

## Chewing Activities of Selected Roughages and Concentrates by Dairy Steers

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**ABSTRACT :** To evaluate the chewing activity of ruminant feeds, four Holstein steers (average body weight 742±15 kg) were employed. Experimental feeds were four roughages (NH<sub>3</sub>-treated rice straw, alfalfa hay, corn silage, orchard grass hay) and four concentrate ingredients (cotton seed hull, beet pulp pellet, barley grain, oat grain). Regarding palatability for each experimental feeds which was overviewed during the adjustment period, animals were fed roughages alone, but with 50% NH<sub>3</sub>-treated rice straw (NH<sub>3</sub>-RS) for concentrate ingredients. Therefore, all the data for concentrate ingredients was derived by extracting the result per unit obtained from steers fed NH<sub>3</sub>-RS alone. The experiment was conducted using a 4×4 Latin square designs for roughages and concentrate ingredients. Experimental feeds were fed during a 10 d adaptation and 2 d chewing data collection during each experimental period. Animals were gradually adjusted to the experimental diet. Dry matter intake (DMI) was restricted at a 1.4% of mean body weight (10.4 kg DM/d). Time spent eating and eating chews per kilogram of DMI were greatest for beet pulp pellet, and lowest for barley grain (p<0.05). Time spent rumination per kilogram of DMI was greatest for NH<sub>3</sub>-RS, cotton seed hull and orchard grass, but rumination chews were greatest for cotton seed hull and orchard grass except NH<sub>3</sub>-RS (p<0.05). Roughage index value (chewing time, minute/kg DMI) was 58.0 for cotton seed hull, 56.1 for beet pulp pellet, 55.5 for NH<sub>3</sub>-RS, 53.1 for orchard grass hay, 45.9 for corn silage, 43.0 for alfalfa hay, 30.0 for oat grain, and 10.9 for barley grain. The ratio of rumination time to total chewing time (eating plus ruminating) was about 72% for the roughages except corn silage (66.9%), and followed by cotton seed hull (69.5%), and ranged from 49.5% to 52.9% for other feeds. Higher percentages of rumination in total chewing time may be evidently indicate the characteristics of roughage. Therefore, this indicate that the chewing activity of concentrate ingredients can be more fully reflects by the ruminating time than total chewing time (RVI), although it is reasonable to define the RVI for roughages. (*Asian-Aust. J. Anim. Sci.* 2002, Vol 15, No. 7: 968-973)

**Key Words :** Chewing Activity, Dairy Steer, Roughage Index Value, Roughages, Concentrate

### INTRODUCTION

Chewing during eating and subsequent rumination play a major role in the digestion of ruminant feeds since soluble nutrients are released for fermentation, and the inner structures of feeds are exposed, permitting colonisation by rumen microorganisms (Ulyatt et al., 1986). Microbial digestion of forages fed in the long natural form is greatly facilitated by the mechanical damage done to them during chewing because rumen microbes are unable to penetrate the epidermis of undamaged plant material except through stroma (Cheng et al., 1980).

Chewing activity of ruminant is increased with roughage intake and is positively related to saliva production (Balch, 1958; Sudweeks, 1975). Therefore low roughage intake and shorter time spent chewing may adversely affect in roles of saliva which acts as a lubricant to facilitate mastication and swallowing, provides nutrients and a fluid environment for ruminal fermentation, facilitates passage from reticulorumen, and buffers VFA production from microbial fermentation to create more favorable condition for cellulolysis (Bartley, 1976). Chewing during

