubation ($p<0.01$). After 48 h incubation, pH of whole corn decreased with a small range. However the values of pH of other media significantly decreased ($p<0.01$). The gas productions of finely-ground and steam-flaked-ground corns were higher than those of the other corns ($p<0.01$). After 24 h incubation, NH_3-N concentration of finely-ground and steam-flaked-ground corns increased rapidly. Total VFA was the highest in finely-ground corn, followed by steam-flaked-ground, steam-flaked, coarsely-ground and whole corns. Incorporating steam-flaked corn resulted in the highest propionate concentration ($p<0.01$) and the lowest acetate : propionate value ($p<0.05$). Finely-ground corn showed the highest *in situ* DM digestibility throughout the incubation period ($p<0.01$), followed by coarsely-ground, steam-flaked and whole corns, respectively. Overall, DM of whole corn was merely digested *in vitro* as well as *in situ*. ***(Asian-Aust. J. Anim. Sci. 2002. Vol 15, No. 6 : 851-858)***

Key Words : *In vitro, In situ*, Processing Corn, DM Digestibility

INTRODUCTION

Corn is a primary source of energy in diets of beef cattle, especially of the finishing phase. Thus, optimal corn utilization is fundamental in improving efficiency of beef production. It has been well documented that proper processing of corn, such as grinding, cracking, rolling, roasting, popping, exploding, flaking etc. for beef cattle fed high concentrate enhances *in vitro* and *in situ* starch utilization (Theurer, 1986). This improvement appears to be mainly due to increase in the digestibility of starch in the rumen, resulting in enhancing the digestibility of total digestive tract, thereby improving the energy availability from the corn (Owens et al., 1997; Kim et al., 1996).

Physical processing decreases the particle size of corn, thus increasing the surface area available for microbial attack (Bowman and Firkins, 1993), and enhancing the rate and extent of ruminal digestion of starch (Kim et al., 1996; Walker et al., 1973). Steam-flaked corn enhances the starch digestibility in the rumen as well as the total starch digestibility by cattle (Huntington, 1997; Theurer, 1986). These improvements might be caused by disruption of the protein matrix surrounding the starch granules in the endosperm and disorganization of the starch granules (Rooney and Pflugfelder, 1986).

Meanwhile, considerable interest has developed recently in feeding all-concentrate diets to finishing cattle, especially Holstein steers in Korea. Contrary to the facts mentioned above, it has been demonstrated that when all-concentrate diets are fed *ad libitum* to finishing cattle, whole corn shows the superior performance to ground, cracked, or even steam-flaked corn (Vance et al., 1972; Loerch, 1992). The mode of action of whole corn in the rumen has been suggested that whole corn may serve as "roughage factor" when whole corns are incorporated in all-concentrate feed. Furthermore, prolonged periods of feeding all-concentrate may induce metabolic disorders, such as blot, acidosis, ruminitis, parakeratosis, liver abscesses and founder, which resulting from the excessively rapid fermentation to organic acids (Huntington, 1997). Thus, use of the whole corn in feeding all-concentrate for the finishing phase of cattle is economically better choice than that of the processed corn.

However, so far, extremely few *in vitro* and *in situ* studies included intact (unprocessed) corns are available. And researchers usually compared processed corn with dry-rolled corn as a control or baseline treatment. The objective of this study was to determine effects of different corn processing including whole corn as a control on *in vitro and in situ* DM digestibilities and also *in vitro* fermentation characteristics.

MATERIALS AND METHODS

Experiment 1: Effects of corn processing on *in vitro* DM digestibility and fermentation characteristics

Animal and grain sample preparation: A cannulated

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Holstein steer of approximately 550 kg body weight was used as a donor of rumen fluid. The Holstein steer was *ad libitum* fed twice daily (09:00 h and 17:00 h) with 50% concentrate and 50% forage diet and given free access to water and mineral-vitamin block. Grain samples were prepared as followings. Unprocessed whole corn was used as a control. Coarsely-ground and finely-ground corns were prepared by grinding through 4 mm and 1 mm mesh screens of a Wiley mill, respectively. Steam-flaked corn was prepared by steaming (100-103°C, 40 min.) and then rolling to provide flakes with a density of approximately 377 g/liter. Steam-flaked-ground corn was prepared by grinding steam-flaked corn through a 1mm mesh screen of a Wiley mill.

