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RESEARCH PAPER

GT Biplot Analysis for Silage Potential, Nutritive Value, Gas and Methane Production of Stay-Green Grain Sorghum Shoots

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Abstract

M. Kaplan, M. Arslan, H. Kale, K. Kara, and K. Kokten. 2017. GT Biplot Analysis for Silage Potential, Nutritive Value, Gas and Methane Production of Stay-Green Grain Sorghum Shoots. Cien. Inv. Agr. 44(3): 230-238. This study was conducted to investigate the possible silage of stay-green sorghum genotypes using GT biplot analysis. Following the grain harvest, 41 sorghum genotypes were chopped to make silage. Biochemical analyses were performed after 60 d of silage. The results revealed that green herbage yields varied between 13.40–65.96 t ha^{-1}, pH between 3.92–4.25, dry matter ratios between 24.26–35.83%, crude protein ratios between 3.44–7.03%, acid detergent fiber (ADF) ratios between 27.46-52.01%, neutral detergent fiber (NDF) ratios between 40.80–69.12%, crude ash ratios between 5.89–15.14%, lactic acid contents between 1.657–4.914%, and propionic acid contents between 0.000–0.247%. Methane production values varied between 14.15–21.80%, gas production between 18.51–47.36 mL, metabolic energy (ME) between 6.68–11.67 MJ kg^{-1} DM, and organic matter digestibility (OMD) between 47.20–89.93%. According to GT biplot analysis, there were positive correlations among ADF, NDF and DM; among methane, ME, OMD and gas-methane production; and among acetic, butyric and propionic acids, pH, ash and protein contents. There were negative correlations among gas production, ADF, and NDF and among herbage yield, crude protein, organic acids, pH and crude ash. Among the genotypes, Sugargraze was prominent with herbage yield, while genotypes G4 and G3 were prominent with crude protein. Considering all parameters, genotype G20 seemed to be the ideal genotype. Although some silage samples had low silage and nutritional characteristics, others yielded values close to or even higher than full sorghum silage. These varieties can constitute a quality roughage source for livestock in winter. Further breeding research on stay-green genotypes may provide significant contributions to plant and livestock production activities.

Keywords: Digestibility, gas production, residue product, silage, sorghum.

Introduction

Compared to other cereals, sorghum is more resistant to environmental stressors and its production is more economic than other grains (Awika and Rooney, 2004). It is the fifth most significant cereal in the world (Li *et al.*, 2010). Sorghum is commonly adapted to drought-prone regions with severe salinity and regions with relatively low production inputs (Li *et al.*, 2010). Therefore, it is widely used for feeding animals, especially over marginal lands (Barile *et al.*, 2007). The

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parts of the plant that remain after grain harvest are usually not attractive for animals, but parts of stay-green plant species can be used to make silage for easy consumption and digestion. Such silage can both constitute a feed source for animals and allow recycling of waste materials.

In vitro gas production techniques and chemical composition analyses are commonly used to identify potential nutritional values of feeds. These methods are fast, easy and cost-effective techniques (Kaplan *et al*., 2014) and are also used to determine methane production. Methane is created through rumen fermentation and contributes significantly to global warming (Lin *et al*., 2013).

GT biplot analysis allows visual assessment of data and is commonly used in economic, medical, genetic and agronomic studies. In GT biplot analysis, several attributes of the genotypes can be presented graphically, and thus, relations among several genotypes and attributes can be visually assessed and compared (Yan *et al*., 2001). Therefore, researchers commonly prefer the GT biplot method due to ease of interpretation and assessment (Yan, 2014).

The present study was conducted to investigate yield, chemical composition, fermentation, gas and methane production of stay-green sorghum genotypes for silage production to estimate metabolic energy and organic matter digestibility of these genotypes and ultimately to compare the genotypes with regard to investigated traits.

Material and methods

Among 274 local populations commonly used in sorghum breeding, 41 sorghum genotypes identified as stay-green after harvest and a standard cultivar (Sugargraze) were used as the plant material of the present study. Sorghum genotypes were sown in a lattice experimental design (6×7). As fertilizer, 180 kg ha^{-1} N and 80 kg ha^{-1} P_2O_5 were used. All the phosphorus and half of the nitrogen were applied at sowing, and the remaining half of the nitrogen was applied when the plants reached a height of 50 cm. Cultural practices were performed for weed, disease and pest control.