eating and ruminating reduce the particle size of feeds, releases soluble nutrients of feeds for rumen fermentation, exposes the interior portions of the feed to microbial attack, and hydrates feeds during insalivation (Pond et al., 1984; Ulyatt et al., 1986). Furthermore, low roughage (fiber) intakes by ruminants induce the off feed, erratic milk yield, low milk fat percentage and metabolic disorders in feedlot cattle (Britton and Stock, 1987). Therefore, resultant of chewing activity facilitates digestion of feed and is subsequently sustainable animal health. Several factors affect the chewing activity of ruminant: NDF content (Beauchemin, 1991), feed particle size and gravity (Woodford and Murphy, 1988), amount of feed intake (Luginbuhl et al., 1989), season (Sharma et al., 1998) and concentrate level (Sudweeks et al., 1975). Although the NRC (1989) recommended 19 to 21% ADF and 25 to 30% NDF in dairy cattle diets, quantitative (fiber concentration in the diet) as well as qualitative (physical form of the fiber) aspects of dietary fiber must be considered to ensure that chewing activity maintains normal ruminal function (Woodford et al., 1988). Balch et al. (1955) reported that chewing time was reduced as particle size decreased (substitution of grain for hay and straw pulp for grain), and they concluded that chewing time was a reliable indicator of "roughage value". Later, Balch (1971) proposed that time spent chewing (both eating and ruminating) per kilogram of dietary dry matter be used as an index of roughage value (RVI). RVI has been mainly used to evaluate for roughage.

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and seldom applied for cereal grain and by-products containing high dietary fiber. The objective of this research was to evaluate the respective chewing activity on eight feeds (four roughages, two by-products, two cereal grains) being widely used for ruminant.

## MATERIALS AND METHODS

### Animals and diets

Four Holstein steers (average body weight  $742 \pm 15$  kg) were used to investigate the chewing activity on four roughages (NH<sub>3</sub>-treated rice straw, corn silage, alfalfa hay, orchard grass hay) and four fibrous concentrate ingredients (cotton seed hull, beet pulp pellet, barley grain, oat grain). NH<sub>3</sub>-treated rice straw (NH<sub>3</sub>-RS) was treated with 3% ammonia gas and chopped coarsely (approximately 7 cm). Corn silage (Silage) prepared at yellow ripe stage had been in storage for about 6 month. Alfalfa hay (Alfalfa) and orchard grass hay (Orchard) were in long form. Cotton seed hull (CSH), beet pulp pellet (Beet), barley grain (Barley) and oat grain (Oat) were purchased from a commercial feedmill cooperation in Korea. Chemical composition of experimental feeds and nutrient intake are shown in table 1.

### Experimental procedure and feeding management

Regarding palatability for each experimental feeds which was overviewed during the adjustment period, animals were fed roughages alone, but with 50% NH<sub>3</sub>-RS for four concentrate ingredients. The experiment was conducted using a 4×4 Latin square design for roughages and concentrate ingredients. Experimental feeds were fed during a 10 d adaptation and 2 d chewing data collection during each experimental period. Dry matter (DM) intake was restricted at a 1.4% of mean body weight (10.4kg/d). This amount allowed for 90% *ad libitum* of NH<sub>3</sub>-RS during the preliminary experiment. Animals were fed diets in equal portions at 08:00 and 18:00 h daily. Water and trace mineralized salt block were available at all times. Animals were housed in individual stanchion barn with rubber mats to prevent from consuming additional fiber. Animals were

weighed at the start of the study and at the end of each period.

### Data collection and statistics

Animals were fitted with halters equipped with strain gauge (EA-06-125AD-120, Intertechnology Ltd., Toronto, Ont., Canada) transducers to record chewing activities on a chart recorder (056, Hitachi Co.) during the last 5 d of total 12 d. Transducer that measure voltage changes occurring in proportion to jaw movement consisted of magnet sewn to an elastic band and amplifier, and the sensing unit was located around the lower part of the muzzle of animal. Chewing stages classified into idling, eating and ruminating categories, characterization of meals, water drinking behavior, rumination periods, and latency before the onset of rumination periods were verified by examination of chewing patterns on a chart recorder and visual observation of chewing activity.

Chewing data for four concentrate ingredients supplemented with NH<sub>3</sub>-RS was derived by extracting the chewing data per dry matter intake obtained by animals fed NH<sub>3</sub>-RS alone from total chewing data.

Data are expressed as least square means, with differences among means were compared by Duncan's multiple range test (SAS, 1988).

## RESULTS AND DISCUSSIONS

Typical analog signals produced during eating and rumination are presented in figure 1. Chewing during eating displayed a repetitive pattern. In contrast, rumination is characterized by series of boli separated by short pauses. The chewing speed during a bolus is relatively constant.

