Original Research Article

Bromatological Composition of Elephant Grass Genotypes for Bioenergy Production

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ABSTRACT

Aimed to evaluate the bromatological composition of different genotypes of elephant grass (*Pennisetum purpureum* Schum.) to energy production through combustion. The experimental design was a randomized block with 3 repetition and treatments arranged in a subdivided plots scheme, considering as a plots the thirteen genotypes and harvests (dry and rainy) as subplots. The genotypes evaluated were Cubano Pinda, Porto Rico, Vrukwona, Piracicaba 241, Cuba 116, Taiwan A-25, Mecker, Napíer, Canará, Guaçu, Cameroon, CNPGL 93-41-1 and CNPGL 91-25-1 clones. The experiment lasted two consecutive years with cuts made every 6 months, with a harvest in the dry season (September) and another one in the rainy season (March), totaling 4 harvests. For dry matter content analysis, three tillers were selected at random and dried in an oven at 55 ºC until reaching a constant mass. For biomass quality analysis, the samples were ground in Willey type mills with 1mm sieves, submitted to bromatological analysis to determine the neutral detergent fiber, acid detergent fiber, hemicellulose, volatile materials, and fixed carbon content. The elephant grass genotypes evaluated have great potential for energy production because they have a desirable dry matter, acid detergent fiber, neutral detergent fiber, hemicellulose and volatile materials content. Higher levels of dry matter, acid detergent fiber and volatile matter occur in the dry season of the year in the following Mercker, Piracicaba 241, Guaçu, Cubano Pinda and BRS Canará genotypes.

Keywords: Bioenergy, Combustion, Fiber Content, Volatile Material, Fixed Carbon

1. INTRODUCTION

Currently the world energy matrix focuses on the use of fossil fuels for the generation of energy, especially the petroleum products that with their combustion release harmful gases are not only for the environment, but also for human health. Thanks to petroleum, humanity has had a big evolution. However, because it is an exhaustible resource with a high potential to pollution, the development of new sustainable technologies for energy generation is of crucial importance. In this way, many countries are developing research, looking for alternatives that make them less dependent on the use of fossil fuels, mainly petroleum and its derivatives [2].

The use of plant biomass is an option to use as an alternative energy source, having the advantage of being a renewable source of "clean energy" that fits into the greenhouse gas mitigation plan (GHG) due its potential of conversion into thermal energy, electrical or chemical energy and to carry out a considerable carbon sequestration [3]. Characteristics that aroused the interest both public and private sector not only for their economic applicability, but mainly environmental due to the goals and agreements stipulated in the meetings Rio 21, Kyoto Protocol and Paris Agreement [4].

In Brazil, eucalyptus and its coproducts (sawdust, firewood and chipwood) are traditional alternative energy resources that have different uses, for example: coal, cellulose, wood production for plywood and paper factoring. The agricultural sector has species that are promising for energy use, among them elephant grass (*Pennisetum purpureum* Schum.), one of most widespread tropical forage species in the world, used on livestock properties as a roughages [5]. The elephant grass emerges as an option because it presents: dry matter yields above 50 t ha^{-1} $year^{-1}$ [6], approximately twice the eucalyptus; shorter productive cycle with semester harvest; C4 metabolism that ensures greater carbon assimilation; calorific power between 4,100 and 4,500 kcal kg^{-1} [7]; low cost of production and the possibility of producing briquettes and pellets which adds value to biomass and burning quality [8].

The elephant grass culture has great genetic variability, developing well in subtropical and tropical Brazilian conditions. The BRS Capiaçu cultivar for forage purposes was recently launched by the Brazilian Agricultural Research Corporation (Embrapa) for the Atlantic Forest biome [9]. However, there are cultivars that are in disuse and can be promising for direct burning, due to the high levels of dry matter and fiber present [10].

In view of the need to obtain alternative sources of sustainable energy and the potential that elephant grass presents for the biomass production with favorable chemical characteristics for energy generation, aimed to evaluate the bromatological composition of different elephant grass genotypes for bioenergy production.

2. MATERIAL AND METHODS

The experiment was conducted in the Experimental Field of *Empresa Mato-grossense de Pesquisa, Assistência e Extensão Rural* (EMPAER) in Cáceres - MT, located 16º 09’ 04’’ Latitude South; 57º 38’ 03’’ West Longitude; altitude of 157 m. The climate in the municipality, according to the Köppen classification, is Aw type, that is, tropical, metamérmico climate, characterized by two well-defined periods: dry (May to September) and rainy (October to April).

The experiment lasted two years, with cuts every 6 months counted after the harvest of standardization (March 2016), with one harvest in the dry season (September) and another one in the rainy season (March), in a total of four harvests in two consecutive years.

The chemical and granulometric analysis of the soil of the experimental area (Table 1) was done before planting where the establishment fertilization recommendation was made. After the last harvest of the elephant grass, a new soil analysis was made to verify the soil fertility level after the four harvests made. The soil was characterized as Chernosolic Eutrophic Red-Yellow ARGISSOLO, medium / clayey texture.

