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# Effects of Synchronization of Energy and Nitrogen Release in the Rumen on the Starch Disappearance in the Gastrointestinal Tract and Growth Performance of Hanwoo Steers

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## ABSTRACT

The objectives of experiments were to compare directly the effects of synchrony of slowly fermented (corn and corn gluten meal; C-CGM) and of rapidly fermented ingredients (barley and soybean meal; B-SBM) in the rumen on starch disappearances in gastrointestinal tracts (Experiment 1) and growth performance (Experiment 2) of Hanwoo steers in the feedlot barn. In experiment 1, four Hanwoo steers (288 ± 21 kg) fitted with ruminal and "T" shaped duodenal cannula were placed in one pen with Calan gate and assigned randomly to a duplicate 2 × 2 Latin square design. In experiment 2, eight intact Hanwoo steers (311 ± 8 kg) were assigned randomly to one of two pens with Calan gate to evaluate the effect of the same diets as like in experiment 1 on growth performance. There were no differences in ruminal pH, ammonia and total VFA concentrations between treatments. Percentage of apparent ruminal starch disappearance was 33.3% unit lower ($p<0.05$) for steers fed C-CGM than for steers fed B-SBM diets and this difference resulted in 268% higher ($p<0.05$) in duodenal starch flows for steers fed C-CGM diet than for steers fed B-SMB diet. There was significant increase ($p<0.05$) in quantity (927 vs. 400 g/d) of corn starch digested post-ruminally compared to barley starch. However, percentage of starch apparently digested post-ruminally was 8% higher ($p=0.1$) in steers fed fast synchrony diet with B-SBM than in steers fed slow synchrony diets with C-CGM. The differences of percentage and amount of starch apparently digested post-ruminally between C-CGM and B-SBM diets did not affect rice straw DM intake, average daily gain (ADG) and feed efficiency. In conclusion, there is some uncertainty in regards to the relationship between site of starch digestion and DM intake, ADG, and feed efficiency in this study.

(**Key words :** Growth performance, Post-ruminal, Starch digestion, Hanwoo steers)

## INTRODUCTION

Beef production with Hanwoo steers in Korea is managed by typical feeding programs for more than 28 months increasing high concentrate diets gradually to produce muscle with very high marbling characteristics. Therefore, optimal starch utilizationis fundamental to improving the efficiency of the Hanwoo beef production. When high concentrate diets are fed to beef cattle, up to 42% of dietary starch may escape ruminal fermentation and be available in the small intestine (Orskov, 1986). Starch digestion in the small intestine is more energetically efficient than ruminal fermentation (Harmon and McLeod, 2001). Huntington (1997) emphasized in his review that production and outflow of microbial protein from the rumen is responsible for starch digestion in the small intestine. Works with sheep (Taniguchi et al., 1993) and steers (Richards et al., 2002) showed that starch disappearance from the small intestine was increased with greater protein infused into the duodenum.

In the previous report, Kim et al. (2010) demonstrated that synchronizing the degradability of starch and protein sources (diets by mixing barley with soybean meal or corn with

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corn gluten meal) in the rumen showed higher percentages of starch apparently digested post-ruminally than asynchronization (diets by mixing barley with corn gluten meal or corn with soybean meal). However, data demonstrating the degree of synchrony of energy and nitrogen release in the rumen on digestion of starch in the small intestine and improvements in growth performance of animal are limited.

Therefore, the objectives of the present experiments were to compare directly the effects of synchrony of slowly fermented and of rapidly fermented ingredients in the rumen on starch disappearances in gastrointestinal tracts (Experiment 1) and the effect of the different amount of starch digested post-ruminally between treatments on the growth performance (Experiment 2) of Hanwoo steers.

