PERFORMANCE AND PHENOTYPIC SELECTION OF SORGHUM GENOTYPES FOR CUTTING AND GRAZING IN TWO PLANTING SEASONS

Alan Figueiredo de Oliveira[1], José Avelino Santos Rodrigues[2], Lúcio Carlos Gonçalves[1], Roberto Guimarães Júnior[3], Francisco Duarte Fernandes[3], Ângela Maria Quintão Lana[1]

ABSTRACT – This study aimed to evaluate the agronomic performance of 30 sorghum genotypes planted in two seasons. In the agronomic performance evaluation, 15 superior genotypes were selected and submitted to nutritive value and nutrient accumulations evaluations. The genotypes were planted on 20 December 2017 and 5 February 2018 and submitted to three and two cuts. Agronomic and nutritional characteristics were evaluated in all cuts and considered as the average values per season. The hybrids forage accumulation 6,941 kg/ha in the first and 3,370 kg/ha in the second planting season. The plant leaf proportion varied from 41.1 to 55.9% among all hybrids in the two seasons. The whole plant crude protein contents were 111 and 121 g/kg DM in the first and second planting seasons. The *in vitro* dry matter digestibility varied from 579 to 679 g/kg DM among all hybrids. The agronomic and nutritional characteristics were better in first compared to second planting due to better climatic conditions. The hybrids 16F26008, 16F26014 and 16F26007 had superior characteristics. The females (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1) A and (ATF54A*{ATF54B*[((Tx623B*ATF54B)6-1]}-207-C-1)A and the males TX2784 and TX2785 produced superior hybrids.

Keywords: Adaptation, Tropical grasslands, Plant breeding, Annual grazing, Grazing systems

DESEMPENHO E SELEÇÃO FENOTÍPICA DE GENÓTIPOS DE SORGO PARA CORTE E PASTEJO EM DUAS ÉPOCAS DE PLANTIO

RESUMO – Objetivou-se avaliar o desempenho agronômico de 30 genótipos de sorgo plantados em duas safras. Na avaliação do desempenho agronômico, 15 genótipos superiores foram selecionados e submetidos às avaliações de valor nutritivo e produção de nutrientes. Os genótipos foram plantados em 20/12/2017 e 5/2/2018 e submetidos a três e dois cortes. As características agronômicas e nutricionais foram avaliadas em todos os cortes e consideradas como valores médios por época de plantio. O acúmulo de forragem dos híbridos foi de 6.941 kg/ha na primeira e 3.370 kg/ha na segunda época de plantio. A proporção de folhas da planta variou de 41,1 a 55,9% entre todos os híbridos nas duas safras. Os teores de proteína bruta da planta inteira foram de 111 e 121 g/kg MS na primeira e segunda época de plantio. A digestibilidade *in vitro* da matéria seca variou de 579 a 679 g/kg MS entre todos os híbridos. As características agronômicas e nutricionais foram melhores no primeiro em relação ao segundo plantio devido às melhores condições climáticas. Os híbridos 16F26008, 16F26014 e 16F26007 apresentaram características superiores. As fêmeas (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A e (ATF54A*{ATF54B*[((Tx623B*ATF54B)6-1]}-207-C -1)A e os machos TX2784 e TX2785 produziram híbridos superiores.

Palavras-chave: Adaptação, Campos tropicais, Melhoramento de plantas, Pastagem anual, Sistemas de pastoreio

[1] Animal Science Department, Veterinary School, Federal University of Minas Gerais, Belo Horizonte, Minas Gerais, 31270-901, Brazil. alanfigueiredodeoliveira@yahoo.com.br; luciocgoncalves@gmail.com; lana@vet.ufmg.br.
[2] Brazilian Agricultural Research Corporation, EMBRAPA – Maize and Sorghum, Sete Lagoas, Minas Gerais, 35701-970, Brazil. avelino.rodrigues@embrapa.br.
[3] Brazilian Agricultural Research Corporation, EMBRAPA – Cerrados, Planaltina, Distrito Federal, 73310-970, Brazil. roberto.guimaraes-junior@embrapa.br; francisco.fernandes@embrapa.br.

INTRODUCTION

The sorghum hybrids (*Sorghum bicolor x Sorghum sudanense)* for cutting and grazing originate from the crossing between common sorghum (*Sorghum bicolor*) and Sudangrass (*Sorghum sudanense*). This crossing aims to maximize heterosis of productivity and nutritional value of common sorghum and tillering and growth speed of Sudangrass. These hybrids have low water demand and can be used in the beginning and in the end of summer to increase the period of animal production in high quality pastures (Gelley et al. 2016; Dillard et al. 2018). For Dillard et al. (2017) in temperate countries these hybrids are good alternatives for summer pastures production when winter forages have low productivity. In regions with low rainfall, planting in summer allows good forage accumulation in short time period (Peng et al. 2020).

The planting of these hybrids intercropped with perennial grasses or legumes for pasture renewal allows greater production, faster utilization and better forage nutritional value (Basweti et al. 2009; Guretzky et al. 2020). This association increases profitability by area and may enable the recovery of larger area with degraded pastures. Another use is planting in monoculture or intercropped after the main harvest in crop-livestock integrated systems (Nave et al. 2020). Thus, it is possible to keep the forage supply more stable in the off-season and produce straw for no-till (Dillard et al. 2018). These hybrids can still be used for silage production (Li et al. 2016) and hay (Lima et al. 2017).

These hybrids can be used in different ways, however, there are few commercially available cultivars. Thus, agronomic and nutritional characteristics evaluation of these hybrids at different planting seasons and climatic conditions for growth allows selecting superior hybrids and more adapted for different uses (Lauriault et al. 2011). The objectives of this study were: (i) to evaluate agronomic characteristics of 30 sorghum genotypes and nutritional value and nutrient accumulation of 15 sorghum hybrids planted in two seasons; (ii) to select the best hybrids with balance between agronomic and nutritional characteristics and (iii) to establish the kinship between hybrids and parents.

