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Research Article

Effects of Planting Density on Growth Characteristics, Dry Matter Yield and Feed Value of Teosinte New Variety, "Geukdong 6" [*Zea mays* L. subsp. *mexicana* (Schrad.) H. H. Iltis]

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ABSTRACT

This study was carried out to investigate the effects of planting densities on the growth characteristics, dry matter yield, and feed value of "Geukdong 6" (a new variety of corn for feed). The experimental design was arranged in a randomized block design with three replications. Treatments consisted of six planting densities, 60 cm × 25 cm (T1), 60 cm × 30 cm (T2), 70 cm × 25 cm (T3), 70 cm × 30 cm (T4), 80 cm × 25 cm (T5) and 80 cm × 30 cm (T6). All treatments were sown on May 14, 2021, and the harvest was on October 3 (late flowering). Plant length and the number of tillers were the highest in T5 ($p<0.05$), but the number of leaves and stem diameter were the highest in T6 than in the other treatments ($p<0.05$). Leaf length, leaf width, and dead leaf were not significantly different among the treatments. Organic matter was highest in T6, and crude protein was highest in T5 ($p<0.05$). The ether extract was not significantly different among the treatments. Crude fiber, NDF, and ADF were highest in T2 with relatively higher planting density ($p<0.05$). Calcium and phosphorus were not significantly different among the treatments. TDN content was the highest in T3 ($p<0.05$). Sugar degree (Brix), fructose, glucose, dextran, isomerose, and inverted sugar were not significantly different among the treatment. Fresh yield, dry matter yield and TDN yield were higher in order of T6 > T5 > T4 > T3 > T2 > T1 ($p<0.05$). Relatively feed value was higher in order of T3 > T6 > T5 > T1 > T4 > T2 ($p<0.05$). Based on the above results, planting density could be recommended from 80 cm × 30 cm for efficient production of "Geukdong 6".

(Key words: Dry matter yield, Planting density, TDN yield)

Ⅰ. INTRODUCTION

It was investigated that livestock farms in South Korea intend to increase the use of imported forage by at least 44.8% when the imported forage market is opened by the abolition of tariffs on major importing countries according to the free trade agreement (MAFRA, 2021). As of 2020, the total domestic forage requirement was 4,820,000 tons. Of these, domestic production was 3,923,000 tons (81.4%). As for domestic forage use by type, rice straw was about 68% and about 28% was Italian ryegrass, rye, oat, corn, sudangrass etc. (MAFRA, 2021). The problem was that the domestic forage supply was highly dependent on rice straw, which has low palatability and nutrients (Kim and Lee, 2019). Contrary to the current status of domestic forage production, the number of beef cattle (Hanwoo + Holstein) and dairy cattle has been continuously increasing since 2015. Based on statistical data from the Korea Rural Economic Institute (KREI), as of March 2022, the number of Hanwoo and beef cattle has reached 3,510,000 (KREI, 2022). Therefore, the demand for forage crops is expected to increase more than the capability of domestic forage supply. One of the solutions is to grow good palatable, high-yielding forage crops (Wang and Lee, 2020). "Geukdong 6" is a hybrid of Teosinte, which has recently been developed for high forage yield due to high tiller producing ability. In addition, "Geukdong 6" has more leaf to stem ratio, so palatability is good (Cui et al., 2016). However, in Korea, only the growth characteristics, yield (Cui et al., 2016), seeding dates (Kim and Lee, 2019), and nitrogen fertilization levels (Wang and Lee, 2020) were studied. Therefore, it is necessary to investigate the planting density for "Geukdong 6". Planting density is one of the most critical cultivation methods for determining yield. Stand density affects plant architecture, alters growth and developmental patterns, and influences carbohydrate production (Abuzar et al., 2011). Farnia and Mansouri (2014)

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also reported that plant density affects the photosphere and rhizosphere exploitation by the plants, especially when spacing is inadequate and the plants suffers clustering together. Testa et al. (2016) reported that the higher plant density of maize led to a decrease in the stalk area, leaf greenness, and cob length.Therefore, the objectives of this study were to determine the effects of planting density on growth characteristics, chemical composition, dry matter yield, and total digestible nutrient yield of a newly developed Teosinte hybrid, “Geukdong 6”.

