INTRODUCTION

The forages for feeding cattle in South Korea comprises rice straw (36%), cultivated forage crop (44%), and imported forage (20%) (MIFAFF, 2011). Except for rice straw that is low quality forage, barley as winter forage occupies the largest share of the domestic forage production. Therefore, improvement of nutritional quality of barley forage may help to increase animal productivity and thus farm profitability. Increasing cutting height at harvest is one of the good options for improving nutritional quality of forage or silage. Higher yield of dry matter (DM) and amount of grain from forage (Neylon and Kung, 2003) are considered as quality indicators for whole crop forage or silage. Above characteristics may be brought into whole crop forage or silage by increasing the cutting height to make whole crop silage (Weller, 1992; Neylon and Kung, 2003; Caetano et al., 2011; Lynch et al., 2015). The potential benefit of increasing cutting height is to reduce the proportion of the fibrous bottom part which has poor digestibility (Caetano et al., 2011). Several studies reported that harvesting the forage at higher cutting height can improve nutritive value of silage and animal performance (Sinclair et al., 2003; Kennington et al., 2005; Wu and Roth, 2005). However, most of studies have been done with corn silage (Neylon and Kung, 2003; Kennington et al., 2005; Wu and Roth, 2005; Caetano et al.,...
2011; Lynch et al., 2015) and very rarely with barley. Therefore, the present study was conducted to evaluate effects of different cutting height on chemical composition, fermentation characteristics of whole crop barley (WCB) silage and, in vitro and in vivo nutrient digestibility of total mixed rations (TMR) made up of silages of different cutting height. Our hypothesis was that the increase in cutting height at forage harvest could improve the silage quality and nutrient digestibility of WCB silage.

MATERIALS AND METHODS

Silage experiment

Forage production and silage making: The Yuyeon hybrid of barley was used in this experiment, which was developed in Korea by traditional crossbreeding having ruminant palatable awns and better silage quality (Park et al., 2008). The WCB was cultivated at the Animal Research Unit, Gyeongsang National University, Jinju, Korea with a seed rate of 220 kg/ha. It was planted in October 2011 and harvested in May 2012 at soft dough stage of maturity. The forage was mowed at a height of 5, 10, and 15 cm, from the ground level. Approximately 500 kg forage from each cutting height was rolled to make round bale with a baler (BWR1-150, JUKAM Machinery Co., Ltd, Suncheon, Korea) followed by wrapping (27 layers of 0.03-µm poly-ethylene film) with a wrapper and ensiled in 3 replicates for 100 days. Representative samples of fresh forage were collected from each cutting height before ensiling and stored at −20°C for chemical analysis. After ensiled for 100 days, bales were opened and silages were sub-sampled for subsequent laboratory analysis (500 g), aerobic stability (1 kg) determination and storage (−20°C) for further use in later.

Preparation of silage extract: Twenty grams of fresh silage were homogenized with 200 mL of sterile double-distilled water in a blender (HM-1600PB, HANIL Electric Corporation, Korea) at 2,568×g for 15 minutes. The pH of the silage extract was measured right after extraction, sampled for microbial enumeration and then stored at −20°C for analysis of fermentation products (NH₃-N, lactic acid volatile fatty acids) in silages.

Microbial enumeration: The microbial enumeration (yeast, mold, and lactic acid bacteria [LAB]) was done from silage extract immediately after silo opening. A 20 g sample of silage in 180 mL of sterile peptone water was homogenized in a blender, filtered through 2 layers of cheesecloth and used for microbial enumeration. The pH of the silage extract was measured right after extraction, sampled for microbial enumeration and then stored at −20°C for analysis of fermentation products (NH₃-N, lactic acid volatile fatty acids) in silages.
min. Rumen pH, NH₃-N and volatile fatty acid (VFA) were analyzed from the supernatant.