Table 1: Chemical and granulometric analysis in the 0-20 cm soil layer of the experimental area before planting (A) and after the last harvest of the elephant grass (B).

	pH ($CaCl_2$)	P (mg dm^{-3})	K	Ca	Mg	Al	H+Al	SB	CEC	V (%)	OM (g dm^{-3})	SAND	SILT	CLAY
			(cmol$_c$ dm^{-3})									(g kg^{-1})		
A	5.6	6.90	0.12	2.2	0.8	0.0	2.1	3.1	5.2	60	27.0	723	56	221
B	5.8	4.10	0.09	3.3	1.2	0.0	2.1	4.7	6.8	69	24.1			

P = Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; Al = Aluminium; H = Hydrogen; CTC = Cation exchange capacity; V = Base saturation; OM = Organic matter.

Soil preparation was done with a plowing and two harrowing in the month of September 2015, without application of limestone, due to the percentage of saturation per desired base being above 50%, considered adequate for establishment of elephant grass [11]. The elephant grass seedlings were obtained in the nursery of the Experimental Field of the EMPAER. The planting of the stems was done in a "foot-with-tip" system, with the seedlings placed in the planting groove and covered with soil, using a spacing of 1.0 m between rows.

The single fertilization was carried out in the establishment of elephant grass in the amounts of 70 kg of P_2O_5 ha^{-1}, 100 kg of K_2O ha^{-1} and 100 kg of N ha^{-1} using the following fertilizers: simple superphosphate, potassium chloride and ammonium sulfate, respectively. Both nitrogen and potassium fertilizer were divided in two applications, the first one in planting (November 2015), and the second one shortly after the harvest to uniformity (March 2016).

The experimental design was a randomized block with 3 repetition. The treatments were arranged in subdivided plots scheme, considering as genotypes (Cubano Pinda, Porto Rico, Vrukwona, Piracicaba 241, Cuba 116, Taiwan A 25, Mercker, Napier, Canará, Guaçu, Cameroon and the CNPGL 93-41-1 and CNPGL 91-25-1 clones) and harvests (dry and rainy) as subplots. The experimental unit consisted of four rows of 5.0 m in length with spacing between rows of 1.0 m, totaling 20 m^2. The two central lines were considered as useful area, scoring 1.0 m at the ends.

The first harvesting cut was made in September 2016 (dry harvest), and successive harvests were carried out every 6 months, as follows: March 2017 (rainy harvest), September 2017 (dry harvest); March 2018 (rainy harvest).

The dry matter content – DM (%) was obtained from three tillers selected at random within the useful area, being then chopped and conditioned in a paper bag, weighed and placed in a 55 °C oven until reaching a constant mass. Afterwards, the samples were again weighed to obtain the air-dried sample.

For analysis of the biomass quality the whole plant samples were ground in a Willey type mill with a 1 mm sieve and placed in plastic pots for analysis of the bromatological composition for acid detergent fiber – ADF (%), neutral detergent fiber – NDF (%) and hemicellulose content – HEM (%), according to the [12] methodology.

In the determination of the volatile matter contents – VM (%) and fixed carbon – FC (%) were according to the methodology quoted by [13], in which the biomass samples were introduced in an oven at 100 ± 5 °C until the mass was constant, after this step the samples with no moisture were introduced into a muffle at 850 ± 10 °C for seven minutes. Subsequently, the sample was placed in a desiccator for cooling and subsequent weighing.

The data collected were submitted to normality tests (Lilliefors) and homogeneity of variances (Bartlett). The analysis of variance and Scott-Knott clustering test, according [15].

3. RESULTS AND DISCUSSION

3.1 Dry matter, Acid detergent fiber, Neutral detergent fiber and Hemicellulose content

For the dry matter (DM) content, a statistical difference (P> .05) was observed between the seasons and genotypes studied. In the first year of cultivation, when comparing the seasons, the dry season provided higher DM in the genotypes CNPGL 91-25-1, Mercker, Porto Rico, Guaçu, Cubano Pinda and BRS Canará (Table 2). This difference was expected because the higher content of moisture contained in the plant (rainy season) causes dilution effect by reducing the DM%, in the dry season as the lower moisture content in the vegetable causes the DM percentage to increase.

Table 2: Dry matter (DM), Acid detergent fiber (ADF), Neutral detergent fiber (NDF) and Hemicellulose (HEM) in elephant grass genotypes at 6 months age in the dry and rainy season of the first year of cultivation (2016-2017).