Preparation of ruminal fluid: Ruminal fluid (ruminal content) was obtained from the rumen of a cannulated Holstein steer, 1 h after feeding. Rumen content was collected in the bottle previously kept warm and filled with O_2 free-CO_2 gas and then filtered through four layers of cheese cloth. The filtered rumen content was used as inoculum.

Medium and incubation: Buffer mixture by Menke and Steingass (1988, table 1) was used for medium. The rumen fluid was mixed with buffer medium in the ratio of 1:2 (v/v). Sixty ml of rumen fluid-buffer mixture was placed in 125 ml serum bottles (Wheaton Scientific) containing 0.4 g of corn samples as substrate under a CO_2 gas phase. The bottles were sealed with butyl rubber stoppers and aluminum seals (Wheaton Scientific). Three bottles were prepared for each processed corn. To account for potential substrates effect from inoculum, one serum bottle per sample was prepared with inoculum and no added corn as a blank. Serum bottles were incubated in 39°C incubator for 2, 6, 12, 24 and 48 h.

Preparation of samples for analysis: After each incubation period, gas production in serum bottles was measured by water displacement in an inverted graduated cylinder. The cultures were transferred into centrifuge tube, and then pH of cultures were determined with pH meter (Mettler® Delta 340). The cultures were centrifuged at 3,000 rpm for 15 min. Residual pellets were harvested for analysis of DM digestibility and supernatants were used for analysis of volatile fatty acid (VFA) and NH_3-N.

Table 1. Compositions of incubation medium

Solution	Volume (ml/L)
Buffer solution[1)]	237.00
Macro element solution[2)]	237.00
Trace element solution[3)]	0.12
Resazurin solution[4)]	1.22
Reduction solution[5)]	50.00
Distilled water	474.00

[1)] Buffer solution: $NaHCO_3$, 35 g; $(NH_4)HCO_3$, 4 g (/1L D.W.).

[2)] Main element solution: Na_2HPO_4, 5.7 g; $KHPO_4$, 6.2 g; $MgSO_4 \cdot 7H_2O$, 0.6 g (/1L D.W.).

[3)] Trace element solution: $CaCl_2 \cdot 2H_2O$, 13.2 g; $MnCl_2 \cdot 4H_2O$, 10.0 g; $CoCl_2 \cdot 6H_2O$, 1.0 g; $FeCl_2 \cdot 6H_2O$, 0.8 g (/100 ml D.W.).

[4)] Resazurin solution: resazurin, 100 mg (/100 ml D.W.).

[5)] Reduction solution: 1N NaOH, 2ml; $Na_2S \cdot 7H_2O$, 285mg; D.W. 47.5 ml.

Analytical methods: Gas production was measured by water displacement in an volumetric pipette at the ends of incubations immediately, and calculated by accumulation of each incubation time. *In vitro* DM digestibilities were measured by centrifugation method. The cultures were centrifuged at 14,000×g for 20 min. Residual pellets were harvested, dried in 60°C oven for 48 h to use for analysis of dry matter digestibility. Blank without corn was used to correct effects of potential substrates contained in inoculum. VFA concentration was analyzed by the method of Erwin et al. (1961). The supernatant in an amount of 1.0 ml, prepared as above procedure, was added to the Eppendorf® tube containing 0.2 ml of 25% HPO_3 solution, and then, mixed for 30 min at the room temperature. After centrifuging at 3,000 rpm for 15 min, 0.2 ml of the supernatant were collected and used for the assay of VFA concentration by Hewlett Packard® 6890 GC System. NH_3-N concentration was analyzed by the method of Chaney and Marbach (1962). The supernatant in an amount of 0.1 ml, prepared as above procedure, was mixed with phenol color reagent and alkali-hypochlorite reagent. NH_3-N concentration was determined by using Milton Roy® Spectronic 21D spectrophotometer at 630 nm.

