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Research Article

Comparison of Productivity and Feed Value of Silage Corn according to the Cutting Height

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ABSTRACT

Corn silage is extensively utilized in ruminant feeding on a global scale, with substantial research efforts directed towards enhancing its nutritional worth and managing moisture content. The purpose of this study was to assess the impact of normal cutting height and elevated cutting height on whole-crop corn silage. Corn was harvested at heights of 15 cm and 45 cm above the ground, respectively, 45 days after heading. The harvested corn was cut into 2-3 cm lengths and packed into 20-liter plastic silos in triplicate. The results showed that dry matter (DM), crude protein (CP), water soluble carbohydrates (WSC), and *in vitro* dry matter digestibility (IVDMD) of C45 were significantly higher than those of the control, while the neutral detergent fiber (NDF) was significantly lower in C45 ($p<0.05$). The C15 had higher yields than C45 ($p<0.05$). There was no significant difference in the total digestible nutrients (TDN) yield of whole-crop corn silage. The increase in cutting height resulted in a larger change in moisture content and NDF per centimeter. After 60 days-ensiling, C45 showed significantly lower NH_3-N concentrations. Moreover, C45 had significantly higher lactic acid concentration, lactic acid/acetic acid ratio, and lactic acid bacteria count compared to the control. Mold was not detected and the yeast count was less than 2 log10 cfu/g fresh matter in both control and C45. In summary, C45 improved the feeding value and fermentation quality of whole-crop corn silage at the expense of forage productivity.

(Key words: Cutting height, Feed value, Productivity, Silage, Whole corn)

Ⅰ. INTRODUCTION

Corn silage is widely recognized and utilized as a ruminant feed worldwide. Its popularity stems from several advantageous characteristics that make it highly appealing to livestock producers. Firstly, corn silage is known for its palatability, ensuring that animals readily consume it. Additionally, it offers consistent quality and higher yield and energy content compared to many other forages. Moreover, corn silage is a highly digestible crop that can be easily harvested and stored using mechanized methods. As a result, numerous research efforts have been dedicated to enhancing the quality and feeding value of corn silage, with ongoing advancements in this field.

Indeed multiple factors contribute to the quality of whole corn silage, including maturity, chopped length, and cutting height. These factors have been extensively studied as established methods to improve the physical and chemical properties of corn silage, ultimately enhancing nutrient digestibility (Bernard et al., 2004; Lewis et al., 2004; Ferraretto and Shaver, 2012; Ferraretto et al., 2018; Mendonça et al., 2020).

Additionally, chemical methods, such as additive treatments, can also alter the silage quality of whole corn (Sheperd and Kung, 1996; Queiroz et al., 2013; Xuye et al., 2023). However, it is important to consider that the use of additives may increase costs and some chemical additives could potentially pose risks to animals. Therefore, it is crucial to focus on enhancing the nutritional value of whole corn silage by controlling its physical and chemical properties, thus avoiding the need for additives and minimizing potential harm.

Numerous management practices have been identified to enhance digestibility and improve the nutrient composition of whole-plant corn silage (WPCS) (Ferraretto et al., 2018; Adesogan et al., 2019). One important management practice is adjusting the cutting height of the corn crop during harvest,

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which can impact the fermentation profile and nutritional value of the resulting silage (Aoki et al., 2013).

A review conducted by Wu and Roth (2005) examined 11 studies on the effect of cutting height on whole-plant corn silage. The review concluded that while higher cutting heights may lead to a decrease in dry matter yield, the improvement in silage quality typically compensates for this reduction. Moreover, Lewis et al. (2004) found that increased cutting heights from 15 to 46 cm resulted in decreased dry matter yields but were accompanied by an increase in milk yield. These findings suggest that the benefits of higher cutting heights, such as improved silage quality, can outweigh the decrease in dry matter yield. Ferraretto et al. (2018) argued that incorporating increased amounts of high-cut whole corn silage forages into the total mixed ration (TMR) can be a viable alternative to adding corn grain to the diet. This substitution can provide economic advantages, emphasizing the potential benefits of implementing higher cutting heights.