Genotype	DM (%)		ADF (%)		NDF (%)		HEM (%)	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
CNPGL 93-41-1	37.90bA	35.27bA	55.85aA	49.55aB	77.03aA	79.69aA	21.33aB	30.00aA
CNPGL 91-25-1	39.36bA	32.13bB	52.11aA	52.57aA	77.07aA	78.52aA	24.67aA	26.00aA
Taiwan A 25	40.16bA	40.53aA	50.59aA	51.93aA	75.06aA	76.75aA	24.67aA	25.00aA
Cuba 116	39.96bA	42.76aA	53.43aA	51.15aA	76.47aB	81.24aA	23.00aA	30.00aA
Mercker	45.23aA	37.36bB	51.97aA	49.80aA	75.89aA	75.88aA	24.00aA	26.00aA
Cameroon	37.22bA	36.27bA	52.46aA	51.42aA	75.27aA	78.05aA	22.67aA	26.33aA
Piracicaba 241	37.11bA	34.93bA	52.65aA	51.35aA	73.45aA	75.90aA	20.67aA	24.67aA
Vrukwona	35.58bA	36.67bA	49.45aA	54.10aA	72.32aA	76.53aA	23.00aA	22.33aA
Napier	36.08bA	34.66bA	52.54aA	52.43aA	79.64aA	76.21aA	27.00aA	24.00aA
Porto Rico	45.21aA	36.27bB	50.16aA	52.89aA	74.85aA	77.21aA	24.67aA	24.33aA
Guaçu	41.01bA	33.07bB	53.97aA	51.26aA	79.45aA	75.27aA	25.67aA	24.33aA
Cubano Pinda	40.50bA	33.27bB	53.58aA	52.02aA	76.35aA	79.21aA	22.67aA	27.33aA
BRS Canará	43.69aA	36.80bB	49.64aA	53.55aA	77.18aA	76.57aA	27.67aA	23.00aA
Average	38.04		52.02		76.81		24.81	
CV (a) (%)	6.11		5.20		4.42		18.45	
CV (b) (%)	7.61		6.77		3.55		17.23	

CV (a) (%): Coefficient of variation of plot; CV (b) (%): Coefficient of variation of the subplot.

Averages followed by the same letter, lowercase vertical and uppercase horizontal do not differ from each other by the Scott Knott test at 5%.

[15], when evaluating the morphoagronomic and biomass quality characteristics of 52 elephant grass genotypes at the end of the rainy season at 10 months age, obtained DM content average of 37.16%, with an amplitude of 29.42 % to 68.24% among genotypes. This indicates the importance of the study of this variable in the selection of elephant grass

genotypes for energy production that can be influenced not only by phenotypic variation, but also genotype. The low dry matter content present in the biomass can interfere with the bromatological and chemical properties of the biomass, mainly the lower calorific value (LCV), which is closely related, as it decreases with the reduction of DM [16].

In the first year of cultivation at dry season, the genotypes Mercker, Porto Rico and BRS Canará had higher DM (P> .05) with 45.23; 45.21 and 43.69%, respectively. Otherwise, at the time of the rainy season, the genotypes Taiwan A 25 and Cuba 116 obtained higher DM (P> .05) with contents of 40.53% and 42.76%, respectively. When the biomass presents a high moisture content, it also causes the combustion process to be lower, compared to the use of drier material. Thus, the higher the moisture present in the biomass, the more energy is needed to start the burning process, that is, more energy is required to vaporize the water and less energy is then supplied to the endothermic reaction (burning).

In the second year of cultivation (Table 3), when comparing the two seasons, similar to the first crop, all genotypes had higher DM in the dry season, with the exception of Cuba 116 that did not present a difference. Otherwise, during the dry season, the genotypes that stood out were Taiwan A25, Piracicaba 241, Guaçu, Porto Rico and Cuban Pinda with values from 54.34 to 47.51%. In addition, within the rainy season, there was also no difference between the genotypes, obtaining a mean of 39.24%.

The presence of moisture makes this burn difficult, as the calorific value is reduced, increasing the consumption of the fuel. [17] further states that the presence of a high moisture content generates environmental pollution due to the increased volume of combustion products and particulate matter, not to mention that the corrosion process is accelerated at the final part of the steam generator and accumulation of dirt on the heating surfaces.

As the elephant grass matured, there was a decrease in the cellular content and an increase in the constituents of the cell wall, which directly reflected the DM content and fiber, a characteristic inherent to the genotype, occurring normally and in a desirable way for the production of energy biomass.

Table 3: Dry matter (DM), acid detergent fiber (ADF), neutral detergent fiber (NDF) and hemicellulose (HEM) in energetic elephant grass genotypes at 6 months age in the dry season and rainy season of the second year of cultivation (2017-2018).