Preparation of silage samples and chemical analyses

Following the grain harvest, plants were reaped, chopped into 2.5–3.0 cm pieces, and placed into 2 kg plastic vacuum bags. The bags were then deaerated, closed tightly and preserved in the dark (24±2°C). At the end of the 60th d, silage bags were opened, and a 30 g sample was taken from each bag. Samples were mixed with 270 mL of distilled water, and the pH was measured. Another 250 g silage sample from each bag was dried in an oven at 70 °C until a constant weight and dry matter ratio was determined. Dried silage samples were ground in a hand mill with a 1 mm screen and prepared for chemical analyses. Crude protein ratio was determined with the Kjeldahl method, and crude ash analyses were performed through ashing the samples at 550 °C for 8 h (AOAC, 1990). NDF and ADF analyses were performed respectively in accordance with the method specified by Van Soest and Wine (1967) and with an ANKOM 200 Fiber Analyzer (ANKOM Technology Corp. Fairport, NY, USA). Acetic, propionic and butyric acid contents were determined with a gas chromatographer (Shimadzu GC-2010 Kyoto, Japan; column parameters: 30 m×0.25 mm×0.25 µm; Restek, temperature range of 45–230 °C), and lactic acid analysis was performed using a spectrophotometric method.

In vitro gas production technique

In the present study, rumen fluid, which was required for the *in vitro* gas production technique, was procured from a steer (Simmental breed, at 12 mo of age and approximately 600 kg live weight) using a stomach tube. Rumen fluid was transported to the Laboratory of

Animal Nutrition and Nutritional Diseases, University of Erciyes (Kayseri, Turkey), in a thermos container at approximately 39 °C. It was filtered through four layers of muslin under constant CO_2 gas. *In vitro* gas production was performed in forty-two different silage samples. The samples of dried sorghum silage (200±10 mg) were incubated in rumen fluid and a buffer mixture in glass syringes (Model Fortuna, Germany), according to the procedures of Menke and Steingass (1988), in triplicate over the course of 24 h. In addition, three blank syringes, which included only rumen fluid and buffer mixture, were used to calculate the gas produced for each silage samples.

Determination of total gas and methane productions

The total gas volume in incubation was recorded from the calibrated scale on the syringe for 24 h. The quantity of methane gas out of the total gas produced at 24 h was determined using a methane analyzer (Sensor Europe GmbH, Erkrath, Germany) according to the method described.

Determination of metabolic energy (ME) and organic matter digestibility (OMD)

The ME and OMD values of silage samples were calculated using the formulas of Menke *et al.* (1979) as follows:

$$\text{ME (MJ kg}^{-1}\text{ DM)} = 2.20+0.136\times GP+0.057\times CP$$

$$\text{OMD (\% DM)} = 14.88+0.889\times GP+0.45\times CP+0.0651\times CA$$

GP = 24 h total gas production (ml 200 mg^{-1}).

CP = Crude protein (mg g^{-1} DM)

CA = Crude ash (mg g^{-1} DM)

Statistical analysis

Data were subjected to variance analyses with SAS 9.0 statistical software (SAS Inst., 1999). An LSD multiple range test was employed to compare the treatment means.

As a complement of ANOVA procedure, genotype trait biplot analysis (GT biplot) was performed using investigated traits for two major objectives. The first is to understand the relations among traits, particularly among those that are key breeding objectives. The second is to evaluate the trait profiles of the genotypes. We evaluated genotypes for chemical composition, fermentation parameters and gas production parameters using GT biplot analysis. The GT biplot display proposed by Yan and Kang (2003) was used. Data were analyzed using the Genstat 12.0 statistical software.

Results

Variation of yield and chemical composition in sorghum genotypes

Possible silage of stay-green sorghum genotypes was assessed in this study, and the mean values of the investigated traits are provided in Table 1. The differences in all traits of the genotypes were found to be highly significant ($P<0.01$). Green herbage yields of sorghum genotypes varied between 13.40–85.00 t ha^{-1}, crude ash ratios between 5.89–15.14%, and crude protein ratios between 3.44–7.03%. Cell membrane components, ADF and NDF ratios, varied, respectively, between 27.46–50.01% and between 40.80–68.75%. Among the most significant parameters of silage, pH values varied between 3.80–4.25, and dry matter ratios varied between 24.26–35.83%. Of the volatile fatty acids of sorghum silage, lactic acid contents varied between 1.657–4.914%, propionic acid contents between 0.000–0.247%, acetic acid contents between 0.057–1.778% and butyric acid contents between 0.000–0.002%.