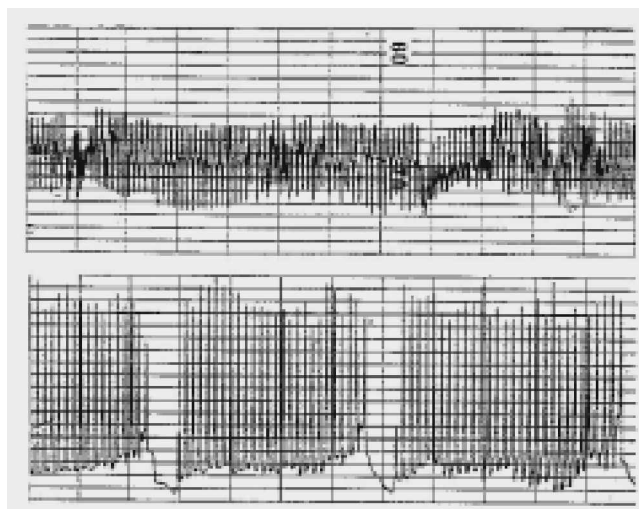
As shown in table 1, DMI was strictly restricted to about 10.4 kg per day, however NDF intake (0.71-1.31 kg/100 kg of body weight) was different among feeds. Previous studies (Deswysen et al., 1987; Luginbuhl et al., 1989) noted that chewing during eating and ruminating increased as feed intake levels increased. However, although steers spent more time chewing at high intakes,

**Table 1.** Chemical composition of experimental feeds and nutrient intake means

| Items            | Roughages                        |         |        |         | Concentrate ingredients |       |        |       |
|------------------|----------------------------------|---------|--------|---------|-------------------------|-------|--------|-------|
|                  | NH <sub>3</sub> -RS <sup>1</sup> | Alfalfa | Silage | Orchard | CSH <sup>2</sup>        | Beet  | Barley | Oat   |
| DM, %            | 86.00                            | 87.12   | 24.09  | 88.71   | 86.36                   | 86.95 | 88.05  | 87.67 |
| CP, % DM         | 8.50                             | 19.41   | 9.29   | 11.64   | 7.80                    | 9.97  | 11.20  | 11.67 |
| Ash, % DM        | 13.85                            | 10.04   | 5.94   | 8.50    | 3.06                    | 3.19  | 2.50   | 4.13  |
| NDF, % DM        | 67.88                            | 52.40   | 50.50  | 64.56   | 84.91                   | 68.50 | 21.18  | 56.47 |
| ADF, % DM        | 46.60                            | 39.93   | 40.74  | 31.94   | 59.10                   | 23.73 | 7.80   | 20.63 |
| DMI, kg/d        | 10.40                            | 10.33   | 10.48  | 10.40   | 10.45                   | 10.37 | 10.40  | 10.40 |
| NDF intake, kg/d | 7.11                             | 5.43    | 5.33   | 6.71    | 9.70                    | 6.93  | 5.82   | 6.94  |

<sup>1</sup> NH<sub>3</sub>-treated rice straw.

<sup>2</sup> Cotton seed hull.



**Figure 1.** Typical analog signals produced during eating (top) and rumination (bottom).

they actually chewed less per unit of feed consumed (Shaver et al., 1986). Therefore, this experiment was strictly restricted in dry matter intake to prevent the effects of chewing activities by feed intake. But, as concentrate ingredients were refused at any levels of intakes, it was impossible to investigate the effects of chewing activities by

feeding alone.

Mean times spent eating, ruminating, and total chewing is shown in table 2. Time spent eating during a day was greater for CSH and Beet which was supplemented with 50%  $\text{NH}_3$ -RS than when roughages were fed alone. According to visual observation on the eating behavior, fleecy CSH and hardness of Beet spent more time in eating.

Ruminating time was greater in CSH,  $\text{NH}_3$ -RS and Orchard than for the other feeds. Macgregor (1989) reported that cotton seed was spent a great deal of time in ruminating because of the characteristics to be bulkiness in the rumen. Barley resulted in less ruminating time than oat. Voskuil and Metz (1973) and Brouk and Belyea (1993) reported rumination times of about 539 min/d and about 400 min/d for cows eating alfalfa hay, respectively, compare with 319 min/d in our study. Variation of chewing activity may be due to the differences of physical form and variation among cows as it also was in the studies by Deswysen et al. (1987) and Brouk and Belyea (1993).