Overall, these studies highlight the potential benefits of adjusting cutting height in whole-plant corn silage, including improved silage quality and potential economic advantages through increased inclusion of high-cut silage in the TMR. Currently, various corn hybrids have been developed worldwide to enhance productivity, quality, and efficiency of corn plants. However, in Korea, the most commonly grown corn hybrids for ruminant feed are Kwangpyeongok (KW) and Pioneer 1543 (PI), as mentioned in a study by Lee et al. (2019). Additionally, Kim et al. (2022) recommended Dacheongok as the domestic maize variety suitable for planting in mountainous areas of Gangwon-do, Korea. Despite its favorable growth characteristics and yield, the popularity and utilization of the Dacheongok variety remain limited due to insufficient research.

Notably, there is a lack of research exploring the impact of cutting height on the silage characteristics and nutritional value of the Dacheongok variety. Moreover, in Korea, there are limited studies specifically addressing the relationship between cutting height at corn harvesting and corn silage. Hence, the purpose of this experiment is to compare the effects of different cutting heights on the productivity and feeding value of corn silage, shedding light on this aspect of corn silage production in the Korean context.

Ⅱ. MATERIALS AND METHODS

1. Forage and ensiling

To experiment, corn seeds were sown on April 28, 2022, at Seoul National University's Pyeongchang campus. The harvest took place on September 1, 2022, at the yellow ripening stage, which occurred 45 days after silking. The seeding conditions and management methods were consistent with those described by Kim et al. (2022). The experiment consisted of two treatments. The first treatment, referred to as the Control group (C15), involved harvesting the corn at a normal cutting height of 15 cm above the ground. The second treatment, known as C45, involved harvesting the corn at a cutting height of 45 cm above the ground. Each treatment had three replicates. After harvesting, the fresh corn yield was measured. The harvested corn was then cut into 2-3 cm lengths using a forage cutter (Richi Machinery Co., Ltd, Henan, China). Subsequently, the chopped corn was individually packed into 20-liter plastic silos in triplicate. The silos were stored at room temperature, which ranged from 23-28℃. After a 60-day ensiling period, the silage samples were collected for further analysis.

2. Nutritional and fermentation quality analysis

To analyze the various parameters of the corn silage, several methods were employed. The DM content was determined by drying the samples at 65℃ for 72 hours. ADF and NDF analysis followed the method described by Van Soest et al. (1991). *In vitro* dry matter digestibility (IVDMD) was measured by incubating the samples with buffered rumen fluid for 48 hours using an Ankom Daisy incubator from Ankom Technologies, Inc., following the procedure outlined by Goering and Van Soest (1970). The rumen fluid was obtained from Holstein steers, and its preparation was described in a previous study by Ahmadi et al. (2022). Total nitrogen (N) analysis was performed using an elemental analyzer (Euro Vector EA3000, EVISA, Milan, Italy) following the Dumas combustion method. Water-soluble carbohydrates (WSC) concentration was determined using the anthrone method as specified by Yemm and Willis (1954).

Silage extracts were prepared to assess the fermentation quality of the corn silage, according to the method described by Wei et al. (2022). The acidity of the extract was measured

immediately using an AB 150 pH meter from Fisher Scientific International. Ammonia-nitrogen (NH_3-N) was quantified using a UVIDEC-610 spectrophotometer, following the procedure outlined by Broderick and Kang (1980). Lactic acid and acetic acid were analyzed using HPLC (Detector, RI; Column, Agilent Hi-Plex H; Agilent Technologies 1260 Infinity, Santa Clara, CA, USA) based on previously specified protocols (Wei et al., 2022). Bacterial profiles, including agar-culturable lactic acid bacteria (LAB), yeast, and mold, were determined using the spread-plating method.

3. Statistical Analysis

The data obtained from the experiment were analyzed using a one-way analysis of variance (ANOVA) with the general linear model procedure (Proc) in SPSS. The specific version of SPSS used for the analysis was IBM SPSS Statistics for Windows, Version 24.0, developed by IBM Corp. in Armonk, NY, USA.