Ⅱ. MATERIALS AND METHODS

1. Experimental site and treatment

The experiment was conducted at the Kyungpook National University experimental farm, Korea (Sangju), from May 14 to October 3, 2021. A randomized complete block design with six factors and three replicates was employed. The six factors were planting density levels: 60 cm × 25 cm (T1), 60 cm × 30 cm (T2), 70 cm × 25 cm (T3), 70 cm × 30 cm (T4), 80 cm × 25 cm (T5) and 80 cm × 30 cm (T6). At this time, the fertilizer used in the experiment was urea. The test plot area was 9 m^2 (3 m × 3 m). The variety of seed was the “Geukdong 6” of Teosinte hybrid [*Zea mays* L. subsp. *mexicana* (Schrad.) H. H. Iltis].

2. Crop establishment and field management

The fertilizer was applied as nitrogen (350 kg/ha) and potassium (150 kg/ha), with 60% as the basal fertilizer, and 40% as the additional fertilizer. The phosphorus (200 kg/ha) used the entire amount as the basal fertilizer. The time of additional fertilizer application was performed when crop growth was at the six leaves stage. Herbicide treatment was performed on the first day after sowing, and human resources carried out weeding work at a plant height of 70 cm. As shown in Table 2, the soil characteristics were slightly acidic sand soil with high available phosphate content and low total nitrogen content. The monthly meteorological data during the experimental period are presented in Table 3.

3. Field data collection and laboratory analysis

Growth characteristics (plant length, leaf length, leaf width,

Table 1. Experimental design of the study

Items	Treatments					
	T1	T2	T3	T4	T5	T6
Planting density (cm)	60 × 25	60 × 30	70 × 25	70 × 30	80 × 25	80 × 30

Table 2. Chemical properties of the soil at the experimental field

pH (1:5)	OM[1] (%)	Available P_2O_5 (mg/kg)	T-N[2] (%)	Exchangeable cation ($cmol^+/kg$)			EC[3] (dS/m)
				Ca	Mg	K	
6.31	2.63	573.6	0.11	6.0	1.4	0.6	0.34

OM[1]: organic matter, T-N[2]: total nitrogen, EC[3]: exchange capacity.

Table 3. Monthly meteorological data during the experimental period

Month	Mean temp. (°C)	Total Sunshine (hr.)	Precipitation (mm)	Rainy days (day)
May	16.7	201.0	166.5	17
June	22.5	210.8	57.0	8
July	26.2	219.9	216.1	14
August	24.4	131.2	324.9	17
September	20.6	130.5	188.8	12
October	14.5	171.2	41.4	7

leaf number, dead leaves, stem hardness, and tiller number) were measured from 10 plants randomly selected from each plot in the experimental field. These characteristics were measured just prior to harvesting. The fresh yield was calculated after cutting the two central rows. Dry matter concentration was determined by drying forage samples in an forced air drying oven at 65℃ for more than four days. Dried samples were ground and stored under vacuum until use for analysis.

Chemical composition were analyzed for crude protein (CP), ether extract (EE), crude ash (CA), and crude fiber (CF) according to the methods of the Association of Official Analytical Chemists (AOAC, 2019). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed by the Goering and van Soest method (1970). Total digestible nutrients (TDN) were calculated using the formula [TDN% = 88.9 - (0.79 × ADF)] by Holland et al. (1990). Relative feed value (RFV) was estimated as [(dry matter intake × digestible dry matter)/1.29] (Linn and Martin, 1989). In this case, the DDM was 88.9 - (0.779 × ADF%), and for the DMI (% of body weight), 120 ÷ NDF% formula was used. The brix degree content was measured using a PR-101 sugar degree meter (Atago Co. Ltd., Tokyo, Japan). PAL-14S, PAL-15S, PAL-12S, PAL-16S, and PAL-18S of the refractometer (Atago Co. Ltd., Tokyo, Japan) were used for the content of fructose, glucose, dextran, isomerose, and inverted sugar, respectively. These measurements were carried out with the juice after compressing the plants. At this time, the compressing point was about 10 cm from the cutting part of the plant.

4. Statistical analysis

The results were subjected to a one-way analysis of variance with the planting density as the main effect. The mean values and standard deviations of the experimental results were obtained using SAS (Statistical Analysis System, USA, 2002) program. Duncan's multiple comparison test was used to identify differences among the treatments, which was considered significant when $p<0.05$.