Time spent eating per kilogram of dry matter intake was longest when steers fed Beet (27.3 min), and shortest for Barley (5.5 min). Hardness of beet pulp pellet (Beet) is attributed to increase the eating time.

Rumination time per kilogram of DMI was greater in order by  $\text{NH}_3$ -RS (40.0 min), CSH (39.0 min), Orchard

**Table 2.** Chewing time of steers fed experimental feeds

| Items                             | Roughages                      |                        |                       |                        | Concentrate ingredients |                       |                       |                        |
|-----------------------------------|--------------------------------|------------------------|-----------------------|------------------------|-------------------------|-----------------------|-----------------------|------------------------|
|                                   | $\text{NH}_3$ -RS <sup>1</sup> | Alfalfa                | Silage                | Orchard                | CSH <sup>2</sup>        | Beet                  | Barley                | Oat                    |
| Min/d                             |                                |                        |                       |                        |                         |                       |                       |                        |
| Eating                            | 161.6                          | 123.5                  | 159.3                 | 150.3                  | 235.1<br>(89.0)         | 223.4<br>(150.1)      | 125.9<br>(28.6)       | 156.9<br>(78.0)        |
| Ruminating                        | 415.9                          | 319.2                  | 321.8                 | 401.4                  | 424.1<br>(202.9)        | 354.8<br>(160.3)      | 314.6<br>(28.1)       | 329.5<br>(78.0)        |
| Total                             | 577.5                          | 442.7                  | 481.1                 | 551.7                  | 659.2<br>(291.9)        | 578.2<br>(310.4)      | 440.5<br>(34.8)       | 486.4<br>(96.1)        |
| Min/kg of DMI                     |                                |                        |                       |                        |                         |                       |                       |                        |
| Eating                            | 15.5±1.7 <sup>b</sup>          | 12.0±1.8 <sup>c</sup>  | 15.2±1.3 <sup>b</sup> | 14.5±1.6 <sup>bc</sup> | 17.1±1.1 <sup>b</sup>   | 27.3±3.9 <sup>a</sup> | 5.5±0.9 <sup>d</sup>  | 15.0±2.2 <sup>b</sup>  |
| Ruminating                        | 40.0±2.1 <sup>a</sup>          | 31.0±2.4 <sup>b</sup>  | 30.7±2.6 <sup>b</sup> | 38.6±1.6 <sup>a</sup>  | 39.0±2.8 <sup>a</sup>   | 30.7±2.3 <sup>b</sup> | 5.4±1.1 <sup>d</sup>  | 15.0±0.9 <sup>c</sup>  |
| Total <sup>3</sup>                | 55.5±2.8 <sup>a</sup>          | 43.0±3.2 <sup>b</sup>  | 45.9±1.0 <sup>b</sup> | 53.1±3.1 <sup>a</sup>  | 56.1±2.4 <sup>a</sup>   | 58.0±4.6 <sup>a</sup> | 10.9±1.4 <sup>d</sup> | 30.0±2.6 <sup>c</sup>  |
| Ruminating/Total <sup>4</sup> , % | 72.1                           | 72.1                   | 66.9                  | 72.7                   | 69.5                    | 52.9                  | 49.5                  | 50.0                   |
| Min/kg of NDF intake              |                                |                        |                       |                        |                         |                       |                       |                        |
| Eating                            | 22.2±1.0 <sup>c</sup>          | 20.1±1.4 <sup>cd</sup> | 30.0±0.7 <sup>b</sup> | 22.4±2.4 <sup>c</sup>  | 18.2±1.1 <sup>d</sup>   | 39.8±5.8 <sup>a</sup> | 24.9±4.9 <sup>c</sup> | 26.5±3.8 <sup>c</sup>  |
| Ruminating                        | 57.2±3.1 <sup>a</sup>          | 51.9±4.0 <sup>b</sup>  | 60.7±1.4 <sup>a</sup> | 59.8±2.5 <sup>a</sup>  | 41.5±3.0 <sup>c</sup>   | 44.8±3.3 <sup>c</sup> | 25.6±5.2 <sup>d</sup> | 26.6±1.6 <sup>d</sup>  |
| Total                             | 79.4±4.0 <sup>bc</sup>         | 72.0±5.4 <sup>c</sup>  | 90.7±2.0 <sup>a</sup> | 82.2±4.8 <sup>b</sup>  | 59.7±2.5 <sup>d</sup>   | 84.6±6.7 <sup>b</sup> | 50.5±6.1 <sup>e</sup> | 53.1±4.7 <sup>de</sup> |

<sup>1</sup>  $\text{NH}_3$ -treated rice straw.