MATERIAL AND METHODS

Study area, planting and treatments

The study was carried out at Embrapa Cerrados located in Planaltina, Federal District, Brazil (15°36'36.31"S, 47°42'11.63"W, 987 m altitude) with 21.9 °C average annual temperature, 1383.7 mm average annual rainfall and rainy tropical climate Awa (A – rainy tropical climate; w - summer rain, a - hot summer) (Silva et al. 2014). The climatic data during the experiment are shown in Figure 1. In the first planting, total rainfall was 179, 234 and 284mm and the average temperature was 22.1, 21.8 and 21.5 ºC during the three growth periods. In the second planting, total rainfall was 220 and 198 mm and the average temperature was 22.1 and 21.1 ºC during the two growth periods. The soil analysis, collected in the 0-20 cm layer, showed: pH ($CaCl_2$) of 4.5; Ca, Mg, Al and H+Al of 0.81, 0.73, 0.54 and 6.20 $cmol_c/dm^3$, respectively; K and P of 48 and 0.4 mg/dm^3; CTC and SB of 7.9 and 1.66 $cmol_c/dm^3$; V (%) of 21.1; sand, silt and clay of 180, 200 and 620g/kg.

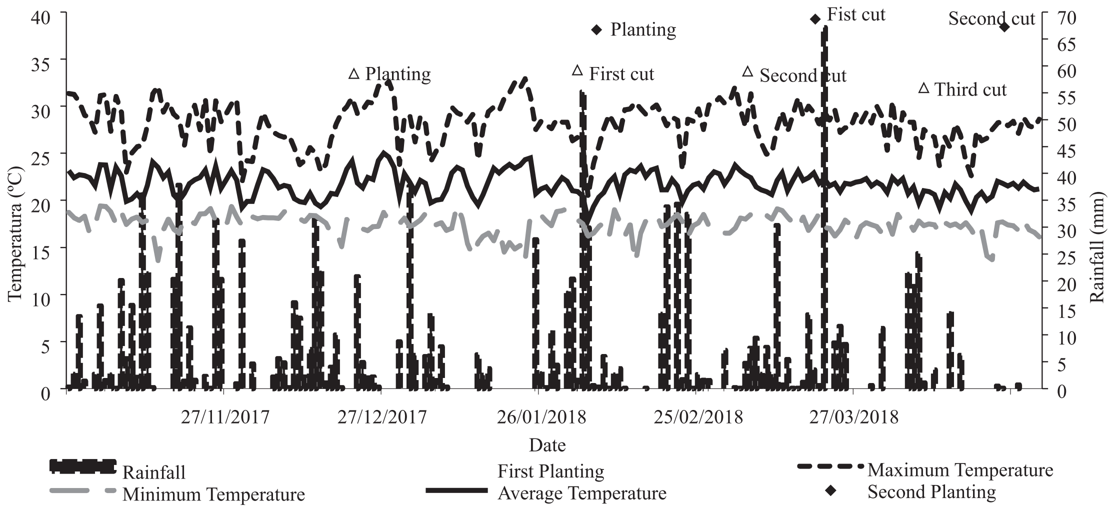

Figure 1 - Minimum, average and maximum temperatures and rainfall at Embrapa Cerrados-DF during the experiment.

Twenty-seven sorghum hybrids for cutting and grazing (*Sorghum bicolor x Sorghum sudanense*) and the Sudangrass parental CMSXS912, TX2784 and TX2785 (*Sorghum sudanense*) were tested (Table 1). These hybrids were developed at the National Corn and Sorghum Research Center (Sete Lagoas, Minas Gerais, Brazil). The breeding program started in 1990 and the main selection criteria were productivity, resistance to lodging and nutritional value.

Table 1 - Sorghum hybrids for cutting and grazing description and their male and female parents

Genotype	Male	Female
16F24005	TX2785	BR007A
16F24006	TX2785	CMSXS222A
16F24007	TX2785	(ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A
16F24008	TX2785	(ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-207-C-1)A
16F24012	TX2785	CMSXS156A
16F24014	TX2785	(ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-295-C-1)A
16F24015	TX2785	(CMSXS156BxATF30)6-3-C-1-1)A
16F24016	TX2785	CMSXS157A
16F24020	TX2785	CMSXS205A
16F26005	TX2784	BR007A
16F26006	TX2784	CMSXS222A
16F26007	TX2784	(ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A
16F26008	TX2784	(ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-207-C-1)A
16F26012	TX2784	CMSXS156A
16F26014	TX2784	(ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-295-C-1)A
16F26015	TX2784	(CMSXS156BxATF30)6-3-C-1-1)A
16F26016	TX2784	CMSXS157A
16F26020	TX2784	CMSXS205A
16F27005	CMSXS912	BR007A
16F27006	CMSXS912	CMSXS222A
16F27007	CMSXS912	(ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A
16F27008	CMSXS912	(ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-207-C-1)A
16F27012	CMSXS912	CMSXS156A
16F27014	CMSXS912	(ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-295-C-1)A
16F27015	CMSXS912	(CMSXS156BxATF30)6-3-C-1-1)A
16F27016	CMSXS912	CMSXS157A
16F27020	CMSXS912	CMSXS205A

The genotypes were planted in two seasons (20 December 2017 and 5 February 2018) and the cultivation was carried out without irrigation. The planting was done in double lines of five meters length spaced by 0.5 m. The first and last line meters and the two end lines were considered as borders. The useful area was considered as the central three meters of each line. The experimental area was prepared with subsoiling harrowing and leveling harrowing. The seeds were planted three cm deep together with 300 kg/ha of commercial fertilizer 4:30:16 (N:P:K). After 15 days of emergency and immediately after the cuts, topdressing fertilization was performed with 75 kg/ha of urea. Thinning was carried out 10 days after plants emergence to standardize the population at 300,000 plants/ha.

Agronomic characteristics

In the first planting, three cuts were made with 36, 33 and 42 days of growth. In the second planting, two cuts were made with 36 and 35 days of growth. The cuts were made with metal bar fixed at 20 cm from the ground and mechanical brush cutter. Plant heights and tillers number were measured in the useful area before all cuts. In each row, plant heights were measured at four points with graduated ruler and the average height was evaluated. The tillers number was counted in the useful area and used to determine tillers number per hectare. The average regrowth rate was determined as the ratio between plants number in the current and previous cut.

The leaf area index (LAI) was measured before the first cut in the two planting seasons. The LAI was measured by one assessment above canopy and eight measurements at ground level between the rows of each hybrid with the Plant Canopy Analyzers, LI-2000 (*LICOR Inc., Nebraska*). After cutting, useful area plants were weighed with dynamometer-type field scale to determine the green matter accumulation per hectare (GMA/ha). After weighing, five plants were randomly removed to detach fully expanded leaves and measure stem diameters with digital caliper.

Leaf and stem separation was carried out on 15 random plants. After separation, leaves and stems were weighed separately and placed for 72 hours in forced ventilation oven at 55 ºC for drying. After drying, leaves and stems samples were used to determine dry matter (DM) content in oven at 105 ºC (AOAC 1995). In addition, the plant leaf proportion (PLP) was determined as the leaf participation in whole plants weight.