Ⅲ. Results and Discussion

1. Effects of planting density on growth characteristics

The results of the effects of different planting densities on growth characteristics are shown in Table 4. Plant length was the highest in the T5 treatment at 387 cm, while the lowest in the T1 at 358 cm ($p<0.05$). There was no significant difference between the T1, T2, T3, T4, and T6 treatments. It was reported that as the planting density increased, the plant length increased (El-Lakany and Russell, 1971; Akman, 2002). However, in this experiment, the medium density (T3 and T5) was higher than the high density (T1 and T2) and the low density (T6). Leaf length and leaf width were not different according to planting density.

The highest leaf number was T6, followed by T5, T4, T2, T1, and T3 ($p<0.05$). The reason for the higher number of leaves in the T6 with low planting density is that a branch is formed on the upper part of the plant, and leaves are formed

Table 4. Effects of planting density on growth characteristics

Items	Treatments					
	T1	T2	T3	T4	T5	T6
Plant length (cm)	358±10^{b}	370±13^{b}	386±27^{ab}	372±10^{b}	387±8^{a}	372±12^{b}
Leaf length (cm)	121±3^{ns}	123±13	108±17	115±11	132±4	112±25
Leaf width (cm)	5.7±0.4^{ns}	6.7±0.5	7.1±0.9	6.8±0.5	6.9±0.9	7.2±1.5
Number of leaf (No.)	19.6±0.6^{c}	22.0±2.0^{bc}	18.3±1.5^{c}	24.0±1.7^{b}	29.0±2.7^{a}	30.0±2.7^{a}
Dead leaf (No.)	8.6±1.2^{ns}	8.0±1.5	6.3±2.5	7.0±1.7	8.0±1.0	6.0±1.0
Number of tillers (No.)	8.3±0.6^{b}	9.0±2.7^{b}	10.0±1.7^{ab}	9.1±0.6^{b}	12.0±1.0^{a}	10.3±1.5^{ab}
Stem diameter (mm)	16.6±1.5^{d}	22.6±1.5^{c}	25.3±2.5^{b}	27.3±0.6^{ab}	27.6±0.6^{ab}	30.0±1.0^{a}

T1: 60 cm × 25 cm, T2: 60 cm × 30 cm, T3: 70 cm × 25 cm, T4: 70 cm × 30 cm, T5: 80 cm × 25 cm, T6: 80 cm × 30 cm.
ns: not significant.
^{a,b,c,d}Means with different superscripts in the same row are significantly different ($p<0.05$).

from the branch. It is thought that further research is needed to determine the cause of this unusual phenomenon. T1 and T2 with high planting density were higher in dead leaves than T6 with low planting density, but there was no significant difference. Youngerman et al. (2018) reported that the dead leaves increase when the planting density is high, but it showed a difference from the results of this experiment. The number of tillers was high in T5 and T6 and low in T1 and T2. This was consistent with the report that the low planting density increased tiller generation because photosynthesis increased (Agdag et al. 2001). Moreover, the stem diameter appeared in the order of T6 > T5 > T4 > T3 > T2 > T1, and it became thicker as the planting density decreased ($p<0.05$). These result were similar to those reported by Jung et al. (2016) and Jung et al. (2019).

2. Effects of planting density on chemical compositions

The effects of the different planting densities on chemical compositions are shown in Table 5. Organic matter showed the highest content in the T6 while T1 was the lowest content ($p<0.05$), but there was no significant difference between T4, T5, and T6. Crude protein was the highest in the T5 at 6.0% and the lowest in the T1 at 4.2% ($p<0.05$). The higher organic matter and crude protein content in T6 is thought to be the cause of fewer dead leaves and more leaves than in T1. Masaoka and Takano (1980) reported that the crude protein content was increased when sorghum and sudangrass hybrids were high density populations. However, Fairey (1982) reported that the crude protein content decreased as the planting density increased in the corn experiment.

Kim et al. (1998) reported that there was no change in crude protein content according to planting density. The ether extract was not significantly different according to planting density. The content of crude fiber, NDF, and ADF were significantly lower in T5 and T6 with low planting density compared to T1 and T2 with high planting density ($p<0.05$). Jeon et al. (1992) reported that when the density increases, the content of fiber, ADF, and cell wall content increases due to aging plants caused by the light competition of plants. Therefore, such a report was the same as the result of this experiment. The contents of Ca and P showed no significant difference according to planting density. The TDN content was the highest in the T3, with low NDF and ADF content.