Experiment 2 : Effects of corn processing on *in situ* DM digestibility

Experimental animal and diet: A nylon bag digestion trial was carried out using a ruminally cannulated Holstein steer fed twice daily (09:00 h and 17:00 h) with a 50% concentrate and 50% forage diet. The steer was adapted to the diet for 7 d prior to the trial.

Incubation and measurement of *in situ* dry matter digestibility (ISDMD): Five sets of triplicate nylon bags containing 3 g samples of whole, coarsely-ground, finely-ground and steam-flaked corns were placed in the rumen. A triplicate set of bags for each processed corn was removed after 2, 6, 12, 24 and 48 h incubation in the rumen. Additional triplicate bags were also incubated in autoclaved rumen fluid for 0.5 h to correct for washing losses. All bags were removed at the end of the incubation period and washed under cold tap water until the water appeared clear. Three bags from each time period were dried at 60°C for 48 h and weighed to determine ISDMD.

Statistical analysis

Data were analyzed using the general linear model (GLM) procedure of the Statistical Analysis System Institute, Inc. (SAS) (1985). Differences among means were

tested for significance using the least significant difference (LSD) procedure of SAS (1985).

RESULTS

Effects of corn processing on *in vitro* DM digestibility and fermentation characteristics

In vitro dry matter digestibilities of differently processed corns are presented in table 2. After 48 h incubation, *in vitro* dry matter digestibilities of whole, steam-flaked, coarsely-ground, steam-flaked-ground, and finely-ground corns were 6.79, 61.68, 76.48, 85.72 and 90.31%, respectively. It was not until 12 h incubation when whole corn started to be digested. Even after 48 h incubation, digestibility for whole corn was only 6.79%. Steam-flaked-ground corn showed the highest digestibility until 24 h incubation ($p<0.01$), followed by finely-ground, coarsely-ground, steam-flaked and whole corns. But finely-ground corn showed higher digestibility after 48 h incubation than steam-flaked-ground corn, although it was not significantly different.

Differences ($p<0.01$) in the pH of medium were observed among differently processed corns at all incubation times (table 3). Generally, pH of all medium except steam-flaked-ground corn was similar each other during 6 h incubation. After 48 h incubation, pH of whole corn decreased with a small range. However, the values of pH of other media significantly decreased, especially those of finely-ground and steam-flaked-ground corns decreased below 6.20.

Changes in the gas production are shown in table 4. Both the gas productions of finely-ground and steam-flaked-ground corns showing the similar amount were higher than those of the other processed corns ($p<0.01$). Throughout the incubation period, the gas production from the treatment of whole corn was the lowest among the treatments. The result showed that the patterns of gas production were remarkably similar to those of dry matter digesibilities among differently processed corns at all incubation times.

NH_3-N concentration influenced by incubating differently processed corn grains are shown in table 5. Between 6 h and 24 h incubation, finely-ground and steam-flaked-ground corn were lower in NH_3-N concentration than whole, coarsely-ground and steam-flaked corns. However, after 24 h incubation, NH_3-N concentration of finely-ground and steam-flaked-ground corns increased rapidly. At the end of incubation (48 h), NH_3-N concentrations of all corns except the whole corn were similar each other within ranging from 25 to 28 mg/dl.

VFA concentrations after 48 h incubation are shown in table 6. Total VFA was the highest in finely-ground corns, followed by steam-flaked-ground, steam-flaked, coarsely-ground and whole corns. All processed corns showed higher

Table 2. *In vitro* DM digestibilities (%) of differently processed corn grains

Corns	Incubation time (h)					
	0	2	6	12	24	48
Whole	-3.74^{b}	-2.76^{e}	-2.78^{d}	5.04^{e}	6.65^{f}	6.79^{f}
Coarsely-ground	-2.74^{b}	8.61^{d}	9.22^{d}	27.89^{d}	60.09^{de}	76.58^{d}
Finely-ground	6.43^{ab}	15.71^{cd}	31.23^{c}	56.75^{c}	73.88^{cd}	90.31^{c}
Steam-flaked	-1.52^{b}	0.89^{e}	9.57^{d}	23.27^{d}	45.80^{e}	61.68^{e}
Steam-flaked-ground	14.06^{a}	23.24^{c}	43.65^{c}	67.32^{c}	83.84^{c}	85.72^{cd}
SEM[1]	2.41	2.71	4.95	6.16	7.79	8.15

[1] Pooled standard error of means.