**In vivo experiment**

**Management of animals:** The experiment was carried out at Junga Hanwoo Farm, Jinju, Korea. Animals were cared according to the guidelines of the National Livestock Research Institute (NLRI), Korea. Diets were formulated to meet the nutrient requirements of growing Hanwoo heifer according to the Korean Feeding Standards for Hanwoo cattle developed by NLRI, Rural Development Administration, Ministry of Agriculture and Forestry (Korean Feeding Standard, 2002).

Twelve Hanwoo heifers weighing 375±46 kg were randomly assigned into three dietary treatments. Heifers were housed in individual tie-stalls and fed TMR diets as in the *in vitro* experiment. The diets were provided at a rate of 2.2% of live weight (Table 8; 3.25 kg) at 0800 and 1700 h daily. Free access to clean drinking water was confirmed throughout the experimental period. The trial was continued for 15 days of which first 10 days were for adaptation and last 5 days were for sample collection.

**Collection and sampling:** The diets were formulated daily and sub-sampled for DM, crude protein (CP), ether extract (EE), crude ash, neutral detergent fiber (NDF), and acid detergent fiber (ADF) analysis. In collection period, the feed refusals and feces were collected and weighed every morning 30 min before feeding. The feces were collected into covered plastic buckets, weighed, mixed and sub-sampled (10%) separately for each animal. At the end of collection period, the samples were composited by animal, mixed and sub-sampled representatively, dried at 65°C for 48 h, ground to pass a 1-mm screen using grinder (Cutting Mill, Shinmyung Electric Co., Ltd, Gimpo, Korea) and analyzed for DM, CP, EE, NDF, and ADF. Then DM, CP, EE, NDF, and ADF digestibility was calculated. The samples were stored at –20°C until end of analysis.

**Laboratory analysis**

The samples were dried using an oven at 65°C for 48 h to measure the DM content and then the dried samples were ground through a 1-mm screen using a grinder for the *in vitro* digestibility study. Content of CP was calculated as N ×6.25, after N was quantified using N analyzer (B-324, 412, 435 and 719 S Titrino, BÜCHI, Flawil, Switzerland). The EE concentration was analyzed using the Soxhlet method (AOAC, 1965). Crude ash concentration was determined by burning the sample in a muffle furnace at 550°C for 5 h. Contents of NDF and ADF were analyzed according to Van Soest et al. (1991) using ANKOM200 fiber analyzer (Ankom Technology, Macedon, NY, USA). Heat-stable α-amylase and sodium sulfite were used in NDF analysis and results were expressed inclusive of ash.

The pH was measured from silage extract using a pH meter (SevenEasy pH Meter S20, Mettler Toledo, Greifensee, Switzerland) and the content of NH₃-N in silage extract was analyzed by distillation using BÜCHI apparatus (B-324, BÛCHI, Flawil, Switzerland) followed by titration with 0.1-N H₂SO₄ according to AOAC (1984). Silage extract was centrifuged at 21,500×g for 15 min at –4°C constant temperature. The supernatant was used to measure the lactate and VFA contents by an high-performance liquid chromatography system with a pump (L-2130, HITACHI, Tokyo, Japan), auto sampler (L-2200, HITACHI, Tokyo, Japan), UV detector (L-2400, HITACHI, Japan) and a column (Metacarb 87H, Varian, Middelburg, Netherlands) as described by Adesogan et al. (2004).

**Statistical analysis**

The data were analyzed using the general linear model procedure of SAS (2002). Data for microbial enumeration were transformed by log₁₀. The model was \( Y_{ij} = \mu + T_i + e_{ij} \), where \( Y_{ij} \) = response variable, \( \mu \) = overall mean, \( T \) = effect of treatment i, and \( e_{ij} \) = error effect. Tukey’s test was performed to differentiate means. Significance was declared at \( p \leq 0.05 \).