## MATERIALS AND METHODS

### 1. Animals and Diets

In Exp. 1, four Hanwoo steers (288 ± 21 kg) were placed in one pen (5.3 × 10.6 m), giving each steer 14 $m^2$ of floor space, equipped with Calan gate feeder and assigned randomly to a duplicate 2 × 2 Latin square design to study the effect of two experimental diets on ruminal fermentation and nutrient disappearance in gastrointestinal tracts. Steers were fitted with ruminal and "T" shaped duodenal cannula (approximately 10 cm distal to the pylorus). All animal-based procedures were in accordance with the "Guideline for the Care and use of Experimental Animal of National Institute of Animal Science". In Exp. 2, eight intact Hanwoo steers (311 ± 8 kg) were assigned randomly to one of two pens with Calan gate to evaluate the effect of the same diets as using in experiment 1 on performance.

In Exp. 1 and 2, dietary treatments (Table 1) consisted of ground corn with corn gluten meal (C-CGM) and ground barley with soybean meal (B-SBM). The B-SBM diet represents a synchronization of rapidly fermented ingredients whereas the C-CGM diet is slowly fermented in the rumen. Dry matter intake of concentrate was adjusted to 1.7% of BW, twice (09:00 and 18:00 h) daily in an equal amount along with free access to water and a trace-mineralized salt block. Rice straw was offered ad libitum at 30 min. after feeding concentrate to measure intake amount of concentrate and rice straw separately. In Exp. 2, steers were adopted to experimental diets and pens with Calan gates for one month prior to main experiment for two months. Feed refusals were

Table 1. Ingredient and chemical composition of the concentrate and rice straw

| Constituents | Concentrate[1] | | Rice straw |
|---|---|---|---|
| | C-CGM | B-SBM | |
| Ingredient (% fed basis) | | | |
| Corn (ground) | 56.1 | – | |
| Barley (ground) | – | 56.1 | |
| Soybean meal | – | 11.2 | |
| Corn gluten meal | 11.2 | – | |
| Soybean hull | 11.2 | 11.2 | |
| Wheat hull | 19.7 | 19.7 | |
| Calcium phosphate | 0.4 | 0.4 | |
| Limestone | 1.1 | 1.1 | |
| Vitamin premix [2] | 0.4 | 0.4 | |
| Chemical composition (% DM) | | | |
| Dry matter | 87.53 | 88.19 | 88.24 |
| Crude protein | 18.81 | 18.64 | 4.99 |
| Crude fiber | 3.50 | 2.75 | 1.53 |
| Ash | 4.07 | 5.16 | 14.26 |
| Starch | 50.53 | 44.52 | 3.46 |

[1] C = corn, B = barley, SBM = soybean meal, CGM = corn gluten meal.
[2] Vitamin A, 2,650,000 IU/kg; Vitamin D, 3,530,000 IU/kg; Vitamin E, 1,050 IU/kg; Niacin, 10,000 mg/kg; Mn, 4,400 mg/kg; Zn, 4,400 mg/kg; Fe, 13,200 mg/kg; Cu, 2,200 mg/kg; I, 440mg/kg; Co, 440 mg/kg; Butylated hydroxy toluene, 10,000 mg/kg.

weighed daily prior to the morning feeding. Orts were sampled, dried at 60℃ for 72 h. Body weight was recorded before morning feeding at the beginning and at the end of each experimental period.

### 2. Sample collection and analyses

Exp. 1 consisted of two periods of 30 days; 28 days for diet adaptation and 2 days of sample collection. Steers were confined in the crate only at the sampling day. On day 17, chromic oxide was added into the concentrates at 0.2% for 14 d. On day 29, rumen fluid (300 mL) was taken at 08:30 h just prior to feeding, and at 11:00, 13:00, 15:00 and 17:00 h post feeding. On day 30, duodenal digesta (400 mL) and fecal grab samples (200 g) were taken at 08:30 h just prior to feeding, and at 11:00, 14:00 and 17:00 h post feeding. Duodenal and fecal samples were frozen until the formation of composite samples by steers within period. Duodenal and fecal composited sample were formed by combining 150 g from each, then samples were homogenized for 1 min. These were dried in an oven at 60℃ for 72 h. Samples were ground through a 1 mm screen and analyzed for DM, CP, ash, crude fiber, Cr (AOAC, 1990) and starch (McCready et al., 1950).