^{a,b} Means in the same column with different superscripts differ ($p<0.05$).

^{c,d,e,f} Means in the same column with different superscripts differ ($p<0.01$).

Table 3. The pH values of incubation medium supplemented with differently processed corn grains

Corns	Incubation time (h)					
	0	2	6	12	24	48
Whole	6.68	6.67^{a}	6.72^{ab}	6.69^{a}	6.62^{a}	6.65^{a}
Coarsely-ground	6.68	6.65^{b}	6.69^{c}	6.60^{b}	6.40^{c}	6.20^{c}
Finely-ground	6.68	6.62^{c}	6.64^{d}	6.43^{c}	6.27^{d}	6.18^{c}
Steam-flaked	6.66	6.63^{bc}	6.70^{bc}	6.67^{a}	6.46^{b}	6.30^{b}
Steam-flaked-ground	6.66	6.59^{d}	6.56^{e}	6.42^{c}	6.23^{d}	6.19^{c}
SEM[1]	0.004	0.009	0.015	0.028	0.034	0.044

[1] Pooled standard error of means.

^{a,b,c,d,e} Means in the same column with different superscripts differ ($p<0.01$).

Table 4. Gas production (ml) as influenced by differently processed corn grains

Corns	Incubation time (h)				
	2	6	12	24	48
Whole	9.27[b]	13.83[b]	27.37[c]	36.63[d]	42.75[c]
Coarsely-ground	9.87[b]	17.07[b]	41.93[b]	70.48[b]	103.18[b]
Finely-ground	12.37[a]	29.70[a]	66.70[a]	92.68[a]	119.65[a]
Steam-flaked	9.17[b]	15.20[b]	32.10[c]	58.55[c]	90.68[b]
Steam-flaked-ground	13.53[a]	34.20[d]	69.40[a]	92.30[a]	121.70[a]
SEM[1]	0.41	2.01	4.34	5.00	6.90

[1] Pooled standard error of means.
[a,b,c] Means in the same column with different superscripts differ ($p<0.01$).

Table 5. NH_3-N concentration (mg/dl) of incubation medium supplemented with differently processed corn grains

Corns	Incubation time (h)					
	0	2	6	12	24	48
Whole	7.42	7.14	14.58[a]	19.08[a]	17.23[a]	21.33[f]
Coarsely-ground	7.15	8.22	12.90[ab]	19.36[a]	16.61[ab]	25.42[ef]
Finely-ground	7.60	8.18	10.93[bc]	12.47[b]	13.00[c]	28.39[e]
Steam-flaked	7.36	7.40	15.32[a]	17.67[a]	17.09[a]	26.76[e]
Steam-flaked-ground	8.11	6.97	9.32[c]	11.13[b]	13.30[bc]	26.96[e]
SEM[1]	0.32	0.19	0.59	0.99	0.78	0.81

[1] Pooled standard error of means.
[a,b,c,d] Means in the same column with different superscripts differ ($p<0.01$).
[e,f] Means in the same column with different superscripts differ ($p<0.05$).