3. Effects of planting density on sugar contents

The effects of the different planting density on sugar contents are summarized in Table 6 (fresh basis %). The brix degree was higher in the T1, T3 and T6 than in other treatments, but there were no significant difference among the treatments. In fructose, glucose, dextran, isomerose, and inverted sugar, T3 showed a high content and T5 showed a low content, but there was no significant difference among the treatments.

When analyzing these results, it was revealed that the sugar

Table 5. Effect of planting density on the chemical composition of Geukdong 6 (% of dry matter)

Items	Treatments					
	T1	T2	T3	T4	T5	T6
Organic matter	92.3±0.2^{b}	91.6±0.2^{c}	91.6±0.1^{c}	93.2±0.2^{a}	93.1±0.1^{a}	93.4±0.2^{a}
Crude protein	4.2±0.1^{b}	5.6±0.2^{a}	5.7±0.1^{a}	5.7±0.3^{a}	6.0±0.3^{a}	5.8±0.4^{a}
Ether extract	1.3±0.2^{ns}	1.4±0.1	1.5±0.1	1.4±0.1	1.5±0.1	1.4±0.2
Crude fiber	37.5±0.6^{b}	38.9±0.5^{a}	33.1±0.3^{d}	37.9±0.6^{b}	35.4±0.9^{c}	32.8±0.4^{d}
NDF	69.9±1.1^{ab}	71.3±0.6^{a}	64.1±0.6^{c}	70.1±0.4^{ab}	68.7±1.3^{b}	64.5±0.6^{c}
ADF	43.5±0.7^{ab}	44.9±0.2^{a}	37.8±0.7^{d}	44.8±0.3^{a}	42.6±1.9^{b}	39.6±0.4^{c}
Calcium	0.21±0.2^{ns}	0.23±0.01	0.24±0.02	0.21±0.01	0.22±0.01	0.22±0.01
Phosphorus	0.31±0.03^{ns}	0.27±0.02	0.29±0.03	0.27±0.03	0.29±0.02	0.28±0.02
TDN$^{1)}$	54.6±0.5^{cd}	53.4±0.1^{d}	59.0±0.6^{a}	53.5±0.2^{d}	55.2±1.5^{c}	57.6±0.3^{b}

T1: 60 cm × 25 cm, T2: 60 cm × 30 cm, T3: 70 cm × 25 cm, T4: 70 cm × 30 cm, T5: 80 cm × 25 cm, T6: 80 cm × 30 cm.

$^{1)}$TDN: total digestible nutrients, ns: not significant.

^{a,b,c,d}Means with different superscripts in the same row significantly different ($p<0.05$).

Table 6. Effects of planting density on sugar contents of Geukdong 6

Items	Treatments					
	T1	T2	T3	T4	T5	T6
Brix degree (%)	5.3±0.7^{ns}	4.4±0.8	5.3±1.0	5.0±0.4	4.2±0.2	5.3±0.5
Fructose (%)	5.7±0.7^{ns}	4.8±0.8	6.0±0.8	5.4±0.5	4.7±0.3	5.5±0.6
Glucose (%)	5.5±0.7^{ns}	4.5±0.7	5.7±0.8	5.2±0.6	4.4±0.4	5.3±0.5
Dextran (%)	5.1±0.7^{ns}	4.2±0.7	5.3±0.8	4.8±0.5	4.0±0.3	4.9±0.4
Isomerose (%)	4.4±0.7^{ns}	3.7±0.4	4.5±0.9	4.0±0.5	3.2±0.2	4.2±0.5
Inverted sugar (%)	5.9±0.7^{ns}	5.0±0.8	6.2±0.7	5.7±0.6	4.8±0.2	5.6±0.5

T1: 60 cm × 25 cm, T2: 60 cm × 30 cm, T3: 70 cm × 25 cm, T4: 70 cm × 30 cm, T5: 80 cm × 25 cm, T6: 80 cm × 30 cm
ns: not significant.