The other plants were crushed, homogenized, weighed and placed for 72 hours in forced ventilation oven at 55 ºC for drying. After drying, the samples were used to determine the DM content in oven at 105 ºC (AOAC 1995). Based on DM content, dry matter accumulation per hectare (DMA/ha) was determined. The total green forage accumulation (TGFA) and total dry matter forage accumulation (TDMFA) were defined as the accumulations sum of all cuts in each planting. Canopy density (kg DM/ha/cm of height) was determined as the ratio between DMA per hectare and plant height divided by 100. For the variables data analysis, each planting average were considered, aiming the best hybrids selection in each planting.

Nutritional analysis and nutrients accumulation

Based on agronomic characteristic analysis, 15 superior genotypes were considered for nutritive value and nutrient accumulation evaluation. After drying, leaf, stem and whole plant samples were grounded to one mm in WILLEY mill. After drying, DM in oven at 105 ºC, ash in muffle at 550 ºC and crude protein (CP) by the Kjeldahl method (AOAC 1995) contents were determined. The neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) contents were determined according to Van Soest et al. (1991). The *in vitro* dry matter digestibility (IVDMD) was determined according to Tilley & Terry (1963). The analyses were performed in all cuts and the values presented are the average results of all cuts for each planting. The crude protein accumulation (CPA) and digestible dry matter accumulation (DDMA) were determined by multiplying the TDMFA by CP and IVDMD contents.

Statistical analysis

The experimental design was completely randomized with 30x2 factorial design (30 genotypes in two seasons) for agronomic variables and 15x2 factorial design (15 genotypes in two seasons) for nutritional value and nutrient accumulation and was used three replicates per treatment. The normal probability distribution and variances homoscedasticity were tested using Shapiro Wilk and Bartlett tests. The variance analysis (Two-Way) was performed and genotypes means grouped by the Scott-Knott method, while the planting means were compared through the Fisher test, with error rate lower than 5% probability. Statistical analyses were performed using the GLM method. The statistical model is presented in supplementary material 1. The GMA and DMY data did not present normal distribution and were box-cox and square root transformed.

Agglomerative cluster analysis was used to separate groups based on agronomic or nutritional values. Euclidean distance was used to measure similarity between genotypes and Ward's clustering algorithm was used to create groups. The groups number was empirically determined based on researchers experience. All analyses were performed using the statistical analysis software R.

RESULTS AND DISCUSSION

Agronomic characteristics

The sorghum genotypes for cutting and grazing selection have been carried out in Brazil aiming to offering forage options to producers. This improvement sought in the last decades to select superior Sudangrass genotypes.

However, these Sudangrass genotypes must be able to transmit these superior characteristics to their hybrids. Therefore, the three genotypes chosen in this study are the best in the breeding program, mainly CMSXS912. The variables were evaluated considering seasons average values and not cuts because the best hybrids selection in each season generates more relevant practical information for producers. The total nutrient accumulations were higher in first compared to second planting due to the better climatic conditions and cuts number in first planting season. However, this does not impair the objective of selecting the best hybrids within each season.

The hybrid 16F26014 had the highest ($p<0.001$) TDMFA and the Sudangrass genotype TX2785 had the lowest TDMFA, with reduction of 49.9% (Table 2). The genotypes in the first planting showed TDMFA 51.4% higher ($p<0.05$) compared to second planting. The hybrids with higher TDMFA also showed higher TGFA (Table S1, supplementary material 2) and higher canopy densities. The females (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A, (ATF54A*{ATF54B*[((Tx623B*ATF54B)6-1]}-207-C1)A, (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-295-C-1)A and (CMSXS156BxATF30)6-3-C-1-1)A produced hybrids with superior accumulations. In addition, the female ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A produced superior hybrids when crossed with all males.

The genotypes in the first season showed high productivity, which allows their efficient use for cutting or grazing with high stocking rate. Basweti et al. (2009) obtained forage accumulation of 6,540 kg/ha DM in Sudangrass and 3,645 kg/ha DM in millet (*Pearl millet*) planted in early summer in North America. These forage accumulations are lower than those observed in hybrids planted in December in this study, which demonstrate superior productivity of these hybrids. Genotypes in the second planting season showed high accumulations in the first 2 cuts. However, in the third cut, accumulation decreased due to rain scarcity and low night temperatures, which made its use unfeasible for cutting. However, forage accumulation in the off-season is usually sufficient for these genotypes to be used as straw for no-till (Finney et al. 2009) or for grazing (Keyser et al. 2020).

Almaraz et al. (2009) obtained higher biomass accumulations in the sorghum for cutting and grazing hybrids compared to soybeans (*Glycine max*) and corn (*Zea mays*) planted in the summer in North America. The authors highlighted the resistance of these hybrids to heat spikes and to the water deficit resulting from climate change. Guretzky et al. (2020) also observed higher accumulations in hybrids in comparison to corn, millet, common sorghum and Sudangrass in intercropped planting with temperate forages in five locations in the United States of America. The hybrids of our study had similar accumulations, however in several cuts system, with lower growth period and less than half the tillers number. The hybrids rapid growth is important because enables higher biomass accumulation in short period of time and rainfall and to use forage faster (Beyaert & Roy 2005).

In the first planting, the tallest hybrid 16F27007 was 27.5% higher ($p<0.01$) than the smaller genotypes TX2784 and 16F26005 (Table 2). In the second planting, the TX2784 genotype was 26.8% smaller ($p<0.01$) than the taller hybrids 16F24008 and 16F26008. The tallest experimental hybrids in the second planting were also taller in the first planting and had higher leaves number (Table S1, supplementary material 2). The females (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A, (ATF54A*{ATF54B*[((Tx623B*ATF54B)6-1]}-207-C-1)A and (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-295-C-1)A produced taller hybrids. Similar to TDMFA, the female (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A produced taller hybrids when crossed with all males.

The plant heights allow to assess which genotypes have the highest growth rates under the same conditions, and together with the LAI, it allows to define the best time to start grazing. However, it is necessary to develop hybrids that have fast growth, high leaf supply and high productivity. Plant height is influenced by factors such as hybrid characteristics, sowing rate and spacing (Simili et al. 2011), cutting system (Venuto & Kindiger 2008) and fertilization used (Astigarraga et al. 2014). When hybrids are used for animal feeding it is essential to start grazing at lower height to ensure pasture quality. In the study of Beck et al. (2007) hybrid cut at 34 or 63 days more than doubled its height, reduced 8.3% to CP and 10.6% to DM degradability and increased 9.1% to NDF. However, these hybrids with heights lower than 0.8 m should not be used, to avoid poisoning by cyanogenic compounds (Simili et al. 2013). Although height is a practical management indicator, other factors such as maturity and morphological composition need to be considered in tropical forages management such as these hybrids (Gelley et al. 2016).