Genotype	DM (%)		ADF (%)		NDF (%)		HEM (%)	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
CNPGL 93-41-1	41.30bA	29.43aB	46.68aA	41.39aB	75.00aA	75.55aA	28.33aA	34.00aA
CNPGL 91-25-1	44.44bA	26.66aB	44.40aA	40.86aA	71.38aA	71.93aA	27.00aA	31.33aA
Taiwan A25	54.34aA	37.10aB	47.11aA	38.65aB	74.27aA	74.56aA	27.00aB	36.00aA
Cuba 116	40.51bA	35.64aA	45.76aA	40.50aB	74.35aA	75.97aA	28.67aA	35.67aA
Mercker	45.76bA	33.31aB	46.55aA	39.42aB	71.50aA	74.35aA	25.00aB	35.00aA
Cameroon	43.42bA	31.34aB	44.49aA	39.93aB	73.22aA	75.87aA	29.00aA	35.67aA
Piracicaba 241	49.21aA	28.71aB	45.26aA	40.37aB	71.33aA	75.58aA	26.00aB	35.33aA
Vrukwona	42.84bA	33.37aB	44.12aA	40.67aA	70.01aB	75.71aA	25.67aB	35.00aA
Napier	46.35bA	31.33aB	42.40aA	40.09aA	74.83aA	72.11aA	32.67aA	32.00aA
Porto Rico	50.42aA	31.83aB	44.03aA	40.07aA	69.01aB	75.12aA	25.00aB	35.00aA
Guaçu	51.50aA	33.68aB	44.87aA	39.91aB	74.02aA	76.36aA	29.00aB	36.33aA
Cubano Pinda	47.51aA	29.63aB	47.79aA	39.19aB	73.83aA	76.61aA	26.00aB	37.67aA
BRS Canará	44.42bA	36.13aB	46.28aA	38.33aB	74.13aA	72.93aA	27.67aA	34.67aA

Average	39.24	42.66	73.83	31.18
CV (a) (%)	8.45	4.97	4.46	13.54
CV (b) (%)	9.71	6.04	4.33	13.73

CV (a) (%): Coefficient of variation of plot; CV (b) (%): Coefficient of variation of the subplot.

Averages followed by the same letter, lowercase vertical and uppercase horizontal do not differ from each other by the Scott Knott test at 5%.

In terms of the process of conversion of biomass into fuel, specifically in gasification, [18] observed that a high moisture content does not generate technical difficulties in gasification, but a lower efficiency of the process, because the energy needed to evaporate the water and maintain the operating temperature is obtained by feeding more fuel and oxidant.

One way to raise the dry matter content of elephant grass biomass is to pre-dry in full sun under tarpaulins or on cemented soil, similar to that which was performed by [19] to produce chopped elephant grass hay.

The ADF content is an important component to be evaluated, being directly linked to the calorific power of the biomass. The constituents of the cell wall vary according to the different plant species and their proportion depends on the genotype, in addition, in the literature it is reported an increase in the DM content and the fibrous fractions due to advancement of elephant grass age [19], [20] consider ADF values above 40% acceptable [21].

Comparing both seasons (dry and rainy), in the first year of cultivation (Table 2), there was no difference between the genotypes (P > .05), except for CNPGL 93-41-1 that obtained higher ADF content at dry season (55.85%). Within the seasons, there were no differences between the genotypes, presenting an average content of 52.02%.

In the second year of cultivation (Table 3), there was a reduction in the average level of ADF compared to the first year (42.66%). When comparing both seasons, all genotypes obtained a higher content of ADF in the dry season, which is desirable for biomass destined for combustion, with the exception of Napier, Vrukwona and Porto Rico genotypes (P > .05).

The obtained values were close to those found by [22], which, as in this study, did not find a significant difference (P > .05) among the genotypes. These authors found an ADF average of 44.07% in the leaf and 53.44% of ADF in stem of elephant grass genotypes at six months of age and affirm that from this age elephant grass plants will never present levels of less than 50%.

The increase in the NDF content represents the fractions of greater interest in the pyrolysis, which are attributed by the cell wall thickening, besides the greater participation of stem due to the long cut interval (180 days). The NDF has relevance in the energy production by the direct effect on calorific power [23], resulting in less generation of ashes [24].

In the first year of cultivation, there was no difference between the genotypes within each season (P > .05), and comparing the seasons, only Cuba 116 had the highest NDF content (P > .05) during the rainy season (81.24%) (Table 2). In the second year of cultivation, when comparing the seasons, the genotypes Vrukwona and Porto Rico had higher NDF (P > .05) rainy season, with 75.71 and 75.12%, respectively (Table 3).

For the production of biomass for energy use, the higher NDF content, better is the biomass quality. [25] and [26] found an increase in NDF according to elephant grass age, during the cycles of 12, 16 and 24 weeks, the fiber content was 70.03; 78.65 and 79.41%, consistent with the age of 6 months used in the present experiment.

In the first year of cultivation, comparing both seasons (dry and rainy), most of the genotypes had the same hemicellulose content (P > .05), except for the genotype CNPGL 93-41-1 that obtained lower hemicellulose content in the dry period (21.33%). When evaluating the behavior of the genotypes within the seasons, there was no difference in hemicellulose content and the average was 24.81% (Table 2).

[27], studying elephant grass for direct combustion, did not observe differences (P > .05) in the percentage of hemicellulose among 62 genotypes of the Napier and Cameroon groups, which had an average content of 27.0%, very close to found in the present work.

In the second year of cultivation (Table 3), comparing both seasons (dry and rainy), the genotypes Taiwan A 25, Mercker, Piracicaba 241, Vrukwona, Porto Rico, Guaçu and Cubano Pinda obtained lower HEM content (P > .05) during the dry season.