Table 1. Chemical composition of stay-green sorghum silage

Genotypes		HB	ADF	NDF	CA	CP	DM	pH	LA	AA	PA	BA	GP	%CH_4	CH_4	ME	OMD
G1	*MKSB1*	25.87	38.77	55.40	11.47	6.77	32.02	4.23	1.838	0.525	0.003	0.000	29.98	16.55	4.66	10.14	79.47
G2	*MKSB7*	40.90	28.60	43.08	13.76	5.37	26.46	3.97	3.611	1.296	0.040	0.000	47.17	17.45	7.73	11.67	89.92
G3	*MKSB8*	20.21	42.60	54.77	15.14	6.95	29.05	4.14	2.452	1.027	0.119	0.000	31.14	17.80	5.23	10.40	83.69
G4	*MKSB10*	25.99	39.00	55.42	11.31	7.03	29.95	4.24	1.657	0.313	0.005	0.000	27.53	17.80	4.65	9.95	78.34
G5	*MKSB11*	43.69	30.55	46.38	8.07	4.10	28.95	4.04	3.660	1.434	0.210	0.001	44.72	17.75	7.25	10.62	78.36
G6	*MKSB16*	56.51	33.66	49.50	9.26	3.62	30.43	4.11	1.875	1.076	0.218	0.001	43.12	17.60	7.11	10.13	75.54
G7	*MKSB 21*	50.12	37.50	53.55	7.65	5.63	31.00	4.10	2.248	0.956	0.129	0.000	38.67	17.55	6.32	10.67	79.56
G8	*MKSB 25*	31.82	39.17	58.90	8.78	5.08	30.06	4.12	4.415	1.683	0.191	0.001	37.15	18.30	6.39	10.15	76.50
G9	*MKSB 36*	31.61	45.47	64.73	9.66	4.40	28.82	4.13	3.060	0.431	0.010	0.000	27.66	18.10	4.70	8.47	65.54
G10	*MKSB 37*	32.48	42.99	59.36	13.55	4.55	25.38	4.14	1.962	0.642	0.047	0.001	29.34	17.95	4.68	8.79	70.27
G11	*MKSB 40*	16.37	46.90	68.75	9.90	3.66	34.55	4.18	2.130	0.124	0.068	0.000	24.58	18.50	4.14	7.63	59.67
G12	*MKSB 46*	45.36	45.05	64.84	8.95	4.24	28.05	4.07	2.417	1.778	0.000	0.000	25.81	19.00	4.53	8.13	62.75
G13	*MKSB 47*	49.93	30.30	42.37	7.63	4.27	26.88	3.96	4.426	0.414	0.028	0.000	46.96	17.90	7.45	11.02	80.81
G14	*MKSB 51*	40.32	35.95	53.42	8.70	3.80	26.86	4.00	2.926	0.392	0.005	0.000	36.39	17.75	6.10	9.31	69.98
G15	*MKSB 61*	13.91	45.61	62.69	14.50	4.33	26.56	4.25	2.973	0.526	0.019	0.000	31.74	18.65	5.79	8.99	72.02
G16	*MKSB 64*	22.56	44.39	60.73	13.40	4.19	27.45	4.09	3.589	0.652	0.004	0.000	29.59	17.45	4.78	8.61	68.77
G17	*MKSB 73*	36.35	40.26	61.55	13.12	4.74	27.93	4.15	2.305	0.386	0.007	0.000	33.52	17.40	5.36	9.46	74.54
G18	*MKSB 82*	21.42	44.61	65.63	14.63	4.21	25.60	4.15	2.139	0.991	0.124	0.000	24.94	18.25	4.27	7.99	65.51
G19	*MKSB 85*	44.52	31.20	44.38	11.37	4.09	25.73	3.94	3.839	0.132	0.008	0.000	40.44	16.85	5.99	10.03	76.62
G20	*MKSB 92*	13.40	43.32	62.75	14.52	4.80	28.31	4.20	2.599	1.036	0.138	0.000	24.93	18.50	4.34	8.32	68.07
G21	*MKSB 95*	43.31	47.50	67.33	7.63	3.45	35.16	4.22	1.830	0.240	0.012	0.001	27.25	18.55	4.53	7.87	59.62
G22	*MKSB 96*	34.99	32.27	47.29	8.72	3.93	27.83	3.98	3.191	0.871	0.228	0.000	44.01	16.30	6.35	10.43	77.38