Table 6. VFA concentration (mM) of incubation medium supplemented with differently processed corn grains after 48 h incubation

Corns	VFA				
	Acetate	Propionate	Butyrate	Total VFA	A：P
Whole	35.33[bc]	16.04[b]	6.42[b]	63.80[b]	2.20[d]
Coarsely-ground	43.54[abc]	27.11[a]	10.99[a]	88.61[a]	1.61[ef]
Finely-ground	51.15[a]	26.24[a]	11.74[a]	95.44[a]	1.99[de]
Steam-flaked	45.28[ab]	31.36[a]	11.45[a]	93.46[a]	1.44[f]
Steam-flaked-ground	50.28[a]	26.23[a]	11.03[a]	93.64[a]	1.92[de]
SEM[1]	1.80	1.59	0.64	3.87	0.08

[1] Pooled standard error of means.
[a,b,c] Means in the same column with different superscripts differ ($p<0.01$).
[d,e,f] Means in the same column with different superscripts differ ($p<0.05$).

acetate, propionate and butyrate concentration than the whole corn. Incorporating steam-flaked corn resulted in the highest propionate concentration ($p<0.01$) and the lowest A：P value ($p<0.05$). The change of total VFA concentration during the incubation was shown in figure 1. Until 24 h incubation, total VFA for processed corns increased rapidly compared with the whole corn.

Effects of corn processing on *in situ* DM digestibility

Effects of processing on *in situ* dry matter disappearance of corn grains are presented in table 7. Finely-ground corn showed the highest ISDMD throughout the incubation period ($p<0.01$), followed by coarsely-ground, steam-flaked and whole corns, respectively. After 48 h of incubation in the rumen, the ISDMD for whole, steam-flaked, coarsely-ground and finely-ground corns was 4.53, 44.76, 53.80 and 74.40%, respectively. Whole corn was poorly digested even after 48 h of incubation in the rumen.

DISCUSSION

Many researchers have reported that reduction of particle size of corn by mechanical action increases DM digestibility through the studies of *in vitro* (Galyean et al., 1981), *in situ* (Waldhwa et al., 1998; Ha, 1994), and *in vivo* (Wilson et al., 1973; Nocek and Tamminga, 1991). The reason for enhanced digestion by grinding is believed that

Table 7. *In situ* DM digestibility (%) as influenced by differently processed corns in the rumen of a Holstein cow

Corns	Incubation time (h)					
	0	2	6	12	24	48
Whole	-0.32[b]	-0.09[c]	0.16[c]	0.55[d]	1.06[c]	4.53[d]
Coarsely-ground	1.90[b]	6.66[b]	12.61[b]	27.55[b]	51.20[ab]	56.77[b]
Finely-ground	10.74[a]	20.43[a]	29.16[a]	40.69[a]	60.13[a]	77.43[a]
Steam-flaked	-0.25[b]	4.92[bc]	10.35[b]	16.92[c]	32.00[b]	42.68[c]
SEM[1]	1.45	2.42	3.16	4.87	8.53	9.97

[1] Pooled standard error of means.
[a,b,c,d] Means in the same column with different superscripts differ ($p<0.01$).

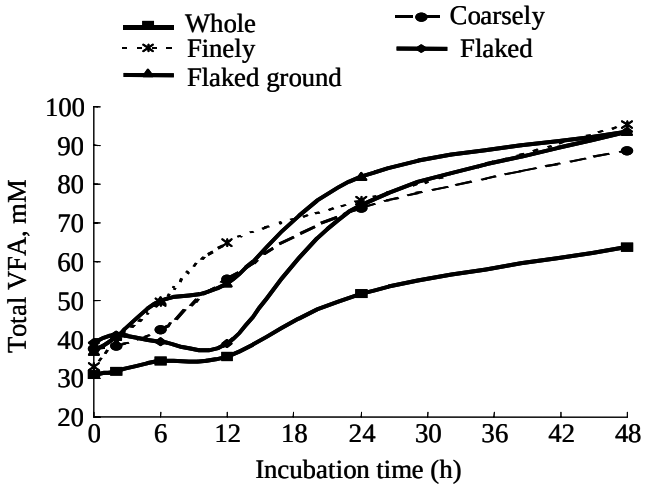

Figure 1. Change of total VFA concentration (mM) of incubation medium supplemented with differently processed corn grains during 48 h incubation.

mechanical processing reduces the size of feed particles and increases the surface area available for microbial attack (Bowman and Firkins, 1993).