[28], analyzing the HEM content of the stem fraction of 8 elephant grass genotypes at 6 months age, showed a variation from 33.8 to 38.4%. The authors concluded that the variation in the content of hemicellulose and other chemical compounds that compose the biomass are

dependent on the conditions of the environment in which they were produced, such as rainy and dry season of this study, besides the temperature, soil condition and crop cycle.

For direct combustion, HEM is less relevant when compared to the other fibrous fractions of elephant grass biomass, due to low thermal stability and lower activation energy [29]. This fraction has importance along with cellulose in the production of alcohol of second generation [30], in addition to coproducts produced by biorefinery [31].

Elephant grass undergoes changes in its yield, morphological and chemical composition as its age is increased. In general, with the increase in the interval between harvest, protein, hemicellulose and biomass digestibility decreases, while fiber, lignin and cellulose, as well as productivity increases. Therefore, larger intervals between harvest should be adopted for use in energy production and smaller intervals for use in animal feed [32].

3.2 Volatile materials and fixed carbon content

The volatile matter (VM) content expresses the ease of burning the material and the fixed carbon (FC) content the burning speed of a material. Therefore, by knowing these two percentage indices, one can estimate the degree of combustion of a biomass and the time of burning of the same, thus maximizing the design of the project to obtain energy from vegetable biomass.

The VM content is that part of the biomass that evaporates as a gas (including moisture) by heating, that is, the volatile content is quantified by measuring the fraction of biomass that volatilizes during the heating of a standardized and previously dried sample. Thus, the VM content interferes with the ignition, because the higher the volatiles content, the higher the reactivity and consequently the ignition. Finally, it determines the ease with which a biomass burn.

For the VM content, comparing both seasons (dry and rainy), in the first year of cultivation (Table 4), the genotypes that presented the highest VM content ($P > .05$) were CNPGL 93-41-1, CNPGL 91-25-1, Mercker, Piracicaba, Napier, Guaçu and BRS Canará. Within the seasons, there were no differences ($P > .05$) between the genotypes and the average obtained was 93.04%.

Table 4: Volatile materials (VM) and fixed carbon (FC) contents of elephant grass genotypes at 6 months age in the dry season and in the first year of cultivation (2016-2017).

Genotypes	VM (%)		FC(%)	
	Dry	Rainy	Dry	Rainy
CNPGL 93-41-1	94.06 aA	92.07 aB	0.13 aA	0.11 aA
CNPGL 91-25-1	94.00 aA	91.20 aB	0.12 aA	0.12 aA
Taiwan A25	92.98 aA	92.17 aA	0.16 aA	0.07 aA
Cuba 116	93.31 aA	92.23 aA	0.17 aA	0.10 aA
Mercker	94.33 aA	92.29 aB	0.14 aA	0.10 aA
Cameroon	93.25 aA	92.08 aA	0.12 aA	0.10 aA
Piracicaba	93.82 aA	94.41 aB	0.10 aA	0.08 aA
Vrukwona	93.11 aA	92.33 aA	0.20 aA	0.09 aA
Napier	94.44 aA	92.53 aB	0.07 aA	0.11 aA
Porto Rico	94.04 aA	93.21 aA	0.08 aA	0.09 aA
Guaçu	94.34 aA	91.77 aB	0.08 aA	0.09 aA
Cubano Pinda	93.29 aA	92.69 aA	0.13 aA	0.07 aA
BRS Canará	94.64 aA	92.40 aB	0.09 aA	0.07 aA
Average	93.04		0.11	
CV (a) (%)	1.01		58.24	
CV (b) (%)	0.85		58.92	

CV (a) (%): Coefficient of variation of plot; CV (b) (%): Coefficient of variation of the subplot.

Averages followed by the same letter, lowercase vertical and uppercase horizontal do not differ from each other by the Scott Knott test at 5%.

Note in the second year of cultivation (Table 5), all genotypes showed higher VM content ($P > .05$) during the dry season. Within each season, there was no difference between the genotypes ($P > .05$) and the VM average was 90.79%. [33] found for the fractions of stem, leaf and whole plant of elephant grass, the respective values of 81.51; 79.06 and 85.17%.

Table 5: Volatile matters (VM) and fixed carbon (FC) contents of elephant grass genotypes at 6 months age in the dry season and in the second year of cultivation (2017-2018).