G23	*MKSB 98*	27.25	32.27	48.44	11.44	4.33	24.26	4.04	3.311	0.633	0.003	0.000	38.10	17.90	6.09	9.85	75.71
G24	*MKSB 107*	37.19	38.20	51.69	12.79	4.06	27.92	4.06	3.007	0.624	0.024	0.000	34.15	18.85	6.04	9.16	71.81
G25	*MKSB 112*	65.96	27.46	40.80	6.65	4.30	26.08	3.93	3.927	0.988	0.004	0.000	45.02	17.85	7.11	10.77	78.59
G26	*MKSB 113*	30.09	40.88	58.76	10.07	4.59	32.23	4.11	1.832	0.449	0.016	0.000	31.29	18.69	5.67	9.07	69.90
G27	*MKSB 114*	57.11	32.77	46.56	5.89	3.53	25.65	3.92	4.881	0.814	0.166	0.000	47.36	17.53	7.52	10.66	76.72
G28	*MKSB 116*	25.50	43.25	57.72	10.35	5.29	26.03	3.94	4.914	0.057	0.044	0.001	31.32	18.65	5.24	9.47	73.26
G29	*MKSB 117*	26.00	43.74	61.76	8.63	4.91	32.50	4.10	2.577	0.882	0.115	0.002	26.15	19.60	4.97	8.55	65.83
G30	*MKSB 120*	35.81	50.01	66.79	10.61	3.44	28.93	4.12	1.938	0.233	0.017	0.000	18.52	21.89	3.82	6.68	53.73
G31	*MKSB 122*	40.34	39.33	54.57	9.33	5.71	25.91	4.00	3.582	0.822	0.127	0.000	31.81	18.65	5.73	9.78	74.94
G32	*MKSB 123*	23.91	42.12	56.48	11.77	5.49	27.69	4.08	2.727	0.951	0.247	0.000	28.65	17.90	5.07	9.23	72.72
G33	*MKSB 124*	27.86	41.23	64.37	8.54	3.94	31.25	4.13	2.194	1.299	0.005	0.000	33.40	17.00	5.26	8.99	67.84
G34	*MKSB 130*	46.39	27.62	41.36	6.72	5.46	27.72	3.96	3.741	0.898	0.188	0.001	44.88	17.30	7.43	11.41	83.71
G35	*MKSB 134*	38.92	38.43	57.09	14.26	4.86	26.19	4.06	2.760	0.582	0.008	0.000	27.97	19.30	5.12	8.78	70.91
G36	*MKSB 135*	29.56	37.95	54.78	8.54	4.71	31.38	4.06	3.399	0.970	0.012	0.000	33.95	18.20	5.83	9.50	71.81
G37	*MKSB 141*	46.84	41.50	58.25	10.17	4.75	30.18	4.00	2.752	0.968	0.104	0.001	30.18	18.10	5.15	9.01	69.70
G38	*MKSB 142*	30.41	41.88	61.36	9.60	4.37	28.08	4.06	3.278	0.805	0.038	0.002	27.33	17.95	4.55	8.41	65.08
G39	*MKSB 143*	26.41	40.48	64.19	8.35	5.20	35.83	4.15	2.075	0.141	0.018	0.000	29.47	18.65	4.91	9.17	69.93
G40	*MKSB 147*	30.31	45.84	66.11	10.46	4.10	32.07	4.11	1.908	0.344	0.004	0.001	25.62	19.40	4.81	8.02	62.93
G41	*MKSB 152*	28.97	44.33	60.91	12.42	5.15	29.50	4.06	3.708	0.423	0.016	0.000	25.89	18.85	4.68	8.65	69.14
Sugar Grazer		85.00	34.63	56.09	8.08	6.26	28.29	3.80	4.630	0.890	0.010	0.000	32.11	14.15	3.85	6.94	47.20
Means		35.75	39.28	56.45	10.39	4.71	28.83	4.07	2.959	0.731	0.066	0.000	33.09	18.06	5.50	9.31	71.53
Sig. Deg.		**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
LSD		4.4802	0.4537	0.5519	0.4018	0.315	1.0798	0.0276	0.1642	0.583	0.077	0.001	2.6099	1.3276	0.7925	2.3182	0.3549