The rumen fluid was squeezed through four layers of cheesecloth and pH was measured immediately (Corning model 530 pH meter) and the rumen fluid (5 ml) was mixed with 0.02 ml $HgCl_2$, 1 ml of 25% phosphoric acid and 0.2 ml 2% pivalic acid solution as an internal standard. The mixed solution was centrifuged at 3,000 × rpm for 20 min, and the supernatant was subjected to determination of the concentration and composition of VFA using gas chromatography (CP-3800; VARIAN, CA, USA) as described by Erwin et al. (1961). The rumen fluid (5 ml) was mixed with 0.02 ml $HgCl_2$ and used to determine the concentration of $NH_3$-N colorimetrically (UVIKON923; double Beam UV/VIS spectrophotometer, BIO-TEK KONTRON, Milano, Italy) as described by Chaney and Marbach (1962).

### 3. Statistical analyses

In Exp. 1, data were analyzed by using the general linear models procedure (Version 9.1, SAS, 2002) cow, period and treatment were the effects in the model. Data were analyzed by paired t-test. Statistically significant differences between treatments were declared for $p<0.05$ and tendency for $0.05< p < 0.10$.

## RESULTS AND DISCUSSION

Diets wereformulated to ensure substantial differences in the extent of ruminal digestion of protein and starch (Table 1), but it did not influence mean ruminal pH or total VFA concentrations (Table 2). In agreement with our data, Khorasani et al. (1994, 2001) and Kim et al. (2010) reported no differences in ruminal pH and total VFA concentrations between corn and barley but McCarthy et al. (1989), Taniguchi et al. (1991) and Khorasani et al. (2001) reported greater total VFA concentrations in barley-based diets and it is due to the greater rate of degradation of nonstructural carbohydrates of barley than of corn. Molar proportions of individual VFA were not affected by the treatments, except for valerate, in the present experiment. McCarthy et al. (1989) and Taniguchi et al. (1994) also reported similar molar concentrations of individual VFA when steers were fed diets based on either corn or barley. However, Khorasani et al. (1994) and Tiffany and Spears (2005) reported lower propionate concentrations for cows fed barley-based diets than corn-based diets. In contrast, Overton et al. (1995) and Beauchemin and McGinn (2005) reported that propionate concentration was greater for barley-based diets than for corn-based diets. Although it is well documented that barley is degraded faster than corn in the rumen, there have been contradictory results on the VFA production, especially for propionate concentration between barley and corn. Molar proportion of valerate was significantly greater ($p<0.05$) from 4 h to 6 h for the barley-based diets than for corn-based diets in the present experiment, in agreement with Overton et al. (1995). Comparing with the previous experiment (Kim et al., 2010), there was a difference in concentrate DM intake (1.7 vs. 1.2% of BW). This contributed to the differences in total VFA (128 vs. 100 mM) between

Table 2. Ruminal characteristics in Hanwoo steers fed experimental diets

| Item | Diets | | SEM[3)] | P value[4)] |
|---|---|---|---|---|
| | C-CGM[1)] | B-SBM[2)] | | |
| pH | 6.63 | 6.7 | 0.05 | 0.336 |
| $NH_3$, mg/100ml | 67.48 | 88.73 | 8.79 | 0.138 |
| Total VFA, mmol | 116.51 | 138.95 | 32.77 | 0.645 |
| VFA concentrations, mol/100mol | | | | |
| Acetate (A) | 70.64 | 69.61 | 0.58 | 0.251 |
| Propionate (P) | 13.16 | 13.27 | 0.70 | 0.918 |
| Isobutyrate | 1.04 | 1.07 | 0.09 | 0.790 |
| Butyrate | 11.95 | 12.66 | 0.63 | 0.461 |
| Isovalerate | 2.06 | 1.87 | 0.20 | 0.522 |
| Valerate | 1.14 | 1.53 | 0.06 | 0.006 |
| A:P | 5.4 | 5.32 | 0.27 | 0.854 |

1) Corn + Corn gluten meal. 2) Barley + Soybean meal. 3) Standard error of mean. 4) P values were calculated by paired t-test.

experiments.