<sup>2</sup> Cotton seed hull.

<sup>3</sup> Roughage index value.

<sup>4</sup> Proportions of rumination chewing to total chewing.

Mean±SD.

Means with different superscripts in the same row significantly differ ( $p < 0.05$ ).

Values in the parenthesis mean the portion of experimental feeds in total chewing data by steers fed concentrate ingredients supplemented with  $\text{NH}_3$ -RS, and calculated as; Total chewing data -  $\text{NH}_3$ -RS intake chewing data per kilogram of  $\text{NH}_3$ -RS intake.

(38.6 min) Alfalfa (31.0 min), Silage (30.7 min), Beet (30.7 min), Oat (15.0 min) and Barley (5.4 min).

When eating and rumination times were combined as chewing time, RVI (chewing time, min/kg of DMI) was greater in order by CSH (58.0), Beet (56.1), NH<sub>3</sub>-RS (55.5), Orchard (53.1), Silage (45.9), Alfalfa (43.0), Oat (30.0) and Barley (10.9). Sudweeks et al. (1975) discussed that neither eating time nor ruminating time alone adequately measures their roughage characteristics because of feed particle size, but the combined value of chewing time more fully reflects the roughage value of the forages. And they reported that RVI was 59.74 for corn silage and 78.54 for bermuda grass hay, and that the steers evidently consumed the moist silage with less mastication than the dry long hay.

The ratio of rumination of total chewing time was 72% for NH<sub>3</sub>-RS, Alfalfa and Orchard, 70% for CSH, 67% for Silage, 52% for Beet, and 50% even for barley or oat. Higher percentages of rumination in total chewing time may be evidently indicate the characteristics of roughage. Therefore, this indicate that the chewing activity of concentrate ingredients can be more fully reflects by the ruminating time than RVI, although it is reasonable to define the RVI for roughages. Eating time per unit of NDF was longest in Beet (39.8 min/kg) and shortest in CSH (18.2 min/kg). Time spent ruminating per kilogram of NDF intake was longer in roughages than concentrate ingredients. Total chewing time per kilogram of NDF intake were greatest for Silage (90.7 min), and followed by Beet (84.6 min), Orchard (82.2 min), NH<sub>3</sub>-RS (79.4 min), Alfalfa (72.0 min), CSH (59.7 min), Oat (53.1 min) and Barley (50.5 min). Consequently, total chewing time per kilogram of NDF intake followed trends similar to those for times spent ruminating except for Beet which was longest in eating time.

Brouk and Belyea (1993) reported that times spent eating, ruminating and total chewing for long alfalfa hay were 463, 393 and 856 min/d when cows (Guernsey) fed 10.2 kg of dry matter per day, respectively. Comparing with our results, remarked difference in time spent eating is probably associated with physical characteristics of alfalfa: it may facilitate bolus formation and swallowing during eating since alfalfa hay used in this study was strongly compressed during making of rectangular bale, and was chopped at 2-7 cm before feeding.

Sudweek et al. (1975) indicated that the chewing time for the concentrate and forage was partitioned by regression, they reported a RVI of 59.74 for corn silage and 78.54 for bermuda grass hay. Therefore RVI for corn silage of Sudweeks et al. (1975) was significantly higher than 45.9 of our study, which may due to the differences of extent of fermentation or storage period (above 6 month in this study).