**RESULTS**

**Silage experiment**

The DM content of fresh WCB before ensiling was increased (\( p < 0.05 \)) with the increase in cutting height, while NDF and ADF contents decreased (\( p < 0.05 \)) (Table 1). The EE content in 10 and 15 cm of cutting height increased (\( p < 0.05 \)), but CP and crude ash were remain unaffected (\( p > 0.05 \)) by increasing cutting height. After 100 days of ensiling, the DM, CP, and Crude ash were unaffected (\( p > 0.05 \)) by cutting height (Table 2). The EE concentration was increased (\( p < 0.05 \)) while NDF and ADF concentration was decreased (\( p < 0.05 \)) by increasing cutting height. The pH of silage was lower (\( p < 0.05 \)) in 5 cm, but not different between

**Table 1. Chemical composition of barley silage before ensiling (%,**

| Items                        | Cutting height (cm) | SEM  |
|------------------------------|---------------------|------|
|                              | 5                   | 10   | 15   |
| Dry matter                   | 33.8b               | 33.9b| 34.6a| 0.285|
| Crude protein                | 8.61                | 8.61 | 8.64 | 0.052|
| Ether extract                | 2.45b               | 3.30b| 3.23a| 0.149|
| Crude ash                    | 9.13                | 9.13 | 9.12 | 0.017|
| Neutral detergent fiber      | 57.9a               | 57.4ab| 56.0b| 0.588|
| Acid detergent fiber         | 33.9a               | 33.4b| 32.8b| 0.432|

DM, dry matter; SEM, standard error mean.

| Items                        | 5                   | 10   | 15   |

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

ab Means in the same row with different superscripts differ significantly (\( p < 0.05 \)).
10 and 15 cm of cutting height (Table 3). The content of lactate and lactate to acetate ratio were increased (p<0.05) in 5 cm of cutting height, whereas the acetate content was higher (p<0.05) in 10 and 15 cm than that of 5 cm cutting height. The concentration of NH3-N in 100 days silage was not affected (p>0.05) by increasing cutting height. Aerobic stability was greater (p<0.05) in silages of 10 and 15 cm of cutting height, whereas yeast, mold and LAB counts were not affected (p>0.05) by cutting height (Table 4).

**In vitro and in vivo experiment**

The ingredient compositions of concentrate mixture used in different TMR are presented in Table 5 and the ingredients and chemical compositions of formulated TMRs are illustrated in Table 6. There were no differences (p>0.05) in contents of DM, CP, EE, and crude ash in different TMRs used as treatments. On the other hand, NDF and ADF were found to be decreased (p<0.05) in the TMRs containing silages from higher cutting heights (Table 6). The concentrations of NDF vs ADF in TMR5, TMR10, and TMR15 were observed as 51.9% vs 27.8%, 50.9% vs 27.4%, and 50.1% vs 26.9%, respectively.

The *in vitro* digestibility and rumen fermentation indices are described in Table 7. The IVDMD was higher (p<0.05) in the TMR5 (47.9%) and TMR10 (46.3%) than that in TMR15 (46.3%), whereas IVNDFD was higher (p<0.05) in the TMR10 (42.9%) and TMR15 (43.5%) than that in TMR5 (38.7%). The pH was lower (p<0.05) in TMR10 (6.98) than in the others, but there were no differences between TMR5 (7.06) and TMR15 (7.00). Concentration of NH3-N (mg/100 mL) was highest (p<0.05) in the TMR10 (34.8) followed by TMR15 (33.6) and TMR5 (27.5). Total VFA was decreased (p<0.05) with increased cutting height (62.7, 59.7, and 53.3 mM/L in TMR5, TMR10, and TMR15, respectively). Molar proportions (%) of acetate, butyrate and acetate to propionate ratio were highest (p<0.05) in TMR5 (58.6, 9.14 and 2.59, respectively). The valerate was increased (p<0.05) in TMR10 and propionate concentration was increased (p<0.05) in TMR 10 and TMR5.