Ⅲ. RESULTS AND DISCUSSION

At harvest, the plant height and ear height were measured as 302.80 cm and 126.67 cm, respectively. The DM contents in the stover and ear were 19.02% and 39.66%, respectively, indicating favorable agronomic characteristics (Table 1). There was a significant difference observed in stover yield, both in terms of fresh weight and DM, depending on the cutting height. However, cutting height did not have a significant effect on ear yield (Fig. 1). Previous studies have indicated that increasing the cutting height of maize plants leads to a decline in dry matter yield per hectare, ranging from 35 (10) kg/ha to 39 (3) kg/ha. However, de Rezende et al. (2015) reported 0.11% increase in kernel content within-the plant structure per centimeter rise in cutting height. Wu and Roth (2005) reported that decreases in corn yield were often offset by enhanced silage quality at higher cutting heights. For each centimeter increase in cutting height, there was an increase of 0.09% units in DM, 0.014% units in crude protein (CP), 0.041% units in water-soluble carbohydrates (WSC), and 0.219% units in

Table 1. Agronomic characteristics and plant height on whole crop corn

Crop	Disease resistance	Insect resistance	Lodging resistance	Stay green	Plant height (cm)	Ear height (cm)	DM (%)	
							Ear	Stover
Corn	3.33	3	1	5	302.80	126.67	39.66	19.02

*Resistance: 1=Good or Strong, 9=Bad or Weak; DM: dry matter.

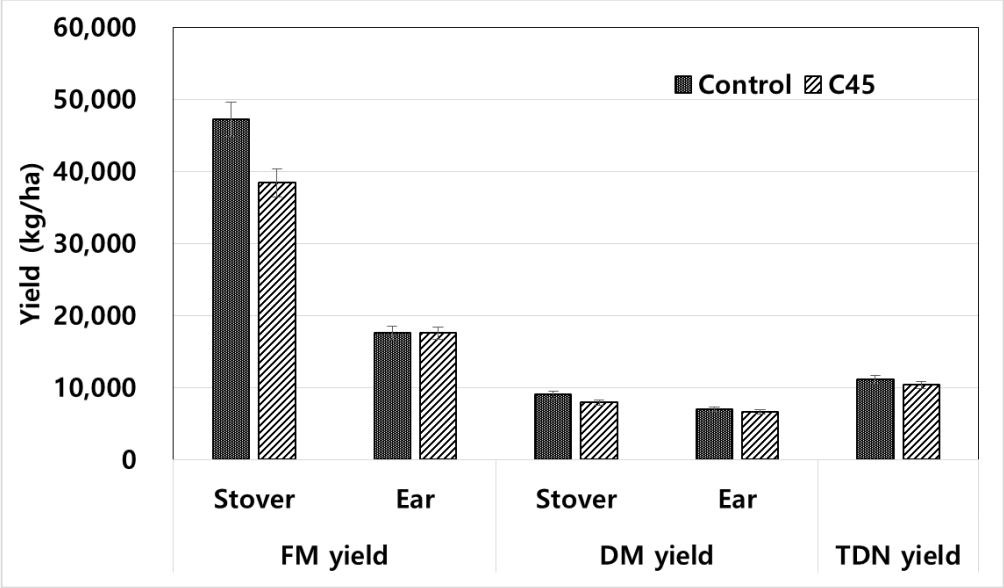

Fig. 1. The effect of cutting height on the stover and ear yield of whole crop corn.

IVDMD. Additionally, there was a decrease of 0.069% units in NDF (Table 2). These findings align with previous studies that have reported an increase in plant cutting height improves the nutritional value by reducing the concentration of cellulose, lignin, NDF, and ADF (Muller, 1987; Ruminants, 2007; de Rezende et al., 2015; Marquardt et al., 2017). Furthermore, increasing cutting height has been shown to positively influence on total digestible nutrients (TDN) and non-fiber carbohydrates, in addition to an increase in grain participation (Neumann et al., 2007; Branco et al., 2010).

Overall, the results of this study support the previous findings that increasing the cutting height of corn plants can improve their nutritional value, enhancing the composition of key components and positively impacting silage quality.