Brouk and Belyea (1993) reported that when cows are fed significant amounts of concentrate, total chewing activity can be reduced by 30 to 50%. But in this study

chewing activity, whether expressed in minutes per day, minute per kilogram of dry matter intake, or minutes per kilogram of NDF intake, was lower than those in the other studies (Jaster and Murphy, 1983; Luginbuhl et al., 1987; Teller et al., 1989) even when cows were fed only forage. Particularly, eating time in this study was no more than 30 to 50% of the other studies, even though cows and steers fed a similar amount of diets (10.2 to 10.9 vs 10.4 kg DM/d). Variation among animals in our study was great as it also was in the studies by Dewswysen et al. (1987) and Brouk and Belyea (1993).

Number of chewing when steer fed the experimental feeds is shown in table 3.

The ruminating chews per minute of experimental feeds ranged from 46.7 to 65.6 times per minute. Steers fed NH<sub>3</sub>-RS had the lowest chewing rate (chews/min) during rumination, even though they had the greatest ruminating time per kilogram of DMI. This appeared to be due to wider movement of jaw during rumination according to visual observation and the height of peak recorded in chart. Eating chews per kilogram of DMI were greatest for Beet, intermediated for CSH, Oat, NH<sub>3</sub>-RS, Silage, Orchard, and least for Alfalfa and Barley. But ruminating chews per kilogram of DMI were greatest for CSH and Orchard, and followed by Silage, Beet, NH<sub>3</sub>-RS, Alfalfa and Oat. Therefore total chews per kilogram of DMI were also greatest for CSH and Beet which were greatest in the chews during ruminating and eating, respectively. Eating chews per kilogram of NDF intake were greater in steers fed Beet, Oat and Silage, but rumination chews per kilogram of NDF intake were greater in Silage, Barley and Orchard than the other feeds. Brouk and Belyea (1993) reported that chewing rates (chews/min) during rumination for long, chopped and reconstituted alfalfa hays were 53.0, 51.4 and 52.6, respectively, compared with 57.8 in our study. And they discussed that when chewing activity was altered (i.e., during eating), the response was attained by fewer chews per unit of DMI and NDF intake than reducing chewing rate (number of chews per minute). In this study, chewing activity does not always depend on number of chews.

Results for rumination boli of steers fed experimental feeds are shown in table 4.

The number of ruminated boli was proportional to rumination time. Duration per bolus was longest for NH<sub>3</sub>-RS, intermediated for CSH, Beet, Orchard, Alfalfa, Silage, Oat, and shortest for Barley. Chews per ruminated bolus were greatest for CSH (50.9) and least for NH<sub>3</sub>-RS (40.7). Steers fed NH<sub>3</sub>-RS had the least chewing rate (chews/bolus), even though they had the longest in duration per bolus. This appeared to be due to wider movement of jaw during rumination according to visual observation and the height of peak recorded in chart.