### Table 2. Chemical composition of barley silage ensiled for 100 days (%, DM)

| Items            | Cutting height1 (cm) | SEM  |
|------------------|----------------------|------|
|                  | 5        | 10     | 15     |
| Dry matter       | 30.6     | 30.9   | 30.6   | 0.996 |
| Crude protein    | 9.04     | 9.02   | 9.02   | 0.016 |
| Ether extract    | 3.34c    | 3.57b  | 3.71a  | 0.074 |
| Crude ash        | 10.2     | 9.00   | 9.00   | 1.376 |
| Neutral detergent fiber | 52.4a | 52.0b  | 52.6b  | 0.363 |
| Acid detergent fiber | 31.0a   | 30.6ab | 30.4b  | 0.301 |

DM, dry matter; SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

**Table 3. Fermentation indices of barley silage ensiled for 100 days**

| Items                        | Cutting height1 (cm) | SEM  |
|------------------------------|----------------------|------|
|                              | 5        | 10     | 15     |
| pH                           | 3.86b    | 4.00a  | 4.02a  | 0.045 |
| NH3-N (% of DM)              | 0.08     | 0.09   | 0.09   | 0.005 |
| NH3-N (% of total N)         | 5.84     | 5.81   | 5.85   | 0.190 |
| Volatile fatty acid (% of DM)|                      |      |
| Lactate                      | 6.31a    | 5.53b  | 5.51b  | 0.117 |
| Acetate                      | 1.28b    | 1.43a  | 1.44a  | 0.017 |
| Lactate:acetate ratio        | 4.93a    | 3.87b  | 3.83b  | 0.057 |

DM, dry matter; SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

**Table 4. Aerobic stability and microbial growth of barley silage ensiled for 100 days**

| Items                        | Cutting height1 (cm) | SEM  |
|------------------------------|----------------------|------|
|                              | 5        | 10     | 15     |
| Aerobic stability (h)        | 139.3b   | 278.3a | 270.5a | 17.86 |
| Microbes (log10 cfu/g)       |                      |      |
| Yeast                       | 2.76     | 2.34   | 2.42   | 0.582 |
| Mold                        | 3.43     | 3.21   | 3.19   | 0.285 |
| Acid bacteria               | 6.27     | 6.58   | 6.21   | 0.299 |

SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

**Table 5. Composition of concentrate mixed into the TMR using the in vitro and in vivo experiment (%, DM)**

| Ingredient            | %     |
|-----------------------|-------|
| Corn meal             | 15.0  |
| Barley meal           | 9.00  |
| Soybean meal          | 12.5  |
| Rice bran             | 14.6  |
| Wheat bran            | 19.0  |
| Corn gluten feed      | 9.50  |
| Soy bean hull         | 8.30  |
| Corn hull             | 0.50  |
| Corn cob              | 8.00  |
| Corn gluten meal      | 1.00  |
| Salt dehydrated       | 0.40  |
| Molasses              | 1.50  |
| Vitamin and mineral premix1 | 0.70  |

1 One kilogram of the diet contained the following: vitamin A, 450,000 IU; vitamin D3, 350,000 IU; vitamin E, 20,000 IU; vitamin K3, 500 mg; vitamin B1, 300 mg; vitamin B12, 15 mg; pantothenic acid, 50 mg; niacin, 20 mg; biotin, 20 mg; folic acid, 10 mg; FeSO4, 4,000 mg; CoSO4, 100 mg; CuSO4, 5,000 mg; MnSO4, 2,500 mg; ZnSO4, 2,000 mg; I, 500 mg; Se(Na), 100 mg.