The increase in dry matter (DM) content with increasing cutting height observed in the experiment aligns with the general understanding that DM content tends to increase with shoot height (Magenau et al., 2021). Bruce et al. (2005) also noted that higher plant parts tend to have lower moisture content. This could be attributed to the higher proportion of leaves in the upper part of the plant. Leaves generally have a lower moisture content compared to stems. Furthermore, the proportion of grain in the upper plant parts increases with cutting height, and the dry matter content of grain is typically higher than that of stalks. This can contribute to the overall increase in DM content with increasing cutting height. Diets with higher DM content are known to promote higher intake, as reported by de Oliveira Pimentel et al. (1998).

In addition to the increase in DM content, the higher cutting height (C45) resulted in lower neutral detergent fiber (NDF)

Table 2. Effects of cutting height on feeding value of whole crop corn before ensiling

Treatments	DM (%)	% in DM				
		CP	WSC	NDF	ADF	IVDMD
Control	26.81[b]	7.25[b]	13.47[b]	56.71[a]	33.21	57.33[b]
C45	28.97[a]	7.67[a]	14.69[a]	54.63[b]	32.07	63.91[a]
Increase rate (%/cm)	0.072	0.014	0.041	-0.069	-0.038	0.219

[a-b] Within columns, means with different superscripts differ ($p < 0.05$).
C45: cutting height = 45cm above the ground; DM: dry matter, CP: crude protein, WSC: water soluble carbohydrates, NDF: neutral detergent fiber, ADF: acid detergent fiber, IVDMD: *in vitro* dry matter digestibility.

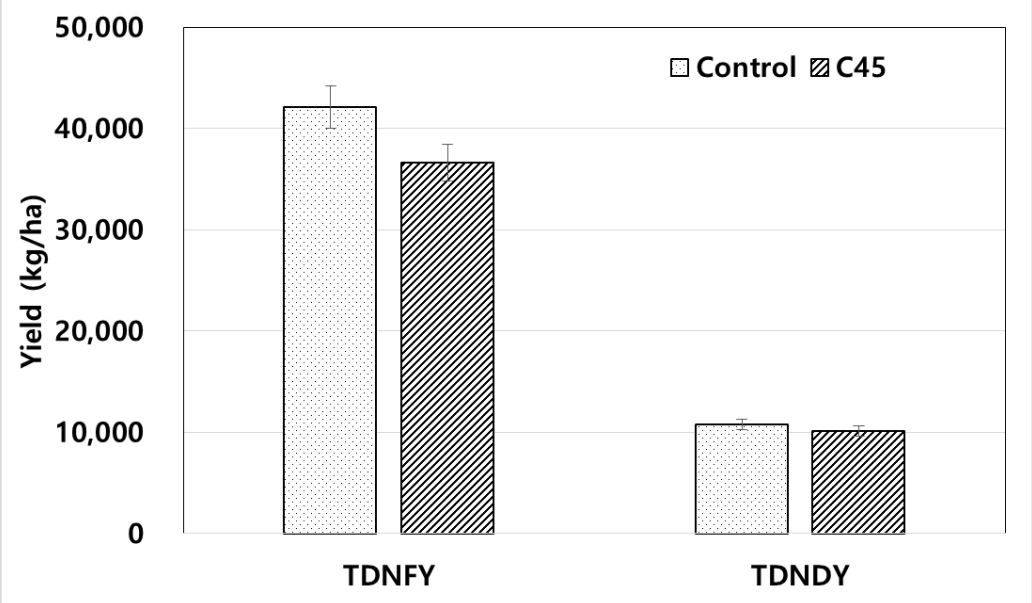

Fig. 2. Total digestible nutrients fresh yield (TDNFY) and dry matter yield (TDNDY) of whole-crop corn silage.

content and higher in vitro dry matter digestibility (IVDMD). This can be attributed to the increased proportion of leaves in the higher cutting height, as leaves generally have lower fiber content compared to stems.