Genotype	VM (%)		FC (%)	
	Dry	Rainy	Dry	Rainy
CNPGL 93-41-1	94.70 aA	87.06 aB	0.08 aA	0.18 bA
CNPGL 91-25-1	92.53 aA	86.20 aB	0.16 aA	0.17 bA
Taiwan A25	93.50 aA	89.33 aB	0.10 aA	0.14 bA
Cuba 116	93.40 aA	87.22 aB	0.15 aA	0.10 bA
Mercker	94.35 aA	89.71 aB	0.15 aA	0.16 bA
Cameroon	92.90 aA	84.80 aB	0.12 aA	0.22 bA
Piracicaba	93.56 aA	88.94 aB	0.14 aB	0.33 aA
Vrukwona	93.62 aA	88.47 aB	0.14 aA	0.13 bA
Napier	94.52 aA	88.26 aB	0.12 aA	0.18 bA
Porto Rico	93.73 aA	88.99 aB	0.10 aA	0.15 bA
Guaçu	92.90 aA	88.29 aB	0.09 aB	0.19 bA
Cubano Pinda	92.19 aA	88.07 aB	0.13 aA	0.17 bA
BRS Canará	94.00 aA	89.23 aB	0.20 aA	0.28 bA
Average	90.79		0.16	
CV (a) (%)	2.00		38.20	
CV (b) (%)	2.21		37.31	

CV (a) (%): Coefficient of variation of plot; CV (b) (%): Coefficient of variation of the subplot.

Averages followed by the same letter, lowercase vertical and uppercase horizontal do not differ from each other by the Scott Knott test at 5%.

[34], evaluating the biomasses of elephant grass and vetiver grass for the production of briquettes, found an average VM content of 89.90 and 90.59%, respectively. According to them, when the biomass presents higher VM content and lower ash content, it will have a higher calorific value.

In general, elephant grass shows an energy potential due to the presence of high VM contents (average of 91.91%), which represents a greater ease of biomass burning, benefiting from the harvest age. [35], studying the energetic properties of elephant grass, verified VM levels of 64.8 and 68.3% in the harvest ages of 60 and 120 days, respectively. These VM values were lower than those obtained in the present study, since elephant grass was harvested younger (60 and 120 days), which is not interesting due to the higher moisture and ash contents in the biomass composition.

For FC content, there was no significant difference (P > .05) of genotypes between the seasons or within the seasons in the first year of cultivation, and the average obtained was 0.11% (Table 4). In the second year of cultivation, comparing both seasons, most of the genotypes did not present differences (P > .05), except for Piracicaba and Guaçu, which obtained higher FC content in the rainy season (Table 9). Otherwise, within the Piracicaba rainy season, it obtained a higher content of FC (P > .05) among genotypes with a value of 0.33%. [36], evaluating biomass from different agricultural residues, found FC contents of 2.39; 0.47 and 1.11% for rice husk, sugarcane bagasse and corn cob, respectively. [34] verified average FC content of elephant grass and vetiver grass the respective values of 0.70 and 0.71%. [33] obtained the FC value of 16.74; 16.94 and 8.49% for elephant grass, stem and whole plant fractions, respectively.

The content of FC establishes the amount of heat generated in the pyrolysis, and the higher this percentage the slower the fuel will burn [37]. The FC content obtained in the elephant grass genotypes of this work indicates that the biomass tends to burn faster, and the factors that accentuate this reaction are the low density of elephant grass in natura and the oxidant content in the work atmosphere. High oxygen contents in their morphological structure and/or low density are undesirable in the production of thermal energy due to the existing correlations between their elemental components (carbon, hydrogen and oxygen) and calorific power [38].

One way to solve this problem and to get better use for the biomass, the briquetting and pelleting of elephant grass have been widely used industrially because it promotes the increase of the energy density, that is, the greater amount of energy released per unit volume during the combustion of biomass [39]. Thus, the densification of the elephant grass biomass will convert in a fuel with higher calorific value, lower VM content, higher FC content, uniformity in shape and size, lower oxygen:carbon ratio and high DM content. [40] when comparing physical, chemical and bioenergetic properties of elephant grass pellets, obtained FC and VM contents respectively of 14.61 and 74.88%

Moreover, the thermal treatments (roasting and carbonization) improve even more quality and commercialization of the biomass since in addition to increasing the energy density, it decreases the moisture content, contributing to the quality of burning [40]; [41].

4. CONCLUSION

The elephant grass genotypes evaluated have great potential for energy production because they have a desirable content of dry matter, acid detergent fiber, neutral detergent fiber, hemicellulose and volatile materials.

Higher levels of dry matter, acid detergent fiber and volatile matter occur in the dry period of the year and in genotypes Mercker, Piracicaba 241, Guaçu, Cubano Pinda and BRS Canará genotypes.

COMPETING INTERESTS

We declare that no competing interests exist.

REFERENCES

1 CARVALHO, J. F. Fossil fuels and unsustainability. Cienc. Culto. São Paulo, v. 60, n. 3, p. 30-33, set. 2008. Portuguese

2 MONTI, A.; FAZIO, S.; LYCHNARAS, V.; SOLDATOS, P.; VENTURI, G. A full economic analysis of switchgrass under different scenarios in Italy estimated by BEE model. Biomass and Bioenergy, Rotterdam, v. 31, n. 4, p. 177-185, 2007.

3 FONTOURA, C.F.; BRANDÃO, L. E.; GOMES, L. L. Elephant grass biorefineries: towards a cleaner Brazilian energy matrix? Journal of Cleaner Production, v. 96, p. 85-93. 2015.