**Table 6. Chemical composition of barley silage ensiled for 100 days (%, DM)**

| Items                        | Cutting height1 (cm) | SEM  |
|------------------------------|----------------------|------|
|                              | 5        | 10     | 15     |
| DM, dry matter; SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

**Table 7. Chemical composition of barley silage ensiled for 100 days (%, DM)**

| Items                        | Cutting height1 (cm) | SEM  |
|------------------------------|----------------------|------|
|                              | 5        | 10     | 15     |
| DM, dry matter; SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

**Table 8. Chemical composition of barley silage ensiled for 100 days (%, DM)**

| Items                        | Cutting height1 (cm) | SEM  |
|------------------------------|----------------------|------|
|                              | 5        | 10     | 15     |
| DM, dry matter; SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

**Table 9. Chemical composition of barley silage ensiled for 100 days (%, DM)**

| Items                        | Cutting height1 (cm) | SEM  |
|------------------------------|----------------------|------|
|                              | 5        | 10     | 15     |
| DM, dry matter; SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

**Table 10. Chemical composition of barley silage ensiled for 100 days (%, DM)**

| Items                        | Cutting height1 (cm) | SEM  |
|------------------------------|----------------------|------|
|                              | 5        | 10     | 15     |
| DM, dry matter; SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

**Table 11. Chemical composition of barley silage ensiled for 100 days (%, DM)**

| Items                        | Cutting height1 (cm) | SEM  |
|------------------------------|----------------------|------|
|                              | 5        | 10     | 15     |
| DM, dry matter; SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

**Table 12. Chemical composition of barley silage ensiled for 100 days (%, DM)**

| Items                        | Cutting height1 (cm) | SEM  |
|------------------------------|----------------------|------|
|                              | 5        | 10     | 15     |
| DM, dry matter; SEM, standard error mean.

1 Barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.
Feed intakes and apparent total tract digestibility of nutrients in heifers are described in Table 8. Feed intakes and the digestibility of CP were not affected (p>0.05) by TMRs. The digestibility of DM and NDF were higher (p<0.05) in TMR5 (61.5% and 58.6%), compared to those in TMR5 (56.5% and 49.3%) and TMR10 (57.8% and 51.0%), whereas ADF digestibility was higher (p<0.05) in TMR5 (45.5%) than that in TMR10 (40.7%). The EE digestibility was increased (p<0.05) with the increase in cutting height.

### Table 6. Ingredients and chemical composition of TMR using in vitro and in vivo experiment (%, DM)

| Ingredient                        | TMR5 | TMR10 | TMR15 | SEM |
|-----------------------------------|------|-------|-------|-----|
| Barley silage (5 cm of cutting height) | 70   |       |       |     |
| Barley silage (10 cm of cutting height) | 70   |       |       |     |
| Barley silage (15 cm of cutting height) | 70   |       |       |     |
| Concentrate                       | 30   | 30    |       |     |
| Chemical composition              |      |       |       |     |
| Dry matter                        | 38.7 | 38.2  | 38.2  | 0.679 |
| Crude protein                     | 13.3 | 13.4  | 13.3  | 0.089 |
| Ether extract                     | 3.25 | 3.30  | 3.23  | 0.153 |
| Crude ash                         | 10.8 | 10.7  | 10.4  | 0.189 |
| Neutral detergent fiber           | 51.9  | 50.9b | 50.1b | 0.283 |
| Acid detergent fiber              | 27.8a | 27.4b | 26.9b | 0.182 |

TMR, total mixed rations; DM, dry matter; SEM, standard error mean.

1 TMR5, TMR10, and TMR15 means TMR based on barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

### Table 7. Effect of total mixed ration with barley silage on in vitro digestibility and rumen fermentation indices

| Property                  | TMR5 | TMR10 | TMR15 | SEM  |
|---------------------------|------|-------|-------|------|
| IVDMD (% of DM)           | 47.9a| 48.8a | 46.3b | 1.267 |
| IVNDFD (% of DM)          | 38.7b| 42.9a | 43.5a | 0.407 |
| pH                        | 7.06a| 6.98b | 7.00a | 0.034 |
| NH3-N (mg N/100 mL)       | 27.5b| 34.8b | 33.6b | 0.330 |
| Total VFA (mM/L)          | 62.7a| 59.7a | 53.3a | 0.607 |
| Acetate (% of molar)      | 58.6a| 52.7a | 52.5a | 1.133 |
| Propionate (% of molar)   | 22.6a| 31.8a | 31.6a | 0.435 |
| Iso-butyrate (% of molar) | 2.12 | 2.08  | 1.97  | 0.114 |
| Butyrate (% of molar)     | 9.14a| 7.49b | 6.84b | 0.531 |
| Iso-valerate (% of molar) | 3.88a| 3.31b | 3.32b | 0.159 |
| Valerate (% of molar)     | 2.82b| 3.10b | 2.54b | 0.065 |
| Acetate-propionate ratio  | 2.59a| 1.66a | 1.66a | 0.043 |