**Table 3.** Chewing number of steers fed experimental feeds

| Items                     | Roughages                        |                              |                              |                              | Concentrate ingredients       |                              |                              |                               |
|---------------------------|----------------------------------|------------------------------|------------------------------|------------------------------|-------------------------------|------------------------------|------------------------------|-------------------------------|
|                           | NH <sub>3</sub> -RS <sup>1</sup> | Alfalfa                      | Silage                       | Orchard                      | CSH <sup>2</sup>              | Beet                         | Barley                       | Oat                           |
| Chews/d ( $\times 10^2$ ) |                                  |                              |                              |                              |                               |                              |                              |                               |
| Eating                    | 108.7                            | 77.9                         | 107.6                        | 110.0                        | 102.8<br>(67.8)               | 161.4<br>(100.2)             | 89.1<br>(16.9)               | 112.0<br>(67.1)               |
| Ruminating                | 193.8                            | 184.1                        | 206.1                        | 248.4                        | 235.6<br>(132.5)              | 209.9<br>(98.3)              | 175.3<br>(41.3)              | 189.7<br>(55.3)               |
| Total                     | 302.5                            | 262.0                        | 313.7                        | 358.4                        | 338.4<br>(200.3)              | 371.3<br>(198.5)             | 264.4<br>(58.2)              | 301.7<br>(122.4)              |
| Chews/kg of DMI           |                                  |                              |                              |                              |                               |                              |                              |                               |
| Eating                    | 1.045 $\pm$ 61 <sup>b</sup>      | 756 $\pm$ 78 <sup>c</sup>    | 1.025 $\pm$ 20 <sup>b</sup>  | 1.058 $\pm$ 177 <sup>b</sup> | 1,305 $\pm$ 134 <sup>b</sup>  | 1,920 $\pm$ 361 <sup>a</sup> | 326 $\pm$ 85 <sup>d</sup>    | 1,290 $\pm$ 220 <sup>b</sup>  |
| Ruminating                | 1.864 $\pm$ 200 <sup>b</sup>     | 1.778 $\pm$ 99 <sup>b</sup>  | 1.963 $\pm$ 113 <sup>b</sup> | 2.389 $\pm$ 107 <sup>a</sup> | 2,548 $\pm$ 143 <sup>a</sup>  | 1,883 $\pm$ 320 <sup>b</sup> | 794 $\pm$ 64 <sup>d</sup>    | 1.063 $\pm$ 171 <sup>c</sup>  |
| Total <sup>3</sup>        | 2.909 $\pm$ 171 <sup>b</sup>     | 2.544 $\pm$ 160 <sup>c</sup> | 2.988 $\pm$ 123 <sup>b</sup> | 3.447 $\pm$ 273 <sup>a</sup> | 3,853 $\pm$ 177 <sup>a</sup>  | 3,803 $\pm$ 632 <sup>a</sup> | 1,120 $\pm$ 59 <sup>d</sup>  | 2,353 $\pm$ 306 <sup>c</sup>  |
| Chews/min. rumination     | 46.7 $\pm$ 4.6 <sup>c</sup>      | 57.8 $\pm$ 1.3 <sup>b</sup>  | 64.0 $\pm$ 2.8 <sup>a</sup>  | 61.9 $\pm$ 2.3 <sup>a</sup>  | 65.5 $\pm$ 3.9 <sup>a</sup>   | 57.3 $\pm$ 2.5 <sup>b</sup>  | 55.9 $\pm$ 8.7 <sup>b</sup>  | 65.6 $\pm$ 9.0 <sup>a</sup>   |
| Chews/kg of NDF           |                                  |                              |                              |                              |                               |                              |                              |                               |
| Eating                    | 1,495 $\pm$ 87 <sup>c</sup>      | 1,266 $\pm$ 131 <sup>d</sup> | 2,030 $\pm$ 40 <sup>b</sup>  | 1,638 $\pm$ 275 <sup>c</sup> | 1,389 $\pm$ 143 <sup>cd</sup> | 2,802 $\pm$ 527 <sup>a</sup> | 1,540 $\pm$ 404 <sup>c</sup> | 2,284 $\pm$ 391 <sup>ab</sup> |
| Ruminating                | 2,667 $\pm$ 287 <sup>b</sup>     | 2,995 $\pm$ 167 <sup>b</sup> | 3,887 $\pm$ 224 <sup>a</sup> | 3,700 $\pm$ 166 <sup>a</sup> | 2,714 $\pm$ 152 <sup>b</sup>  | 2,749 $\pm$ 467 <sup>b</sup> | 3,748 $\pm$ 305 <sup>a</sup> | 1,882 $\pm$ 303 <sup>c</sup>  |
| Total                     | 4,162 $\pm$ 245 <sup>b</sup>     | 4,261 $\pm$ 282 <sup>b</sup> | 5,917 $\pm$ 244 <sup>a</sup> | 5,338 $\pm$ 422 <sup>a</sup> | 4,103 $\pm$ 189 <sup>b</sup>  | 5,551 $\pm$ 922 <sup>a</sup> | 5,288 $\pm$ 280 <sup>a</sup> | 4,166 $\pm$ 543 <sup>b</sup>  |

<sup>1</sup> NH<sub>3</sub>-treated rice straw.<sup>2</sup> Cotton seed hull.Mean $\pm$ SD.Means with different superscripts in the same row significantly differ ( $p < 0.05$ ).Values in the parenthesis mean the portion of experimental feeds in total chewing data by steers fed concentrate ingredients supplemented with NH<sub>3</sub>-RS, and calculated as: Total chewing data - NH<sub>3</sub>-RS intake  $\div$  chewing data per kilogram of NH<sub>3</sub>-RS intake.**Table 4.** Rumination bolus of steers fed experimental feeds