4 SOUZA, M. C. O.; CORAZZA, R. I. From Kyoto Protocol to Paris Agreement: An Analysis of Global Climate Regime Changes Based on a Study of the Evolution of Green Gases Emissions Profiles. Desenvolvimento Meio Ambiente, v. 42, p. 52-80, 2017. Portuguese

5 REIS, M. C., SABRINHO, S. F., RAMALHO, M. A. P., FERREIRA, D. F., LEDO, F. J. S., PEREIRA, A. V. Allohexaploid pearl millet x elephantgrass population potentential for a recurrente selection program. Pesquisa Agropecuária Brasileira, v.43, n. 2, p.195-199. 2008.

6 MARAFON, A. C.; SANTIAGO, A. D.; CAMARA, T. M.; RANGEL, J. H. A.; AMARAL, A. F. C.; LÊDO, F. J. S.; BIERHALS, A. N.; PAIVA, H. L. Production potential and quality of elephantgrass biomass for energy purposes. Aracaju: Embrapa Tabuleiros Costeiros, 2014. 6p. (Technical Circular) Portuguese

7 QUIRINO, W. F.; VALE, A. T.; ANDRADE, A. P. A.; ABREU, V. L. S.; AZEVEDO A.; C.; S. 2005. Calorific power of wood, materials, and ligno-cellulosic materials. Revista da Madeira,89, pp. 100-106. Portuguese

8 SEGUCHI, H. J. M.; VICENTE, N. G., MAZZARELLA, V. N. G.; FERREIRA, P. H.; KATAYAMA, M. T. Cost of production of elephantgrass and eucalyptus compacted in bripells and briquets, using solar and induced drying. Revista Brasileira de Energias Renováveis, v.6, n.2, p. 228-244, 2017. Portuguese

9 PEREIRA, A. V.; LÉDO, F. J. S.; MACHADO, J. C. BRS Kurumi and BRS Capiaçu - New elephant grass cultivars for grazing and cut-and-carry system. Crop Breeding and Applied Biotechnology, v. 17, p. 59-62, 2017.

10 ROCHA J. R. A. S. C.; MACHADO J. C, CARNEIRO P. C. S.; CARNEIRO J. C, RESENDE, M. D. V.; LEDÓ, F. J. S.; CARNEIRO, J. E. S. Bioenergetic potential and genetic diversity of elephantgrass via morpho-agronomic and biomass quality traits. Industrial Crops Production, v. 95, p.485-492, 2017.

11 RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ V., V. H. Recommendations for the use of correctives and fertilizers in Minas Gerais: 5th Approach. Viçosa: Comissão de Fertilidade do Solo do Estado de Minas Gerais - CFSEMG, 1999. Portuguese

12 SILVA, D.J.; QUEIROZ, A.C. Food analysis: chemical and biological methods. 3. ed. Viçosa: UFV, 2004. 235p. Portuguese

13 NOGUEIRA, M. F. M.; RENDEIRO, G. Biomass energy characterization. BARRETO, E. J. F. (Coord.). Combustion and gasification of solid biomass: energy solutions for the Amazon. Brasília: Ministério de Minas e Energia, 2008. p. 52-63. Portuguese

14 BANZATO, D. A.; KRONKA, S. N. Agricultural Experimentation. 2. ed. Jaboticabal: FUNEP, 1992. 247 p. Portuguese

15 ROSSI, D. A. Morphoagronomic evaluation and biomass quality of elephant grass (*Pennisetum purpureum* Schum.) accessions for energy purposes in northern Fluminense. 2010. 66p. (Dissertation) – Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes, Rio de Janeiro, 2010. Portuguese

16 CALEGARI, L. FOELKEL, C. E. B.; HASELEIN, C. R.; ANDRADE, J. L. S.; SILVEIRA P.; SANTINI, E. J. Characteristics of some biomass used in energy generation in southern Brazil. Biomass & Energy, v. 2, n.1, p. 37-46, 2005. Portuguese

17 BRAND, M. A. Forest biomass energy. Rio de Janeiro: Interciência, 2010. 131p. Portuguese.

18 HOFFMAN, B. S. Combined cycle with integrated gasification and CO_2 capture: a solution to mitigate CO_2 emissions from large-scale coal-fired energy plants in the short term? 2010. (Dissertation), UFRJ, Rio de Janeiro: 2010. Portuguese

19 FERREIRA, E. A.; ABREU, J. G.; MARTINEZ, J. C.; BRAZ, T. G. S.; FERREIRA, D. P. Cutting ages of elephant grass for chopped hay production. Pesquisa. Agropecuária Tropical, v. 48, n. 3, p. 245-253, 2018.

20 ROCHA J. R. A. S. C.; MACHADO J. C, CARNEIRO P. C. S.; CARNEIRO J. C, RESENDE, M. D. V.; PEREIRA, A. V.; CARNEIRO, J. E. S. Elephant grass ecotypes for bioenergy production via direct combustion of biomass. Industrial Crops and Products, v. 95, p. 27-32, 2017.