The whole-crop corn used in the experiment exhibited a substantial water-soluble carbohydrates (WSC) concentration before ensiling, with values of 13.47% and 14.69% DM. These concentrations were well above the minimum recommended range (60-80 g/kg DM) for silage with good lactic acid fermentation, as suggested by Woolford (1984). This indicates that the corn had a favorable composition for successful ensiling.

Overall, the findings support the understanding that increasing cutting height can lead to higher DM content, improved fiber digestibility, and favorable WSC concentrations, contributing to enhanced silage quality.

Increasing the cutting height of corn plants can result in a reduction in the volume of the ensiled mass (Oliveira et al., 2011). Therefore, when considering this practice, it is important to weigh the trade-off between quality and quantity of silage (Marquardt et al., 2017). In the experiment, the fresh weight yield of the Control group was higher than that of C45, although the difference was not statistically significant. However, there was no significant difference observed in the dry matter yield of TDN between the two groups (Fig. 2). These findings are in line with the study by Wu and Roth (2005), which highlighted that even with potential decreases in DM yield due to higher cutting heights and more stover left in the field, the predicted milk yield from high-cut whole-plant corn silage (WPCS) could offset the lower yields. Moreover, L. Ferraretto et al. (2018) suggested that high-cut WPCS could potentially lead to greater milk yield, demonstrating good economic benefits for dairy farms. Hülse et al. (2020) also showed that increasing cutting height improved the nutritional values of corn plants, resulting in increased carcass yield. Taken together, while increasing cutting height may have an impact on the overall yield of silage, the potential benefits in terms of milk yield, nutritional value, and carcass yield should be considered when deciding to implement this practice.

After a 60-day ensiling period, the nutritional value of the corn silage showed a similar trend to the pre-silage values. C45 exhibited higher protein content, IVDMD, and RFV, as well as lower ADF and NDF content compared to the Control (Table 3). The decrease in NDF and increase in IVDMD in C45 after ensiling could be attributed to the microbial community present during the fermentation process. The decrease in CP content in C45 was smaller compared to the Control, which aligns with the ammonia nitrogen content. Studies have indicated that corn silage is most recommended when the DM content ranges from 30% to 35% (Johnson and Harrison, 2001). Effluent issues typically arise when the moisture content exceeds critical thresholds, such as 70% for horizontal silos or 60% for tower silos (Pitt and Parlange, 1987; Yao and Jofriet, 1991). To

Table 3. Effects of different cutting heights on feeding value of whole crop corn silage

Treatments	DM (%)	% in DM					RFV
		CP	ADF	NDF	Hemi	IVDMD	
Control	25.61[b]	6.79	32.67	56.77[a]	24.10	59.95[b]	104.31[b]
C45	27.72[a]	7.44	31.96	53.32[b]	21.36	66.40[a]	111.72[a]

[a-b] Within columns, means with different superscripts differ (p<0.05).
C45: cutting height = 45 cm above the ground; DM: dry matter, CP: crude protein, NDF: neutral detergent fiber, ADF: acid detergent fiber, Hemi: hemicellulose, IVDMD: *in vitro* dry matter digestibility, RFV: relative feed value.

Table 4. Effects of cutting height on the fermentation quality of the whole crop corn silage

Treatments	pH	% in DM					LA/AA
		WSC	NH_3-N	LA	AA	BA	
Control	3.68	0.44	5.35[a]	8.03[b]	1.51[b]	ND	5.33[b]
C45	3.65	0.56	3.81[b]	10.17[a]	1.67[a]	ND	6.11[a]

[a-b] Within columns, means with different superscripts differ (p<0.05).
WSC: water-soluble carbohydrate, NH_3-N: ammonia nitrogen, LA: lactic acid, AA: acetic acid, BA: butyric acid.