There were no differences in OM intake, duodenal flow and fecal flow between treatments (Table 3). Steers fed B-SBM diet showed apparent OM disappearances (quantity and percentage of intake) in the rumen were 54 and 73% higher than for C-CGM diet, respectively but no significant differences between treatments. And also, there were no differences statistically in the quantity and percentage of OM apparently digested postruminally between the diets. In the previous study with same diets, however, Kim et al. (2010) showed a significantly higher apparent ruminal OM disappearance (quantity and percentage of intake) and a significantly lower apparent postruminal OM disappearance (quantity and percentage of intake) for steers fed B-SBM diet than for steers fed C-CGM diet.

There were no differences in CP intake, apparent ruminal CP outflows (153 vs. 143% of CP intake) and apparent ruminal CP disappearance (quantity and percentage of intake) between treatments (Table 4). In the previous study, Kim et al. (2010) reported significant difference in apparent ruminal CP outflows (155 vs. 117% of CP intake) and ruminal CP disappearance (quantity and percentage of intake) between C-CGM and B-SBM diets. Fecal flow of CP tended to be lower (p=0.1) and percentage of CP apparently digested postruminally tended to be higher (p=0.09) in steers fed B-SBM than for C-CGM in the present study. These results also were different with the data of Kim et al. (2010) that showed the quantity of CP apparently digested postruminally was 40% higher in steers fed C-CGM diet than in steers fed B-SBM diet and there were no differences in the percentages of CP apparently digested postruminally as well as the quantity and percentage of disappearance in total tract. For both diets, duodenal CP flows were greater than CP intakes. Therefore, the amount and percentage of apparent CP disappearance in the rumen were negative values in both diets. In the study of Milton et al. (1997), finishing beef steers fed high concentrate diets had total duodenal N flow ranging from 188 to 122% of N intake and apparent ruminal N digestibility ranged from -83 to -16%. Soto-Navarro et al. (2003) reported apparent ruminal N digestibility ranged from -71.6 to -8.4% of N intake in yearling wether goats fed diets containing 9.2 to 15.2% CP. Negative values of apparent ruminal N digestion increased linearly with dietary urea (Milton et al., 1997; Sato-Navarro et al., 2003) and SBM levels (Sato-Navarro et al., 2003). The negative ruminal CP outflow might contribute to the lower percentage of apparent OM disappearance in the stomach which ranged from 10% to 18% in the present study which is similar with the previous study (Kim et al., 2010). However, those were lower than 24~42% for a sorghum grain-based diet reported by Drennan et al. (1970) and 31~45% by Spicer et al. (1986). Observations of negative apparent ruminal N digestibilities are in most cases because of extensive N recycling and mobilization of tissue protein. It is also possible that imperfections in use of chromic oxide as an inert, external marker, along with digesta sampling times chosen, may have contributed to some negative apparent ruminal N digestibility. It seems unlikely that any such

Table 3. Apparent organic matter disappearance rates in each segment of gastrointestinal tract in Hanwoo steers fed experimental diets

| Item | C-CGM[1)] | B-SBM[2)] | SEM[3)] | P value[4)] |
|---|---|---|---|---|
| Intake, g/d | 6136.5 | 6030.1 | 334.04 | 0.70 |
| Duodenal flow, g/d | 5505.5 | 4914.4 | 343.01 | 0.19 |
| Fecal flow, g/d | 2863.6 | 2347.5 | 222.64 | 0.15 |
| Disappearance rate, g/d | | | | |
| Stomach | 631.1 | 1115.8 | 245.15 | 0.48 |
| Post-ruminal | 2641.8 | 2566.9 | 192.07 | 0.83 |
| Total tract | 3272.9 | 3682.6 | 218.54 | 0.42 |
| Disappearance rate | | | | |
| Stomach, % of intake | 10.3 | 17.8 | 4.07 | 0.52 |
| Post-ruminal, % of flow | 48.7 | 51.5 | 2.21 | 0.56 |
| Total tract, % of intake | 53.8 | 60.8 | 2.37 | 0.29 |

[1)] Corn + Corn gluten meal. [2)] Barley + Soybean meal. [3)] Standard error of mean. [4)] P values were calculated by paired t-test.

problems impacted measures for one particular treatment differently than for other because similar methodologies have been frequently employed with other ruminant species.