Table 2 - Total dry matter forage accumulation (TDMFA), height and canopy density of 30 sorghum genotypes for cutting and grazing planted in two planting seasons

Genotype	TDMFA (kg/ha DM)			Height (cm)		Canopy density (kg DM/ha/cm of height)		
	1º	2º	Mean	1º	2º	1º	2º	Mean
16F26014	9,490	4,804	7,148a	149a	148a	20.3	16.2	18.2a
16F26007	8,617	4,706	6,662a	149a	152a	18.9	15.5	17.2a
16F26008	8,852	5,085	6,969a	147a	153a	19.6	16.6	18.1a
16F27007	8,992	4,096	6,545a	160a	148a	18.3	13.5	15.9b
16F24008	8,875	4,646	6,761a	151a	153a	19.2	15.2	17.2a
16F24007	9,319	4,514	6,917a	150a	147a	20.1	15.3	17.7a
16F24015	8,401	4,194	6,298a	146a	141b	18.6	14.8	16.7a
16F27015	7,857	4,322	6,090a	142b	142b	17.9	15.2	16.5a
16F27008	8,021	3,046	5,534b	149a	136c	17.8	10.9	14.4b
16F27006	6,949	3,478	5,214b	142b	139b	16.1	12.4	14.2b
16F24006	6,809	3,715	5,263b	143b	139b	15.6	13.1	14.4b
16F24012	6,941	3,057	4,999b	151a	142b	14.9	10.6	12.8c
16F26015	7,113	3,204	5,159b	140b	137c	16.4	11.6	14.0c
16F24005	7,283	3,735	5,509b	131c	130c	17.7	14.2	16.1b
16F27014	6,717	2,803	4,760b	155a	134c	14.1	10.4	12.2d
16F27016	6,737	2,641	4,689b	150a	135c	14.6	9.5	12.0d
16F27005	6,299	3,681	4,991b	120d	129c	17.1	14.1	15.6b
16F26006	6,694	3,096	4,896b	139b	131c	15.6	11.6	13.7c
16F26005	5,595	3,453	4,525b	116d	125d	15.8	13.7	14.7b
CMSXS912	6,620	3,197	4,909b	128c	131c	16.7	12.2	14.5b
16F24014	6,595	2,781	4,689b	142b	132c	14.9	10.5	12.8c
16F27020	5,988	2,464	4,227c	145b	135c	13.4	8.9	11.2d
16F27012	6,105	2,577	4,341c	140b	133c	14.3	9.4	11.8d
16F26012	5,801	2,745	4.274c	135c	126d	13.8	10.5	12.2d
16F24020	5,555	2,872	4,214c	145b	138b	12.3	10.3	11.2d
16F24016	5,836	2,646	4,242c	140b	130c	13.6	9.9	11.8d
16F26020	5,253	2,524	3,889c	132c	128c	12.9	9.5	11.2d
16F26016	4,970	2,527	3,749c	126c	126d	12.8	9.8	11.3d
TX2785	4,764	2,393	3,579c	126c	124d	12.4	9.6	10.9d
TX2784	5,182	2,103	3,643c	116d	112e	14.2	9.3	11.7d
Mean	6,941A	3,370B	-	-	-	16.0A	12.1B	-
CV% §		6.70		4.54			23.7	

§ Coefficient of variation, Means followed by different letters, lowercase in the column and uppercase in the line, differ by Scott-Knott (p<0.05) and Fisher (p<0.05) tests.

The denser hybrid 16F26014 was 39.7% higher ($p<0.001$) than the genotype with lower density TX2785 (Table 2). The genotypes showed canopy densities 24.2% higher ($p<0.001$) in the first compared to second planting. The LAI ranged from 1.6 in the Sudangrass TX2785 genotype to 3.1 in the 16F26008 and 16F26005 hybrids. The genotypes in the first planting showed significantly lower ($p<0.001$) LAI (2.0) compared to second planting (2.7), reduction of 26.6%.

Canopy density is a productivity indicator and hybrid nutritional capacity in providing forage to animals. This indicator shows hybrid ability to maintain balance between height and high forage supply in each grazed strata. The hybrids considered superior 16F26014, 16F24007, 16F24008 and 16F26007 were denser, taller, more productive and had more leaves (Table S1, supplementary material 2). Together with the canopy density, the LAI allows to infer about the physiological parameters and to quantify forages canopy structure. The LAI is generally higher in hybrids with more leaves, taller and with larger plant population (Narayanan et al. 2014). These hybrids with larger leaf area generally have greater photosynthetic capacity, energy production and plant growth (Taiz et al. 2015) and provide more leaves for animals. The LAI was higher in the second compared to first planting, probably due to the measurement only in the first cut of the two seasons and the low rainfall that occurred during the first cut of the first planting.

In the two planting seasons, the CMSXS912 Sudangrass genotype showed more ($p<0.001$) tillers. In the first planting, the CMSXS912 Sudangrass genotype showed 59.4% more ($p<0.001$) tillers than the 16F24020 hybrid with less tillers (Table 3). In the second planting, the CMSXS912 Sudangrass genotype showed 59.5% more tillers than the hybrids 16F27016 and 16F27020 with less tillers. Considering only hybrids, 16F24008, 16F27005, 16F26014, 16F26008, 16F24015, 16F24007 and 16F27015 showed more tillers.

The plants number is linked to forage productivity and leaves supply for animals. The Sudangrass genotypes had higher plant populations, which together with the high tillering capacity and rapid growth, are the main characteristics inherited from Sudangrass by hybrids. Simili et al. (2011) found lower plant populations than those in this study, even with high sowing rate (20 kg/ha). This difference can be attributed to the authors having evaluated only the first cut and the largest populations to occur in the subsequent cuts due to the high regrowth capacity of these hybrids (Table S1, supplementary material 2).