HB: herbage yield (t ha^{-1}); ADF: acid detergent fiber (%); NDF: neutral detergent fiber (%); CA: crude ash (%); CP: crude protein (%); DM: dry matter (%); LA: lactic acid (% DM); AA: acetic acid (%DM); PA: propionic acid (%DM); BA: butyric acid (%DM); GP: gas production (mL);%CH_4: methane, (%); CH_4: methane, (mL DM); ME: metabolic energy (MJ/kg DM); OMD: organic matter digestibility (%); Sig. Deg.: *significant degree; LSD: least significant difference; **: $P \leq 0.01$; h-k: include the letters from h to k; A and B: since the software used all lowercase letters for grouping, the last two groups were indicated with capital letters*

While percent methane productions varied between 14.15–21.89%, methane production in mL varied between 3.82–7.73 mL. The least gas production was measured as 18.52 mL, and the greatest gas production was measured as 47.36 mL. The least ME and OMD values were observed as 6.68 MJ kg^{-1} DM and 47.20%, respectively, and the greatest values were measured as 11.68 MJ kg^{-1} DM and 89.93%, respectively (Table 1).

Relationships between yield and chemical composition of sorghum genotypes

Biplot analysis was used to compare yield and chemical composition of sorghum genotypes and to identify good-genotype groups with regard to genotypes or chemical characteristics. By using reciprocal relationships among the investigated chemical traits, separation power can be obtained from the vector image of GT biplot chemical composition. Traits with long vectors have a high genotype separation capacity. In this case, green herbage yield, ADF, NDF, ME and methane gas production are identified as significant traits for separation of genotypes (Figure 1). Biplot vector images provide information about the relationships among investigated traits. Significant negative relationships were observed among gas production, ADF and NDF, as well as among herbage yield, crude protein, organic acids, pH and crude ash. Significant positive relationships were observed among ADF, NDF and dry matter, as well as among methane, metabolic energy, organic matter digestibility and gas production and among acetic, butyric, propionic acids, pH, crude ash and crude protein (Figure 1).

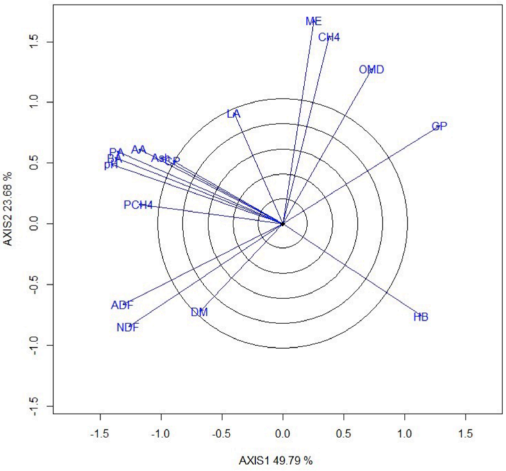

Figure 1. GT biplot based on yield and chemical composition-focused scaling for yield and chemical composition.

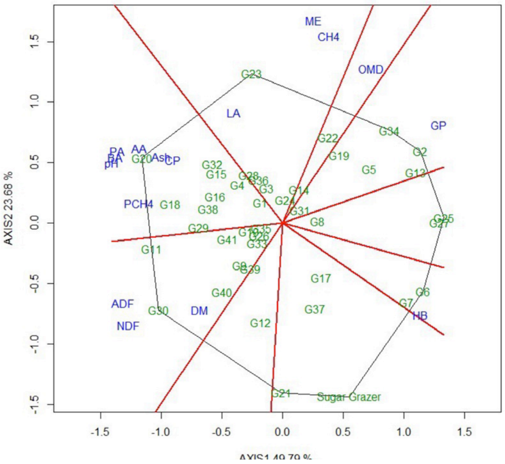

Figure 2. Polygon views of the GT biplot based on symmetrical scaling for the which-won-what pattern for the genotypes and yield and chemical composition. Details of the genotypes are presented in Tables 1.