| Items            | Roughages                        |                              |                              |                              | Concentrate ingredients       |                              |                              |                              |
|------------------|----------------------------------|------------------------------|------------------------------|------------------------------|-------------------------------|------------------------------|------------------------------|------------------------------|
|                  | NH <sub>3</sub> -RS <sup>1</sup> | Alfalfa                      | Silage                       | Orchard                      | CSH <sup>2</sup>              | Beet                         | Barley                       | Oat                          |
| Rumination boli  |                                  |                              |                              |                              |                               |                              |                              |                              |
| Boli/d           | 490                              | 444                          | 467                          | 559                          | 551 (261)                     | 464 (210)                    | 416 (95)                     | 432 (134)                    |
| Boli/kg DM       | 47.2 $\pm$ 1.7 <sup>ab</sup>     | 43.1 $\pm$ 3.7 <sup>b</sup>  | 44.4 $\pm$ 2.8 <sup>b</sup>  | 53.7 $\pm$ 3.7 <sup>a</sup>  | 50.3 $\pm$ 4.5 <sup>a</sup>   | 40.2 $\pm$ 5.3 <sup>b</sup>  | 18.3 $\pm$ 3.9 <sup>c</sup>  | 25.7 $\pm$ 3.0 <sup>c</sup>  |
| Boil/kg NDF      | 67.5 $\pm$ 2.4 <sup>b</sup>      | 72.2 $\pm$ 6.2 <sup>b</sup>  | 88.0 $\pm$ 5.6 <sup>a</sup>  | 83.2 $\pm$ 5.7 <sup>a</sup>  | 53.5 $\pm$ 4.8 <sup>cd</sup>  | 58.7 $\pm$ 7.7 <sup>c</sup>  | 69.6 $\pm$ 8.3 <sup>b</sup>  | 45.5 $\pm$ 5.3 <sup>d</sup>  |
| Duration of boli |                                  |                              |                              |                              |                               |                              |                              |                              |
| sec./bolus       | 51.0 $\pm$ 3.4 <sup>a</sup>      | 43.2 $\pm$ 0.3 <sup>b</sup>  | 41.6 $\pm$ 2.8 <sup>b</sup>  | 43.4 $\pm$ 4.6 <sup>b</sup>  | 46.8 $\pm$ 3.5 <sup>ab</sup>  | 46.6 $\pm$ 6.8 <sup>ab</sup> | 23.6 $\pm$ 6.7 <sup>d</sup>  | 35.6 $\pm$ 5.0 <sup>c</sup>  |
| Chews per bolus  | 40.7 $\pm$ 2.7 <sup>b</sup>      | 41.6 $\pm$ 1.2 <sup>b</sup>  | 43.3 $\pm$ 2.1 <sup>ab</sup> | 44.7 $\pm$ 4.1 <sup>a</sup>  | 50.9 $\pm$ 2.4 <sup>a</sup>   | 46.8 $\pm$ 4.8 <sup>a</sup>  | 43.2 $\pm$ 9.5 <sup>ab</sup> | 41.2 $\pm$ 3.3 <sup>b</sup>  |
| Boli/min         |                                  |                              |                              |                              |                               |                              |                              |                              |
| rumination       | 1.18 $\pm$ 0.08 <sup>d</sup>     | 1.39 $\pm$ 0.01 <sup>c</sup> | 1.45 $\pm$ 0.10 <sup>c</sup> | 1.40 $\pm$ 0.15 <sup>c</sup> | 1.29 $\pm$ 0.10 <sup>cd</sup> | 1.32 $\pm$ 0.20 <sup>c</sup> | 3.22 $\pm$ 1.39 <sup>a</sup> | 1.72 $\pm$ 0.25 <sup>b</sup> |

<sup>1</sup> NH<sub>3</sub>-treated rice straw.<sup>2</sup> Cotton seed hull.Mean $\pm$ SD.Means with different superscripts in the same row significantly differ ( $p < 0.05$ ).Values in the parenthesis mean the portion of experimental feeds in total chewing data by steers fed concentrate ingredients supplemented with NH<sub>3</sub>-RS, and calculated as: Total chewing data - NH<sub>3</sub>-RS intake  $\times$  chewing data per kilogram of NH<sub>3</sub>-RS intake.

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