In the first planting, the hybrid 16F26016 had higher ($p<0.01$) PLP, while the hybrid 16F24007 had lower PLP, reduction of 26.6% (Table 3). In the second planting, the hybrid 16F26016 presented higher ($p<0.01$) PLP, while the hybrid 16F24007 presented lower PLP, with reduction of 28.4%. The taller hybrids and the hybrids with higher TDMFA showed lower PLP. The plant leaves proportion is one of the most important agronomic indicators in the hybrids selection because it shows the ability to offer feed of greater nutritional value to animals. The hybrids 16F27005, 16F26005, 16F26012, 16F26016 and 16F26020 showed higher leaves proportion, however, they were not the most productive and with the largest leaves number. These hybrids were less vigorous and had lower heights, which increased the leaves participation in plant composition. This result demonstrates the need to evaluate this indicator together with productivity. Chaugool et al. (2013) observed mean PLP values in 15 hybrids cut at 57 days of growth of 33.33%. Gelley et al. (2016) observed reduction from 100 to 23.83% of PLP in hybrids with two and eight weeks of growth. This lower leaves proportion may occur because with maturity advancement the plants elongate the stem, which proportionally increase this fraction. In addition to the lower leaf supply, these authors observed worse nutritional value. This fact demonstrates the need to use these hybrids in younger stages to ensure the supply of better quality forage to the animals.

The hybrid 16F27016 with larger stem diameter was 38.1% larger ($p<0.001$) than the Sudangrass TX2784 genotype with smaller stem diameter (Table 3). The genotypes showed larger ($p<0.05$) stem diameters in the first than in the second planting, with reduction of 5.8%. Among the hybrids with the largest stem diameter, 71.43% were from crossing with the male CMSXS912.

The stem diameter and composition of its fibers are essential to maintain plants vertical support. Therefore, plants with very thin stems and/or with low fiber content can lodging and reduce productivity. However, stems have lower nutritional value than leaves and that is why it is desirable that hybrids have thinner stems, as long as there is no plant lodging. In this study, none hybrid presented lodging and the stem diameters were smaller than those found by Venuto & Kindiger (2008) with 14.0 mm and Simili et al. (2011) with 9.3 to 12.5 mm, which demonstrates hybrids superiority in this study. The hybrids 16F24008, 16F24007, 16F26007, 16F26014 and 16F26008 showed higher productivity, more leaves (Table S1, supplementary material 2) and greater height even with intermediate stem diameters.

Table 3 - Tillers number per hectare, plant leaf proportion (PLP) and stem diameter of 30 sorghum genotypes for cutting and grazing planted in two planting seasons

Genotypes	Tillers (tillers/ha)		PLP (%)		Stem diameter (mm)		
	1º	2º	1º	2º	1º	2º	Mean
CMSXS912	898,518a	586,666a	44.7c	42.5b	7.5	7.2	7.3d
16F24008	664,444b	500,555b	42.6c	43.4b	9.1	8.9	9.0b
TX2784	730,740b	459,444c	49.2b	49.4a	6.3	6.5	6.4e
16F27005	690,740b	402,777c	51.7a	50.9a	8.1	8.5	8.3c
TX2785	651,111b	424,444c	43.7c	44.5b	7.2	7.4	7.3d
16F26014	649,629b	405,000c	47.9c	47.8b	8.9	9.3	9.1b
16F26008	644,814b	471,111c	48.7b	44.6b	8.6	9.2	8.9b
16F24015	638,148b	452,222c	44.4c	46.9b	8.7	9.7	9.2b
16F24007	637,037b	458,888c	41.1c	40.1b	8.6	9.3	8.9b
16F27015	637,037b	436,666c	45.9c	50.6a	8.7	9.3	9.0b
16F26007	622,592c	473,333c	46.4c	45.7b	8.8	9.4	9.1b
16F27006	614,814c	398,333c	45.3c	49.3a	8.9	9.3	9.1b
16F24005	614,814c	435,000c	45.1c	48.2b	7.8	9.1	8.5c
16F27008	610,370c	457,222c	43.8c	50.6a	8.6	8.7	8.7c
16F24006	605,555c	405,555c	45.6c	50.8a	8.4	9.4	8.9b
16F26006	592,592c	396,666c	49.3b	51.1a	8.3	8.2	8.3c
16F26005	580,000c	439,444c	54.9a	55.6a	8.2	8.8	8.5c
16F27007	577,407c	358,333d	44.3c	45.1b	9.7	9.6	9.7a
16F24014	570,740c	437,222c	42.3c	53.5a	8.2	8.4	8.3c
16F26015	540,370d	353,333d	49.9b	51.3a	8.8	9.4	9.1b
16F27012	520,370d	340,000d	50.4b	52.0a	9.6	9.4	9.5a
16F24012	498,148d	352,777d	48.5b	51.3a	9.5	10.1	9.8a
16F26012	496,296d	368,888d	53.2a	54.9a	8.6	8.8	8.7c
16F27014	473,333e	328,888d	45.3c	52.3a	9.9	8.9	9.4a
16F24016	464,444e	360,000d	47.5c	52.6a	9.3	8.9	9.1b
16F27016	464,074e	248,333e	46.2c	51.0a	10.0	10.6	10.3a
16F27020	445,555e	237,777e	47.6c	47.8b	9.6	10.0	9.8a
16F26016	445,185e	348,888d	55.9a	55.9a	8.8	8.9	8.9b
16F26020	429,259e	337,777d	52.2a	55.0a	9.2	8.9	9.0b
16F24020	365,185f	318,333d	47.1c	46.4b	9.7	9.7	9.7a
Mean	-	-	-	-	8.7B	8.9A	-
CV% §	9.2		6.2		5.8		

§ Coefficient of variation, Means followed by different letters, lowercase in the column and uppercase in the line, differ by Scott-Knott ($p<0.05$) and Fisher ($p<0.05$) tests.

Nutritional characteristics and nutrient accumulation

The leaves DM contents showed no significant effect (p>0.05) for seasons and genotypes and varied from 16.5 to 20.1% (Table 4). The stems DM contents were higher (p<0.05) in the first compared to second planting, with reduction of 12.3%. In both seasons, the whole plants DM contents were higher (p<0.05) in Sudangrass TX2784 and TX2785 genotypes than in the others. The dry matter content evaluation in different plant parts makes it possible to select hybrids with high accumulations and with higher DM contents, especially in leaves. These hybrids with higher leaves DM contents have higher nutrients density and lower rumen filling (Van Soest 1994).