SEM, standard error mean; IVDMD, in vitro dry matter digestibility; IVNDFD, in vitro neutral detergent fiber digestibility.

1 TMR5, TMR10, and TMR15 means TMR based on barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

### Table 8. Digestibility of total mixed ration with barley silage on Hanwoo heifers

| Property                  | TMR5 | TMR10 | TMR15 | SEM  |
|---------------------------|------|-------|-------|------|
| Feed intakes (kg/d)       | 3.25 | 3.25  | 3.25  |      |
| Digestibility (%)         |      |       |       |      |
| Dry matter                | 56.5a| 57.8a | 61.5a | 0.981 |
| Crude protein             | 56.0 | 55.8  | 55.4  | 1.040 |
| Ether extract             | 73.0b| 78.0b | 80.2a | 0.890 |
| Neutral detergent fiber   | 49.3b| 51.0b | 58.6a | 1.109 |
| Acid detergent fiber      | 45.5a| 40.7b | 41.9a | 1.021 |

SEM, standard error mean.

1 TMR5, TMR10, and TMR15 means TMR based on barley silage had been harvested at 5, 10, and 15 cm of cutting height from the field, respectively.

### DISCUSSION

#### Silage experiment

The increased DM content of fresh forages with the increase in cutting height in this study is related to the higher DM content of the upper part of WCB compared to the lower part. The grain and spike in the upper part in WCB contributed higher DM content (Ji et al., 2007). Similarly, whole crop wheat (446 vs 477 g/kg) and corn (33.9% vs 41.5%) were also reported to have higher DM content with higher cutting height compared to the lower cutting height (Neylon and Kung, 2003; Sinclair et al., 2003). However, the difference in DM content in fresh forage due to cutting height difference before ensiling did not persist after ensiling (Table 2). The CP, NDF, and ADF concentration of barley forage was different from the values reported by Yun et al. (2009) with same barley hybrid, which might be due to different soil characteristics and harvesting stage of barley forage (Ji et al., 2007; Song et al., 2011). The decreased NDF and ADF content of both forage and silage with increasing cutting height was in agreement with most other previous studies. Walsh et al. (2008) reported a decrease in NDF (465 vs 437 g/kg) and ADF (230 vs 194 g/kg) content when increasing cutting height of barley forage. Sinclair et al. (2003) reported that increasing cutting height of whole crop wheat reduced the NDF content (433 vs 384 g/kg). In case of whole plant corn, the NDF content was numerically decreased by cutting height, whereas ADF content (25.3% vs 23.4%) was reduced significantly (Neylon and Kung, 2003; Lynch et al., 2015).

Lactate has the major role in lowering pH of silage (Shaver, 2003; Zahiruddini et al., 2004). The pH was lowest in 5 cm of cutting height in this study because of the higher lactate content in that silage. Oude Eferink et al. (2001) reported that it is possible to convert lactate to acetate under anaerobic conditions. Through unknown mechanisms, lactate was converted to acetate in the higher cutting height (Ji et al., 2007). Similarly, David, et al. (2007) reported a decrease in pH of silage dry matter (5.3 vs 5.7). Lactate content in the silage was converted to acetate in the higher cutting height compared to the lower cutting height (Ji et al., 2007). Similarly, whole crop wheat contributed higher DM content (Ji et al., 2007). Similarly, whole crop wheat contributed higher DM content (Ji et al., 2007). Similarity, whole crop wheat contributed higher DM content (Ji et al., 2007).
Aerobic stability can be improving via the growth inhibition of yeast and mold in silage (Weissbach, 1996). Acetate is one of the antifungal factors for inhibition of yeast and mold (Courtin and Spoelstra, 1990). The yeast and mold counts were not affected in this study at the day of silo opening. However, the increased concentration of acetate in 10 and 15 cm silage might have inhibited yeast and mold growth and thereby increased aerobic stability in those silages. This result was in agreement with other barley studies (Kung and Ranjit, 2001; Taylor et al., 2002).