The results of this study showed that more extensive grinding resulted in higher DM digestibility *in vitro* as well as *in situ*. These results are in agreement with the results of previous *in vitro* (Galyean et al., 1981) and *in situ* (Lykos and Varga, 1995; Ha, 1994) studies, suggesting that reduction in particle size by grinding produced higher degradability of DM. However, those values of DM digestibilities from the previous studies are not similar to values of the current study. It may be likely because we utilized different cattle (dairy cattle versus Holstein steers), diets, grain sources, grinding methods, environmental factors, and so forth. The results of the present study are contrary to those of Nordin and Campling (1976), observing little difference between finely ground (2.5 mm screen) and coarsely ground (3.5 mm screen) corn after 24 h incubation in nylon bags. In terms of *in vivo* studies, Moe et al. (1973) suggested that finely-ground corn showed a higher total tract dry matter digestion (68.3%) than whole corn (59.1%) in 54.5% concentrate diets fed to dairy cattle, which results were reevaluated in beef cattle by Owens et al. (1986), reporting that ruminal digestibility of whole corn to be 58.9%, and total tract digestibility to be 91.7%.

On the other hand, steam-flaking causes starch gelatinization (intermolecular disruption of hydrogen bonds) and enhances the surface of the corn kernel which is available for microbial attachment, resulting in greater ruminal digestion of starch (Nocek and Tamminga, 1991). As noted in a review (Theurer et al., 1986; Kim et al., 1996), the steam-flaked corns caused a remarkable increase in ruminal, intestinal, and total digestibilities of starch. *In vitro* (Frederick, 1973) and *in situ* (Galyean et al., 1981) studies showed that steam-flaked corn produced greater starch degradation than ground corn. These are contrary to results of the present study, showing that DM digestibilities of both the coarsely-ground and finely-ground corns were higher than those of steam-flaked corns. However, the results of present study confirmed the claiming of Theuer (1986), suggesting that ruminal DM degradations of corn grains by grinding (3.2-7.9 mm screen) were greater than those of steam-flaked corns, even though the degradations of total digestive tract tended to be higher in steam-flaked corns. The present study also indicated that steam-flaked-ground (1 mm screen) corn had the highest *in vitro* DM digestibility, which might imply additive effects of flaking and decreased particle size by grinding, as hypothesized by Theuer (1986).

pH, the amounts of gas and VFA released when feedstuffs are incubated *in vitro* with rumen fluid are closely related to digestibility and therefore to the energetic feed value of feedstuffs for ruminants (Galyean et al., 1979). The results of present study showed that increasing levels of processing treatments caused a linear reduction in pH after 12 h incubation with a minimal changes in pH from the treatment of whole corn. It implies that whole corn might be merely digested. Contrarily, finely-ground and steam-flaked-ground corns might be digested readily, so acids such as VFA and lactic acids were produced rapidly, resulting in decreasing pH. With regard to gas production, the present study showed the linear increase of gas production like the pattern of DM digestibilities as the increase of processing level. Furthermore, total VFA

increased in the treatments of grinding and flaking, whereas, the ratio of acetate to propionate decreased in the incubations at 48 h. These are in agreement of results of Ekinci and Broderick (1997), showing increase of total VFA and a decline in the ratio of acetate to propionate in the incubations containing ground high moisture corn. Herrera-Saldana et al. (1990) and Aldrich et al. (1993) also found increased propionate and a lower ratio of acetate to propionate in the rumen of cattle fed rapidly degraded carbohydrate.

By comparing the results of the present study with previous *in vivo* studies, one can find that *in vitro* and *in vivo* results are still controversial. The results of the present study are similar to those of Galyean et al. (1979), who found that cattle fed grinding corn caused greater VFA concentrations and low pH values than those fed whole corn. Murphy et al. (1994) also found that steers fed processed corn showed higher VFA and lower pH than steers fed whole corn did. However, the present study is contrary to results of Reinhardt et al. (1998) in that there was no effect of corn processing on ruminal fermentation as affected by total VFA concentration. In addition, processing of corns has been reported to improve NH_3 utilization and microbial protein synthesis, so that NH_3 concentration in the incubation medium is reduced (Ekinci and Broderick, 1997; Rust et al., 1980), which is similar to results obtained in the present study.