GT biplot polygons also indicate which genotypes are prominent with which traits (GTI: genotype trait interaction) (Figure 2). In this case, G22 OMD, G23, G3, G24 and G14 genotypes were prominent with lactic acid; G32, G20, G15, G4, G16, G38, G29, G18 and G1 genotypes with crude protein, methane %, pH, butyric acid, acetic acid and crude ash; G11, G30, G41, G26, G33, G36, G9, G40 and G39 genotypes with ADF, NDF and dry matter; and G7 and G6 genotypes with green herbage (Figure 2; Table 1).

With GT biplot polygons of investigated traits, it is possible to identify the ideal genotypes. Considering all the traits, it was observed that genotype G20 was the most prominent, followed by G32, G15, G18, G16, G4, G28, G38 and G23. The Sugargraze cultivar, which was used as a standard cultivar, was far behind the genotypes in comparison (Figure 3).

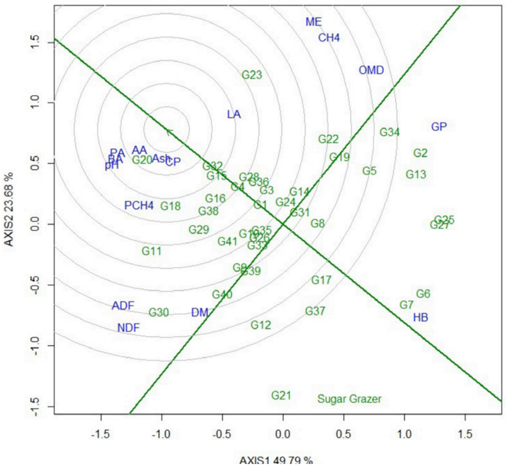

Figure 3. GT biplot based on genotype-focused scaling for comparison of the genotypes with the ideal genotype.

Discussion

Bolsen *et al*. (1996) reported decreased NDF and ADF content of silages because carbohydrate sources increased the number of some anaerobic bacteria such as lactic acid bacteria in silage ambient and accelerated NDF, ADF and crude cellulose degradation of silages. Such a case indicated the availability of stay-green plant parts for silage.

Ball *et al*. (1996) indicated that variations in dry matter and protein contents mostly resulted from genetic differences and that these parameters commonly varied based on leaf, cob and shoot ratios, ripening period, temperature and fertilization practices. Increasing ADF and NDF ratios are observed with the progress of the ripening period (Kaplan *et al*., 2014). Increasing ADF and NDF ratios complicate the digestion and reduce crude protein content, gas production, metabolic energy and digestible organic matter quantities (Kaplan *et al*., 2014).

Low pH levels indicate the existence of an acidified ambient with the fermentation of soluble sugars (Islam *et al*., 2012). Dissolved carbohydrates (i.e., grain) increase lactic acid production, and increased lactic acid quantities reduce the pH levels of the ambient (Bates, 2009). High pH levels of the present silages (the desired level is between pH 3.86–4.02) indicate low lactic acid accumulation in this study (McDonald *et al*., 1991). With the progress of harvest, increased ADF and NDF ratios decrease crude protein and the WSC ratio of the silages (Hargreaves *et al*., 2009) and negatively affect pH levels.

With decreasing grain ratio (i.e., starch), energy also decreases (Mould *et al*., 1983), and silage quality is impaired (Cox *et al*., 1993). The more fermentable carbohydrates are present, the more gas will be produced (Blümmel and Orskov, 1993). For metabolic energy calculations, the principles specified in Menke *et al*. (1979) were used in this study. Gas production and crude protein ratio are used in this calculation. Cutting panicles of sorghum will reduce the carbohydrate ratio and gas production and consequently the metabolic energy.

Dry matter content of sorghum is desired to be 24.60% at minimum for quality silage (Carmi *et al*., 2006). In the present study, a few genotypes had a dry matter ratio lower than this specified value.