The amount of starch intake was 12% greater for steers fed C-CGM than for B-SBM diets (Table 4) because of higher starch content of corn than barley (Table 5). Percentage of apparent ruminal starch disappearance for steers fed C-CGM (42.3%) was 33.3% unit lower ($p<0.05$) than for steers fed B-SBM diets, and this difference resulted in 268% higher ($p<0.05$) in duodenal starch flows for steers fed C-CGM diet than for steers fed B-SMB diet. *In vivo* (Spicer et al., 1986) and *in vitro* (Chai et al., 2004) studies also found lower starch degradability in the rumen for corn than for barley. With greater quantities of corn starch flow to the duodenum than barley starch in the current study, there was increase in quantity of corn starch digested postruminally compared to barley starch (927 vs. 400 g/d; $p<0.05$). However, percentage of starch apparently digested post-ruminally for steers fed fast synchrony diet with B-SBM (76.2%) was 8% unit higher ($p=0.1$) than in steers fed slow synchrony diets with C-CGM. In the previous study (Kim et al., 2010), steers fed C-CGM showed higher percentage of starch apparently digested post-ruminally than B-SBM. It was explained by higher duodenal CP flow for steers fed C-CGM over B-SBM diet, which was supported by the results of Taniguchi et al. (1993) and Richards et al. (2002) who

Table 4. Apparent crude protein disappearance rates in each segment of gastrointestinal tract in Hanwoo steers fed experimental diets

| Item | C-CGM[1)] | B-SBM[2)] | SEM[3)] | P value[4)] |
|---|---|---|---|---|
| Intake, g/d | 949.0 | 950.9 | 57.87 | 0.95 |
| Duodenal flow, g/d | 1457.5 | 1365.0 | 97.06 | 0.38 |
| Fecal flow, g/d | 443.2 | 365.0 | 37.30 | 0.10 |
| Disappearance rate, g/d | | | | |
| Stomach | −508.5 | −414.2 | 77.88 | 0.45 |
| Post-ruminal | 1014.3 | 1000.1 | 83.26 | 0.84 |
| Total tract | 505.78 | 585.9 | 43.44 | 0.19 |
| Disappearance rate | | | | |
| Stomach, % of intake | −53.6 | −47.2 | 9.54 | 0.67 |
| Post-ruminal, % of flow | 69.5 | 73.8 | 2.30 | 0.09 |
| Total tract, % of intake | 53.9 | 61.2 | 2.66 | 0.11 |

[1)] Corn + Corn gluten meal. [2)] Barley + Soybean meal. [3)] Standard error of mean. [4)] P values were calculated by paired t-test.

Table 5. Apparent starch disappearance rates in each segment of gastrointestinal tract in Hanwoo steers fed experimental diets

| Item | C-CGM[1)] | B-SBM[2)] | SEM[3)] | P value[4)] |
|---|---|---|---|---|
| Intake, g/d | 2329.2 | 2085.0 | 130.93 | 0.18 |
| Duodenal flow, g/d | 1386.2 | 517.7 | 224.63 | 0.04 |
| Fecal flow, g/d | 458.8 | 117.1 | 83.40 | 0.05 |
| Disappearance rate, g/d | | | | |
| Stomach | 943.0 | 1567.3 | 156.31 | 0.13 |
| Post-ruminal | 927.4 | 400.6 | 144.69 | 0.03 |
| Total tract | 1870.4 | 1967.9 | 101.42 | 0.69 |
| Disappearance rate | | | | |
| Stomach, % of intake | 42.3 | 75.6 | 8.10 | 0.04 |
| Post-ruminal, % of flow | 68.0 | 76.2 | 2.56 | 0.10 |
| Total tract, % of intake | 80.9 | 94.3 | 3.20 | 0.05 |

[1)] Corn + Corn gluten meal. [2)] Barley + Soybean meal. [3)] Standard error of mean. [4)] P values were calculated by paired t-test.