Table 7. Effects of planting density on yield and relative feed value of Geukdong 6

Items	Treatments					
	T1	T2	T3	T4	T5	T6
FY$^{1)}$ (kg/ha)	78,045 ±9,653^{c}	91,110 ±15,664^{c}	97,907 ±8,815^{c}	128,088 ±8,666^{b}	142,867 ±11,689^{b}	176,075 ±10,021^{a}
DMY$^{2)}$ (kg/ha)	14,672 ±1,815^{d}	16,491 ±2,835^{cd}	18,896 ±1,701^{c}	24,465 ±1,655^{b}	27,430 ±2,244^{ab}	29,581 ±1,683^{a}
TDNY$^{3)}$ (kg/ha)	8,011 ±990^{c}	8,806 ±1,513^{c}	11,149 ±1,004^{b}	13,089 ±885^{b}	15,142 ±1,239^{a}	17,038 ±969^{a}
RFV$^{4)}$	73.2±1.8^{bc}	70.3±0.7^{c}	86.3±1.6^{a}	71.6±0.6^{c}	75.5±3.4^{b}	83.7±1.2^{a}

T1: 60 cm × 25 cm, T2: 60 cm × 30 cm, T3: 70 cm × 25 cm, T4: 70 cm × 30 cm, T5: 80 cm × 25 cm, T6: 80 cm × 30 cm.
FY$^{1)}$: fresh yield, DMY$^{2)}$: dry matter yield, TDNY$^{3)}$: total digestible nutrient yield, RFV$^{4)}$: relative feed value.
^{a,b,c,d}Means with different superscripts in the same row significantly different (p<0.05).

components (brix degree, fructose, glucose, dextran, isomerose, inverted sugar) were not significantly affected by planting density. In the "Geukdong 6 [*Zea mays* L. subsp. *mexicana* (Schrad.) H. H. lltis]" experiment, Cui et al. (2016) reported that the contents of brix degree, fructose, glucose, dextran, isomerose, and inverted sugar were 4.90, 5.19, 4.78, and 4.26%, respectively. Kim and Lee (2019) reported no significant difference in sugar components according to the seeding dates. However, Wang and Lee (2020) reported that the sugar components showed significant differences according to the level of nitrogen fertilization.

Generally, the sugar contents of the forage crops vary depending on the seeding time, growing period, fertilization level, climatic conditions, and soil conditions (Kang et al., 2006; Kim et al., 2012). Sugar content in the silage is crucial because it affects the fermentation quality of the silage ingredients (Smith, 1972; Lee and Lee, 2010).

4. Effects of planting density on yield and relative feed value

The effects of the different planting densities on yield and relative feed value are summarized in Table 7. Fresh yield showed the highest in the T6 (176,075 kg/ha), while T1 was the lowest (78,045 kg/ha) (p<0.05). Dry matter yield was the highest in the T6, followed by T5, T4, T3, T2, and T1 (p<0.05). Therefore, dry matter yield was higher as the planting distance was lower. The use of high plant densities might have reduced the supply of photosynthesis to the growing plant, thereby reducing yield per plant (Sibonginkosi et al., 2020).

Similarly, Abuzar et al. (2011) reported that the number of ears per plant increased with decreased plant population density. The greatest total digestible nutrients (TDN) yield was found in T6 (17,038 kg/ha), followed by T5 (15,142 kg/ha), T4 (13,089 kg/ha), T3 (11,149 kg/ha), T2 (8,806 kg/ha) and T1 (8,011 kg/ha) (p<0.05). Relative feed value (RFV) showed the highest in the T3 (86.3), while T2 (70.3) was the lowest. Kim and Lee (2019) reported that the relative feed value of "Geukdong 6" according to the seeding dates was 97.6 to 108.4. Kim et al. (2021) reported that silage corn was 141 to 173 for each variety, and sorghum × sudangrass hybrid was 94 to 105. The reason why the relative feed value was low in this experiment was that the ADF and NDF contents were high.

Ⅳ. CONCLUSION

"Geukdong 6" is a recently developed crop. This crop is widely cultivated on livestock farms due to its high yield and good palatability. However, while there are studies on the level of fertilization and sowing time, limited reports on its planting density regarding forage production are available. Therefore, it is essential to investigate the optimal planting density to obtain greater feed value and yield. From this experiment, we concluded that considering the growth characteristics, feed value, dry matter yield, and total digestible nutrient yield, planting density is appropriate at 80 cm (row spacing) × 30 cm (plant spacing) per plant. However, this experiment was conducted for one year with limited treatment. Therefore, in order to find the correct planting density, it is necessary to carry out various planting density treatment for many years.

Ⅴ. CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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