Table 4 - Dry matter content (natural matter basis) of leaves, stems and whole plants of 15 sorghum genotypes for cutting and grazing planted in two seasons

Genotype	Leaves (g/kg NM)			Stems (g/kg NM)			Whole plants (g/kg NM)	
	1º	2º	Mean	1º	2º	Mean	1º	2º
16F26006	185	175	179a	98	93	96b	115c	110b
TX2784	201	188	194a	122	111	116a	140a	128a
TX2785	194	187	190a	116	107	111a	138a	125a
16F24014	192	181	186a	122	98	109a	127b	116a
16F26014	193	170	181a	109	90	99b	117c	103b
16F26012	188	175	181a	97	83	90b	118c	110b
16F24005	187	175	181a	110	96	102a	122c	107b
16F24006	186	169	177a	102	86	94b	113c	104b
16F27014	186	169	177a	94	83	89b	106c	102b
16F26008	181	172	176a	99	99	99b	118c	102b
16F24012	182	170	175a	96	78	87b	110c	97b
16F24015	177	173	174a	103	90	96b	119c	101b
16F24007	177	170	173a	115	99	107a	124c	101b
16F24008	179	168	173a	105	90	97b	114c	100b
16F26007	171	165	168a	101	90	95b	113c	98b
Mean	185A	183A	-	106A	93B	-	-	-
CV% §		20.4			7.0		5.1	

§ Coefficient of variation, Means followed by different letters, lowercase in the column and uppercase in the line, differ by Scott-Knott (p<0.05) and Fisher (p<0.05) tests.

The stems DM contents were higher in the second compared to the first planting, possibly due to the greater growth and water accumulation in the hybrids planted in first season. The DM contents found in these genotypes are considered low when compared to other roughage such as silages. This low DM content can impair the animal intake of roughage and nutrients (Mertens 1987). However, the leaves DM contents were much higher than in the stems. Thus, as leaves are the main grazed components, the intake might not be limited when these hybrids are used in grazing. Astigarraga et al. (2014) found dry matter contents much higher than those in this study, possibly due to lesser fertilizer use, which can reduce hybrids accumulation and increase DM content. Furthermore, the whole plant DM contents may make the use of these hybrids impossible to ensilage (McDonald et al. 1991). Thus, it is necessary to use some strategy to increase material DM or cut the hybrids in more advanced phenological stage.

In the first planting season, there was no difference for leaves CP contents between genotypes. In the second planting season, the hybrids 16F24012, 16F26008, 16F26006, 16F26014, 16F26012 and 16F26007 and the Sudangrass genotype TX2784 were superior (p<0.05) to the others (Table 5). The stems CP content was 13.2% higher (p<0.05) in the second compared to the first planting. The whole plant CP contents in the second planting was 9.0% higher (p<0.05) than in the first.

Table 5 - Crude protein content of leaves, stems and whole plants and CP accumulation (CPA) per hectare of 15 sorghum genotypes for cutting and grazing planted in two seasons

Genotype	Leaves (g/kg DM)		Stems (g/kg DM)			Whole plants (g/kg DM)			CPA (kg CP/ha)	
	1º	2º	1º	2º	Mean	1º	2º	Mean	1º	2º
TX2784	182a	200a	85	95	90a	115	131	123a	595c	276b
16F24012	180a	197a	83	93	88a	113	123	118b	784b	378b
16F27014	180a	184b	82	94	88a	110	118	114c	740b	331b
16F26008	178a	205a	82	94	88a	113	120	117b	1,008a	617a
16F24005	177a	184b	86	96	91a	110	124	117b	810b	466a
16F26006	176a	192a	87	100	94a	117	128	122a	786b	396b
16F24015	173a	180b	70	80	75b	104	115	110c	880a	489a
16F24008	172a	185b	74	84	79b	107	112	110c	953a	524a
16F24014	172a	175b	73	82	77b	103	117	110c	684b	326b
16F24007	171a	175b	75	83	79b	108	117	112c	1,010a	534a
16F26014	171a	195a	80	90	85a	118	118	118b	1,119a	571a
TX2785	171a	175b	73	78	76b	109	110	109c	523c	264b
16F26012	171a	194a	84	95	89a	117	130	124a	680b	358b
16F24006	167a	182b	79	90	85a	110	118	114c	750b	438a
16F26007	166a	193a	80	93	87a	109	123	116b	946a	582a
Mean	-	-	79B	91A	-	111B	121A	-	-	-
CV% §	3.7		4.9			4.0			12.5	

§ Coefficient of variation, Means followed by different letters, lowercase in the column and uppercase in the line, differ by Scott-Knott ($p<0.05$) and Fisher ($p<0.05$) tests.

In general, the hybrids 16F26008, 16F26014 and 16F26007 showed high accumulations and CP contents. On the other hand, the Sudangrass genotype TX2784 and the hybrids 16F26012 and 16F26006 had higher CP contents in all plant parts, however, they presented low CPA. Only the male TX2784 produced hybrids with higher contents and CPA.

The stems and whole plants CP contents were higher in the second compared to the first planting season. This reduction may have occurred due to greater water stress in the second planting, which reduced biomass accumulation and might have concentrated plant CP. The CP contents found are higher than 7% considered minimum for the proper ruminal functioning (Van Soest 1994). In addition, the high leaves CP contents, which is the main grazed component, allow high CP supply to animals and reduction concentrated feed cost (Dann et al. 2008). The higher CP in hybrids compared to the Sudangrass genotypes can be attributed to the hybrids having inherited the better nutritional value of common sorghum (Basweti et al. 2009; Bibi et al., 2012).

The leaves NDF contents was 3.5% higher ($p<0.05$) in the second compared to first planting (Table 6). The stems NDF contents was higher ($p<0.05$) in the second compared to the first planting, increase of 1.3%. The whole plant NDF content ranged from 62.2 to 65.8%, with superiority ($p<0.05$) for the hybrids 16F26007, 16F26008, 16F24006, 16F24007 and 16F24008.

The leaves and stems NDF contents were higher in the second compared to first planting season, possibly due to less average rainfall and larger stems diameter during the second planting. The NDF contents are linked to intake limitation in ruminant due to the lower fiber digestibility (Van Soest 1994). Higher NDF values were found by Dann et al. (2008) and Beck et al. (2013), probably because the authors used longer cut ages and smaller line spacing. These factors can increase light competition between plants, stems elongation and fiber content increase in plants. Similar to NDF, the ADF contents (Table S2, supplementary material 3) in leaves and stems were higher in the second compared to first planting season. ADF contents are linked to reduced feed digestibility, mainly due to lignin presence (Van Soest 1994).