**In vitro and in vivo experiment**

The decreased concentration of NDF and ADF in TMR (Table 6) with the incorporation of barley silages of increased cutting height is directly related to the chemical composition of respective silages. Silage was incorporated into the TMR at a rate of 70% (DM basis) while the concentrate mixture was same for all TMRs. Therefore, the fiber concentration of TMRs was dominated by the composition of silages. Weller et al. (1995) reported a decrease in ADF content of silage with the increase of forage cutting height.

It is commonly found that increasing cutting height leads to increase digestibility of whole crop silage due to the proportionate reduction of the fibrous lower part of the plant (Tolera and Sundstøl, 1999) and an increase in the grain portion (Weller et al., 1995). Variety specific increase in IVDMD of maize silage with increased cutting height was reported by Bernard et al. (2004). However, in the present study, the IVDMD was observed lowest in TMR15, which contained the silage of highest (15 cm) cutting height. However, contrasting results in total tract apparent digestibility of DM in Hanwoo heifers was found in in vivo study (Table 8) compared to in vitro. Thus the DM digestibility from in vivo study was in agreement with previous findings (Bernard et al., 2004). The reason for increased NDF digestibility in TMR15 both in in vitro and in vivo experiment may be related to the increased portion of grains in that treatment. Usually grains contain more digestible nutrients than that in roughage. The reason for increased total tract apparent digestibility of ADF in TMR5 is not clear. However, as effects of cutting height on digestibility may also affected by varietal difference (Bernard et al., 2004), it may happen that fibers from the lower portion of Yuyeon barley forage are also easily digestible. Future study is needed to find digestibility of different nutrients from different portions of Yuyeon barley for a better explanation. In agreement with the present study, increasing cutting height of wheat or barley did not affect feed intake (DM intake) as reported previously (Sinclair et al., 2003; Walsh et al., 2008).

The higher production of total VFA, acetate and butyrate in TMR5 may be related to the higher IVDMD in this treatment. With the increase in cutting height, a shift to increase propionate production was (in TMR10 and TMR15) observed, that might be partially due to the increased IVNDFD in those treatments. France and Dijkstra (2005) reported when high sugar content exists in the rumen, there is a shift of fermentation pattern from acetate to propionate, and in most of cases, acetate to propionate ratio was decreased by increased propionate. Decreased acetate to propionate ratio in TMR10 and TMR15 after in vitro incubation is therefore in agreement with the above statement.

**CONCLUSION**

Present study revealed that increasing cutting height increased DM concentration in harvested forage, which, however, was not observed in the silage after 100 day of ensiling. Fiber concentration in terms of ADF and NDF was decreased both in harvested forage and silage. A dramatic increase in aerobic stability of silage was achieved by increasing cutting height, which has great importance when the silage is incorporated into TMR. Significant improvement was observed in DM and NDF digestibility in the TMR incorporated with silage of higher cutting height (15 cm). Considering all above findings, it can be concluded that increasing cutting height, at least up to 10-15 cm, of WCB forage at harvest (Yuyeon) may be beneficial for making silage for TMR formulation and increasing digestibility of DM and NDF.

**CONFLICT OF INTEREST**

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

**ACKNOWLEDGMENTS**

This work was carried out with the support of "Cooperative Research Program for Agriculture Science & Technology Development (Project No. PJ011012032016)" Rural Development Administration, Republic of Korea.

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