Meanwhile, it appears from this present study that DM of whole corn was digested little in both *in vitro* and in *situ* experiment. Wilson et al. (1973) found that DM of corn was nearly not digested from whole kernel incubated *in situ*, even after 3 day in the rumen. It has been well documented that whole corn with an intact pericarp is almost entirely resistant to digestion by ruminants because whole kernels are resistant to bacterial attack (McAllister et al., 1994; Beauchemin et al., 1994). Thus, one can assume that some physical alteration of the whole kernel must be carried out for maximum ruminal digestion. In fact, since corn and sorghum have shown the lowest ruminal and total tract starch digestibilities when they are not processed mainly because corn and sorghum have starch bound by insoluble protein, processing effects on starch availability in rumen can be greater in corn than other grains, such as wheat and barley (Rooney and Pflugfelder, 1986).

Vance et al. (1972) reported that whole corn over the processed one was greater in the performance of beef cattle in the finishing phase. Recently, Owens et al. (1997) claimed that more extensive processing reduced dry matter intake, resulting in the reduction of average daily gain. In addition, extensively processed grain has been attributed to excessive rates of acid production in the rumen and subclinical acidosis (Fulton et al., 1979ab), which increases daily variation in dry matter intake (Stock et al., 1995). Owens et al. (1997) also found that energetic efficiency evaluated as metabolic energy (ME) was higher for whole-shelled corn than dry-rolled corn. One can assume that the greater ME for whole-shelled corn might be resulted from greater chewing and/or rumination of the whole corn owing to greater particle size, eNDF, or slower acid production in the rumen, which resulting in reducing the incidence of acidosis, thereby improving efficiency and dry matter intake. In addition, according to the result of Owens et al. (1986), changing site of digestion from the rumen to the small intestine with a cruder particle size might be expected to improve energetic efficiency.

Even though the results of present study showed the positive outcomes for processed corn in DM digestion and almost no DM digestibilities for whole corn (whole kernel), it is not quite possible for us to mimic our results to field situation not only because intact corns used in this study is not like the shapes of masticated but also because extensive processing might have adverse effects, especially in the final phase of fattening beef cattle where the concentrates occupies almost all the diets, as mentioned above. Moreover, Stock et al. (1987) observed that feeding whole corn to feedlot cattle decreased the extent of ruminal starch digestion and the incidence of acidosis compared with cattle fed finely ground corn as the source of cereal grain. In addition, animal performance was improved due to the increased amount of starch digested in the small intestine.

Since minimizing the surface area available to microbial attachment decreases the rate of starch digestion, thereby maintaining ruminal pH at an optimal level (Galyean et al., 1979), minimal processing of corn grain by slightly cracking the pericarp may slow the rate of starch digestion. It has been also suggested that unprocessed corn can be efficiently fed to beef cattle since the pericarp of the kernel is almost entirely cracked by chewing both during eating and during rumination (McAllister and Cheng, 1996). Therefore, in reality, unprocessed corns may be more effectively utilized for the beef cattle, especially at the final stage.

IMPLICATION

The present study clearly implies that *in vitro* and *in situ* nutrient, especially starch, digestibility of corn was improved with increasing processing level of corn. We also reconfirm that unprocessed corn is almost entirely not digested by rumen microbes since corn kernel is too tough to be degraded. One can not rule out the possibility that mastication and/or rumination may break the corn kernel, thereby unprocessed corn may be more effectively utilized than processed corn by avoiding adverse effects of processed corn, such as acidosis, especially when all-concentrate diets are used. However, studies on

unprocessed and processed corns are still controversial since some researchers reported the positive results for incorporating unprocessed corns in diets, others found considerable amounts of unprocessed corns in feces. Therefore, more extensive studies must be carried out to determine efficacy of corn processing including unprocessed corn for the fattening period of beef cattle.

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