Table 6 - Neutral detergent fiber content of leaves, stems and whole plants of 15 sorghum genotypes for cutting and grazing planted in two seasons

Genotype	Leaves (g/kg DM)			Stems (g/kg DM)			Whole plants (g/kg DM)		
	1º	2º	Mean	1º	2º	Mean	1º	2º	Mean
16F26007	639	678	658a	627	632	629b	651	649	650a
16F26008	647	666	656a	625	637	631b	651	639	645a
16F26014	638	669	654a	640	645	642a	641	629	635b
16F26006	642	664	653a	641	641	641a	629	646	637b
16F24006	648	655	652a	636	644	640a	648	655	651a
16F24016	631	666	649a	624	620	622b	654	620	637b
16F24007	634	657	645a	627	631	629b	669	632	651a
16F24005	633	653	643a	611	639	625b	642	637	640b
16F24008	635	650	643a	620	639	629b	655	662	658a
16F26012	628	646	637b	628	645	636a	640	622	631b
TX2784	624	650	637b	624	646	635a	628	634	631b
16F24014	626	643	634b	625	631	628b	628	616	622b
16F27014	612	644	628c	614	612	613b	632	616	624b
TX2785	616	631	623c	622	618	620b	639	634	637b
16F24012	614	629	621c	620	622	621b	613	633	623b
Mean	632B	654A	-	626B	634A	-	642[a]	635A	-
CV% [§]		1.4			1.5			2.0	

[§] Coefficient of variation, Means followed by different letters, lowercase in the column and uppercase in the line, differ by Scott-Knott (p<0.05) and Fisher (p<0.05) tests.

The leaf, stem and whole plant IVDMD showed no differences (p>0.05) between genotypes (Table 7). The DDMA had significant effect for interaction between seasons and hybrids (p<0.05). The hybrids 16F24005, 16F26007, 16F24006, 16F24007, 16F26014, 16F26008 and 16F24008 had the highest nutrient accumulations, however only the hybrids 16F26008, 16F26014 and 16F26007 had high accumulation and nutritional value.

The digestibility found in this study can be considered high. Beck et al. (2007) found *in situ* DM degradability of 56% in normal hybrids and 58.5% in *bmr* mutant hybrids. The hybrids carrying the *bmr* mutation are recognized for having lower fiber contents and changes in the composition and bonds of lignin with cell wall components, which results in greater digestibility (Beck et al. 2013). The hybrids in our study are common and presented greater digestibility, similar NDF and lower lignin contents (Table S5, supplementary material 3). These results indicate the high hybrids nutritional value.

The tested hybrids showed nutritional value similar or superior to other perennial tropical forage species such as *Panicum* sp. (Paciullo et al. 2016) and *Urochloa* sp. (Santos et al. 2018) or annuals such as millet and Sudangrass (Noland et al. 2017). This fact is important since it makes it possible to offer forage with better nutritional value and to maximize animal performance.

Table 7 - The *in vitro* dry matter digestibility of leaves, stems and whole plants and digestible dry matter accumulation (DDMA) of 15 sorghum genotypes for cutting and grazing planted in two seasons

Genotype	Leaves (g/kg DM)			Stems (g/kg DM)			Whole plants (g/kg DM)		DDMA (kg DM/ha)	
	1º	2º	Mean	1º	2º	Mean	1º	2º	1º	2º
16F24006	664	692	677a	566	567	566a	632a	669a	4,299b	2,488a
16F24007	674	679	676a	581	550	565a	589a	670a	5,499a	3,009a
16F24014	682	670	675a	580	596	588a	637a	625a	4,214b	1,743b
16F26014	693	657	675a	576	561	568a	625a	660a	5,929a	3,174a
16F26006	682	661	671a	575	569	572a	619a	677a	4,137b	2,090b
16F24015	672	667	669a	575	564	569a	622a	633a	5,225a	2,630a
16F26008	658	676	667a	566	553	559a	585a	663a	5,181a	3,365a
16F24008	651	680	665a	548	543	545a	579a	672a	5,145a	3,123a
16F26007	660	665	662a	577	576	576a	630a	594a	5,429a	2,790a
TX2784	669	642	655a	590	548	568a	637a	645a	3,276c	1,362b
16F26012	654	656	654a	587	580	583a	624a	660a	3,621c	1,813b
16F24005	657	647	652a	576	587	581a	639a	658a	4,645a	2,463a
16F27014	637	666	651a	566	577	571a	628a	642a	4,213b	1,811b
TX2785	649	652	650a	551	536	543a	586a	641a	2,790c	1,526b
16F24012	626	645	635a	603	587	594a	631a	632a	4,402b	1,944b
Mean	662A	664A	-	574A	566A	-	-	-	-	-
CV% [§]		3.9			5.3		4.7		11.7	

[§] Coefficient of variation, Means followed by different letters, lowercase in the column and uppercase in the line, differ by Scott-Knott (p<0.05) and Fisher (p<0.05) tests.

Cluster analysis

The cluster analysis with agronomic data divided the genotypes into three groups (Figure 2). The first group contained all hybrids with the female (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A and in the second group all males were TX2784. Group three had great predominance of hybrids from males CMSXS912 and TX2785, contained all hybrids with female CMSXS222A and the Sudangrass genotypes. Comparing cluster grouping with Scott-Knott test for TDMFA, it is observed that all hybrids in group one had higher accumulations. In group two, 75% of hybrids had lower accumulations. In group three there were hybrids with intermediate and low accumulations.

The females (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A, (ATF54A*{ATF54B*[((Tx623B*ATF54B)6-1]}-207-C-1)A, (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-295-C-1)A and (CMSXS156BxATF30)6-3-C-1-1)A and the males TX2784 and TX2785 produced superior hybrids. Although the male CMSXS912 has shown better agronomic characteristics than the other males, it was not able to produce superior hybrids. These results suggest that some parental genotypes do not have ability to transmit their characteristics. For Bibi et al. (2012) the sorghum genotypes combining ability is their ability to combine with another genotype and produce superior hybrids. In plant breeding, testing large hybrids number and crossing allows to provide greater genetic variation and to produce specific combinations that generate superior hybrids. Furthermore, the selection of genotypes most able to produce superior hybrids allows improve the crossings to increase selection speed.

The cluster analysis with the nutritional value data divided the genotypes into five groups (Figure 3). The first two groups contained the Sudangrass genotypes. The third group contained all hybrids with the female CMSXS222A.

The male of all hybrids in group four was TX2785. Comparing the cluster grouping with Scott-Knott test for CP it is observed that group three contained hybrids with high, medium and low contents. The group four contained hybrids with low CP contents and the fifth contained those with intermediate values. Comparing the cluster grouping with Scott-Knott test for DM, it is observed that the first two groups contained higher contents and the other groups had medium and low contents.