Islam *et al*. (2012) reported increasing crude protein contents with increasing water-soluble carbohydrate (WSC) contents. The majority of WSC is fermented by silage microorganisms for lactic acid, ethanol and VFA. Lactic acid is the very last main product, reducing pH levels for better preservation of silage (Miron *et al*., 2006). There was a linear relationship among crude protein, lactic acid and pH of the present study.

Lopez *et al*. (2010) classified the anti-methanogenic potential of the feeds based on gas production through fermentation as low (>11% and ≤14%), medium (>6% and <11%) and high (>0% and<6%). Based on this classification, the anti-methanogenic potential of stay-green sorghum genotypes was classified as low (14.15–21.89% CH_4).

Although biplot analysis is recommended to test a certain trait under different environmental conditions, it can be used just as effectively for all genotypes through user inputs of dual data such as genotype characteristics (Yan and Kang, 2003), and genotypes can be screened for desired characteristics (Yan and Tinker, 2006). In this study, stay-green sorghum genotypes were screened through yield and nutritional characteristics. With GT biplot analysis, it is possible to identify the best genotype with regard to these investigated traits (Yan and Kang, 2003). The ideal genotype is either the one within the central circle or the closest one to the central square (Kaya *et al*., 2006). In present study, the genotype G20 was the closest to the central circle and was consequently identified as the ideal genotype.

Biplot analysis can be used to visualize the interrelationships among the traits because the cosine of the angle between the vectors of any two traits approximates the correlation coefficient between them (Yan and Kang, 2003). Based on this application, ADF and NDF were positively correlated with ME and OMD (Kaplan *et al*., 2014), and crude protein was positively correlated with pH (Islam *et al*., 2012).

The polygon is commonly formed by connecting the markers of the genotypes that are farther away from the biplot origin to gather all other genotypes in the polygon (Kaya *et al*., 2006).

The main conclusions are as follows. Although some silage samples had low silage and nutritional characteristics, others yielded values close to or even higher than full sorghum silage. The genotypes with high green herbage yield, crude protein content, ME, OMD and lactic acid content, as well as low ADF, NDF, gas production and pH, can be used for silage both after grain production and grain harvest. The other sorghum lines with lower quality values than full sorghum silage can be used in ruminant nutrition during periods of deficit for forage supplies. Further breeding research on stay-green genotypes may provide significant contributions to plant and livestock production activities.

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Resumen

M. Kaplan, M. Arslan, H. Kale, K. Kara, y K. Kokten. 2017. Análisis de biplot GT para potencial de ensilaje, valor nutritivo, producción de gas y metano de brotes de sorgo de grano verde. Cien. Inv. Agr. 44(3): 230-238. El objetivo del presente estudio es investigar las posibles ensilajes de genotipos de sorgo que tienen alta tasa de supervivencia del tallo y de las hojas después de la cosecha. Después de cosecha del grano, 41 genotipos de sorgo fueron picados para preparar ensilajes. Los análisis bioquímicos se realizaron después de 60 d de ensilaje. De acuerdo con los resultados obtenidos en el estudio; rendimiento de trigo verde varía entre 13.40–65.96 t ha^{-1}, pH 3.92–4.25, proporción de materia seca entre 24.26–35.83%, proporción de proteína cruda 3.44–7.03%, los ratios de ADF entre 27.46–52.01%, los ratios de NDF entre 40.80–69.12%, los ratios de cenizas en bruto entre 5.89–15.14%, ácido láctico entre 1.657–4914%, ácido propiónico entre 0.000–0.247%. Los valores de producción de metano variaron entre 14.15–21.80%; Producción de gas entre 18.51–47.36 mL, energía metabólica

(ME) entre 6.68–11.67 MJ kg^{-1} MS y digestibilidad de materia orgánica (DMO) entre 47.20–89.93%. Aunque algunos genotipos tienen características de calidad de alimentación baja, la mayoría de los genotipos tienen características cercanas al ensilaje entero y están en el grupo de calidad de forraje para animales en invierno. Otros trabajos de mejoramiento de los genotipos que permanecen siempre verdes pueden producir contribuciones significativas a las actividades de producción vegetal y ganadera.

Palabras clave: Digestibilidad, ensilaje, producción de gas, producto de residuos, sorgo.

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