Table 5. Effects of cutting height on the bacterial counts of the whole crop corn silage

Treatments	Log10 cfu/g fresh weight			
	LAB	Molds	Yeast	Total microorganisms
Control	6.71[b]	ND	<2.00	7.03
C45	6.86[a]	ND	<2.00	6.97

*Microbial count was expressed as the logarithmic number of colony-forming units per gram of fresh mass.
[a-b] Within columns, means with different superscripts differ (p<0.05).
C45: cutting height = 45 cm above the ground; LAB: lactic acid bacteria.

mitigate effluent problems, one simple solution is to wilt forage crops in the field until the moisture content falls below the critical point (Savoie et al., 2002). However, this method may not be suitable for corn crops or during rainy days. In such cases, increasing the cutting height becomes a favorable option to reduce the moisture content of the harvested corn, thereby addressing potential effluent issues.

Even though the DM content in this experiment was lower than the recommended range of 30%, C45 was closer to the recommended value and all the silage exhibited good fermentation characteristics, as indicated in Table 2. After a 60-day ensiling period, the fermentation quality further supported this observation (Table 4 and 5). C45 demonstrated better fermentation, with significantly lower NH_3-N content and higher lactic acid concentration, lactic acid/acetic acid ratio, and lactic acid bacteria (LAB) counts compared to the Control (p<0.05). This improved fermentation quality in C45 could be attributed to its more suitable moisture content and higher WSC content for corn silage. Additionally, in this experiment, C45 had a significantly lower acetic acid content. This finding is consistent with the lower acetic acid concentration and yeast counts observed in whole-plant corn silage (WPCS) at higher cutting heights, as reported by Mendonça et al. (2020). These results collectively suggest that the higher cutting height of C45 contributed to a more favorable fermentation profile, with reduced NH3-N content and increased lactic acid production, which are indicative of improved silage quality. Overall, the findings indicate that C45, with its more suitable moisture content and higher WSC content, resulted in improved fermentation quality, including reduced NH_3-N content and enhanced production of lactic acid, suggesting better preservation and nutritional value of the corn silage. The lower acetic acid content in C45 is also consistent with previous studies highlighting the influence of cutting height on fermentation characteristics in WPCS.

The NH_3-N/total nitrogen (TN) concentration observed in this experiment was 5.35 % in the Control and 3.81% in C45 (Table 4), which is significantly lower than the threshold of 100 g/kg. This indicates that the fermentation process was favorable and the protein was not extensively degraded during ensiling, as described by McDonald et al. (1991). During ensiling, protein can be broken down into various nitrogen-containing compounds, with NH_3-N being one of the byproducts. However, NH_3-N has low nutritional value and can even be toxic (Yuan et al., 2017). The accelerated formation of NH_3-N is usually associated with the activity of undesirable microorganisms that degrade the true protein fractions into ammonia (McDonald et al., 1991). The high concentration of lactic acid, exceeding the typical range of 20-40 g/kg DM, and the lactic acid/acetic acid (LA/AA) ratio greater than 3 (Table 4) indicate that the fermentation of the whole-crop corn silage was primarily homo-fermentation, as stated by Kung Jr et al. (2003). A high lactic acid concentration and a high LA/AA ratio are indicative of a well-preserved silage with a favorable fermentation profile.

Overall, the results suggest an inverse correlation between NH_3-N and lactic acid concentration, as well as the LA/AA ratio. Additionally, there is a positive correlation between lactic acid concentration and the pre-silage WSC content of the corn. These findings highlight the importance of lactic acid production in achieving a successful fermentation process and indicate that the WSC content of the corn plays a role in determining the fermentation quality of the silage.

Ⅳ. CONCLUSIONS

In our experiment, increasing the cutting height of corn plants proved to be beneficial in terms of enhancing the feed value and fermentation quality of the whole-crop corn silage. Nevertheless, it was observed that this enhancement came at the cost of forage productivity. Therefore, it is important to approach the decision to increase cutting height cautiously, considering the trade-off between silage quality and quantity.

Based on your experiment, a cutting height of 45 cm was recommended due to positive effects on the feed value and fermentation quality of the corn silage. This recommendation suggests that higher cutting heights can offer advantageous in enhancing the nutritional composition and fermentation characteristics of the silage. However, it is crucial to evaluate the specific circumstances and goals of each farming operation before adopting this practice, while also taking into consideration the potential impact on forage productivity.

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Ⅵ. CONFLICT OF INTEREST

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

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