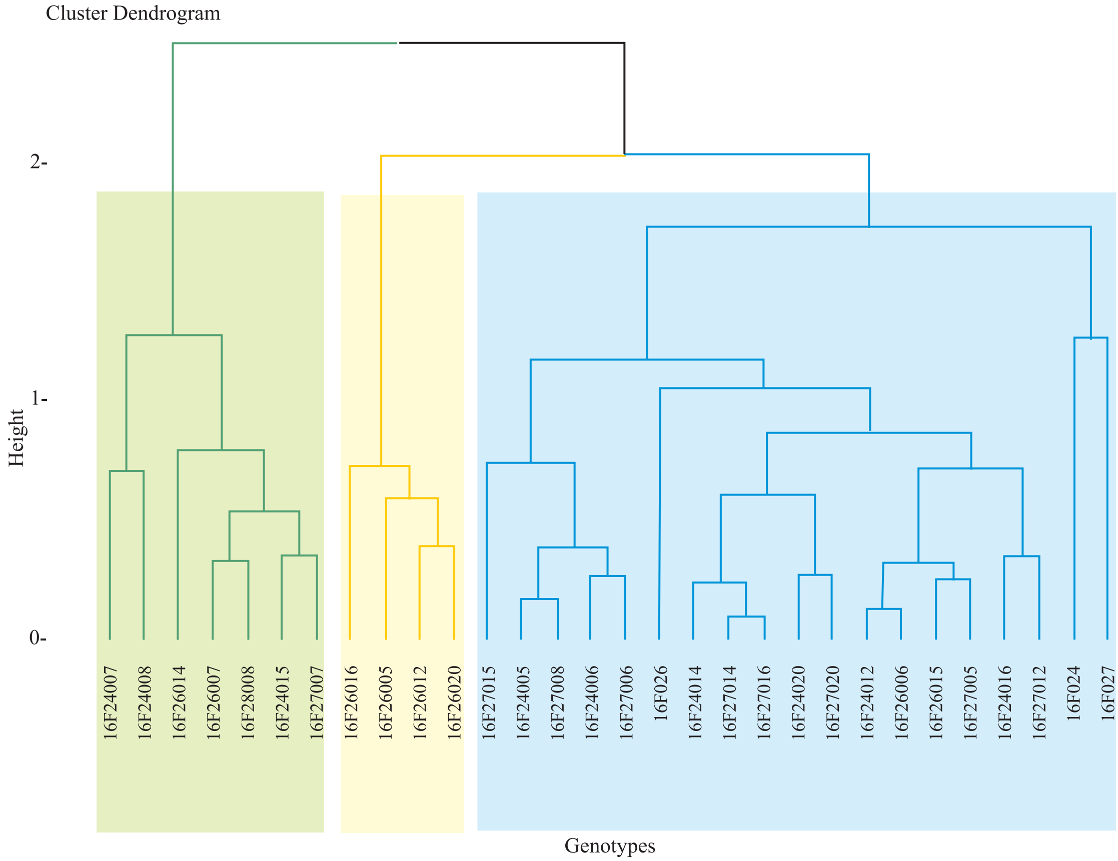

Figure 2 - Cluster analysis with agronomic data from total dry matter forage accumulation and plant leaf proportion.

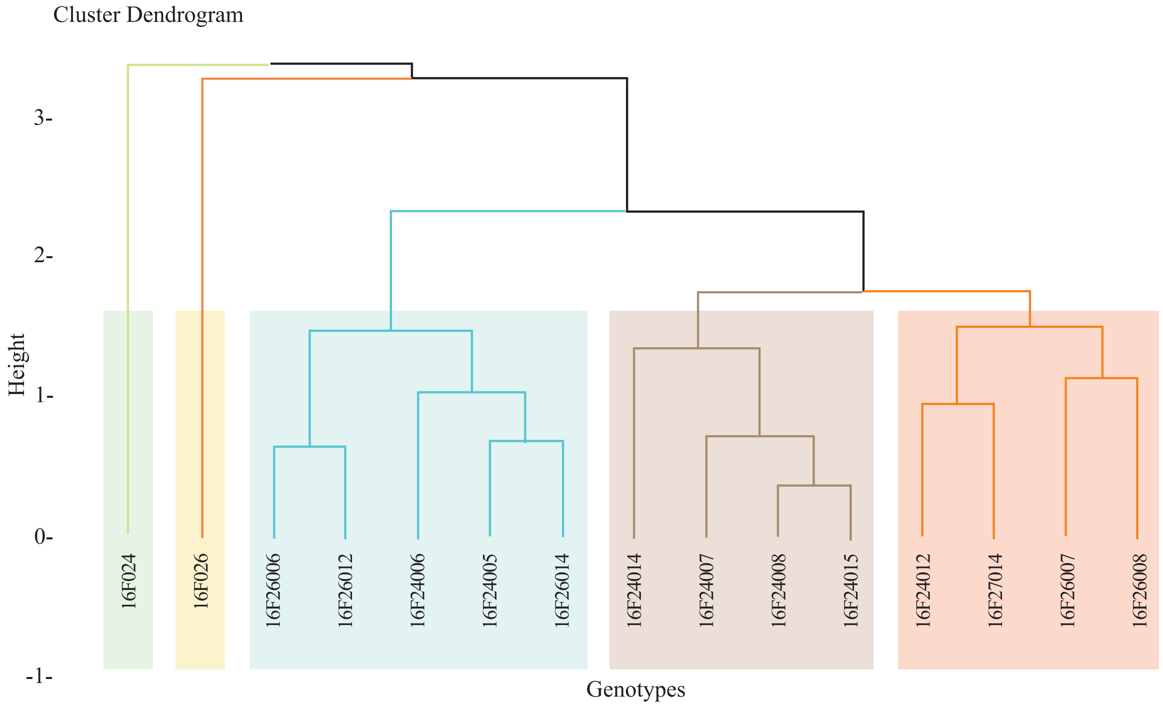

Figure 3 - Cluster analysis with the nutritional values of dry matter, crude protein and *in vitro* dry matter digestibility

CONCLUSION

The hybrids have good agronomic and nutritional characteristics for use in animal feed during the two planting seasons. The agronomic and nutritional characteristics are superior in the first compared to second planting due to better climatic conditions during growth. The hybrids 16F26008, 16F26014 and 16F26007 have superior characteristics and should continue to be tested under other conditions to be commercially available. The females (ATF54A*{ATF54B*[(Tx623B*ATF54B)6-1]}-263-C-1)A and (ATF54A*{ATF54B*[((Tx623B*ATF54B)6-1]}-207-C-1)A and the males TX2784 and TX2785 are the most able to produce superior hybrids.

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