Table 6. Growth performance of Hanwoo steers fed experimental diets

| Item | C-CGM[1)] | B-SBM[2)] | SEM[3)] | P value[4)] |
|---|---|---|---|---|
| Initial body weight, kg | 312.3 | 309.5 | 7.81 | 0.91 |
| Final body weight, kg | 367.0 | 362.9 | 9.45 | 0.88 |
| ADG[5)], kg | 0.60 | 0.58 | 0.03 | 0.84 |
| DMI[6)], kg/d | 7.38 | 7.50 | 0.21 | 0.83 |
| Concentrates, kg/d | 4.85 | 4.88 | 0.13 | 0.94 |
| Rice straw, kg/d | 2.53 | 2.62 | 0.16 | 0.75 |
| DMI/ADG | 12.38 | 13.32 | 0.65 | 0.49 |

1) Corn + Corn gluten meal. 2) Barley + Soybean meal. 3) Standard error of mean. 4) P values were calculated by paired t-test.
5) ADG = Average daily gain. 6) DMI = Dry matter intake.

concluded that starch disappearance from the small intestine was increased with greater protein flow to the duodenum of steers. Taniguchi et al. (1995) and Richards et al. (2003) suggested increased pancreatic α-amylase secretion, in response to increased duodenal CP supply, is responsible for improvements in small intestinal starch disappearance. However, the present data showed the difference in percentage of starch apparently digested post-ruminally may not have been associated with the amount of duodenal CP flow between treatments. Huntington (1997) emphasized in hisreview that production and outflow of microbial protein from the rumen is responsible for starch digestion in the small intestine and Herrera-Saldana et al. (1990) noted that microbial N flow was the highest for the diets which combined fast degradable starch with fast degradable protein. However, the microbial protein synthesis (MPS) in the rumen was not determined in the current study and many literatureshave shown contradictory evidence of synchronizing energy and N supply to the rumen on rumen fermentation, MPS and on productive responses (Henning et al., 1993; Kim et al., 1999a, 1999b, 2000; Kim et al., 2005 Cabrita et al., 2006). Therefore, it is unclear if great protein flow including microbial protein to the duodenum would increase percentage of starch apparently digested post-ruminally in the current study.

We hypothesized that starch digestion in the small intestine would be more energetically efficient than ruminal fermentation (Harmon and McLeod, 2001). Many studies (Beauchemin and McGinn, 2005; Tiffany and Spears, 2005; Loe et al., 2006) reported that cattle fed a corn diet consumed more feed and had higher ADG than those fed a barley diet. McCarthy et al. (1989) suggests the greater passage of starchto the duodenum and its digestibility in the duodenum probably increased the availability of glucose for lactose synthesis and milk yield when corn replaced barley in the diet. Tiffany and Spears (2005) and Loe et al. (2006) reported improvement in marbling score for corn based diets. However, Bengochea et al. (2005) reported that DMI was greater for steers fed corn than barley based diet but it did not result in improved growth or gain efficiency. Khorasani et al. (1994) also reported the fast degradable starch with fast degradable protein may have a limited effect on milk yield. In this study, there was no evidence that higher starch digested post-ruminally for C-CGM, which was two times greater in amount compared to barley starch, should improve roughage dry matter intake (DMI), average daily gain (ADG) and feed efficiency (Table 6). The differences in percentages of starch apparently digested post-ruminally (8%) and digested in the total tract (13%) may also have little biological significance on the growth performances between steers fed B-SBM and C-CGM.

In conclusion, percentages of starch apparently digested postruminally was not affected significantly by treatments, however, the quantity of corn starch digested postruminally was two times greater than barley starch (927 vs. 400 g/d; $p<0.05$) and percentage of total tract digestibility was 14% unit greater for steers fed B-SBM diet than for C-CGM diet ($p=0.05$). Also, there is some uncertainty in regards to the relationship between site of starch digestion and DMI, ADG, and feed efficiency in this study.

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