21 MCKENDRY, P. Energy production from biomass (part 1): overview of biomass. Bioresource Technology, Volume 83, Número 1, maio 2002, p. 37-46, 2002.

22 QUESADA, D. M.; BODDEY, R. M.; REIS, V.M.; URQUIAGA, S. Qualitative parameters elephant grass genotypes (*Pennisetum purpureum* Schum.) studied for the production of energy from biomass. Embrapa: Seropédia, 2004. (Technical Circular 8). Portuguese

23 MARAFON, A. C.; SANTIAGO, A. D.; CAMARA, T. M.; RANGEL, J. H. A.; AMARAL, A. F. C.; LÊDO, F. J. S.; BIERHALS, A. N.; PAIVA, H. L. Production potential and quality of elephantgrass biomass for energy purposes. Aracaju: Embrapa Tabuleiros Costeiros, 2014. 6p. (Technical Circular) Portuguese

24 MORAIS, R. F. Produtive potential and efficiency of the biological nitrogen fixation of five elephant grass (*Pennisetum purpureum* Schum.) genotypes for use as an alternative source of energy. 2008. 75 p. (Dissertation) - Universidade Federal Rural do Rio de Janeiro: Seropédica-RJ. 2008. Portuguese

25 FREITAS, R. S.; BARBÉ, T. C.; DAHER, R. F.; VIDAL, A. K. F.; STIDA, W. F.; SILVA, V. B.; MENEZES, B. R. S.; PEREIRA, A. V. Chemical composition and energy yield of elephantgrass biomass as function of five different production ages. Journal of Agricultural Science; v. 10, n. 1, p. 15-22, 2018.

26 VIDAL, A. K. F.; DAHER, R. F.; FREITAS, R. S.; STIDA, W. F. STIDA, MENEZES, B. R. da S.; PEREIRA, A. V.; da SILVA, V. B.; TARDIN, F. D.; OLIVEIRA, L. J. Estimative of genetic diversity in germ-plasm of elephant grass using the Gower algorithm. Genetic Molecular Research. 17(4). 2018.

27 ROCHA J. R. A. S. C.; MACHADO J. C, CARNEIRO P. C. S.; CARNEIRO J. C, RESENDE, M. D. V.; PEREIRA, A. V.; CARNEIRO, J. E. S. Elephant grass ecotypes for bioenergy production via direct combustion of biomass. Industrial Crops and Products, v. 95, p. 27-32, 2017.

28 RUEDA, J. A.; ORTEGA-JIMENEZ, E.; HENÁNDEZ-GARAY, A.; ENRÍQUE-QUIROZ, J. F.; GUERRERO-RODRÍGUEZ, J. D.; QUERO-CARRILO, A. R. Growth, yield, fiber content and lodging resistance in eight varieties of Q4 Cenchrus purpureus (Schumach.) Morrone intended as energy crop. Biomass and Bioenergy, p. 1-7. 2016.

29 CHEN, Z.; HU, M.; ZHU, X.; GUO, D.; LIU, S.; HU, Z.; XIAO, B.; WANG, J.; LAGHARI, M. Characteristics and kinetic study on pyrolysis of five lignocellulosic biomass via thermogravimetric analysis. Bioresource Technology, v. 192, p. 441–50, 2015.

30 SANTOS, C. C.; SOUZA, W.; SANT'ANNA, C.; BRIENZO, M.; Elephant grass leaves have lower recalcitrance to acid pretreatment than stems, with higher potential for ethanol production. Industrial. Crops & Products, v.111, p. 193-200, 2018.

31 FONTOURA, C.F.; BRANDÃO, L. E.; GOMES, L. L. Elephant grass biorefineries: towards a cleaner Brazilian energy matrix? Journal of Cleaner Production, v. 96, p. 85-93. 2015.

32 FLORES, R.; RILNER, A. F.; URQUIAGA, S.; ALVES, B. J. R.; COLLIER, L. S.; BODDEY, R. M. Yield and quality of elephant grass biomass produced in the cerrados region for bioenergy. Engenharia Agrícola, v.32, n.5, p.831-839, 2012.

33 MOHAMMED, I. Y.; ABAKR, Y. A.; KAZI, F. K.; YUSUP, S.; ALSHAREEF, I.; CHIN, S. A. Comprehensive characterization of Napier grass as a feedstock for thermochemical conversion. Energies, v. 8, 3403-3417. 2015.

34 TAVARES, S. R. L.; SANTOS, T. E. Use of diferente biomass sources fo the production of solid biofuels. HOLOS, v. 5, p.1-9, 2013. Portuguese

35 SALLES, F. A. Biomass of elephant grass and leucine for energy production. 2014. 62p. (Dissertation) – Universidade Estadual de Londrina, Londrina, 2014. Portuguese

36 VIEIRA, A. C. Characterization of biomass from agricultural waste. 2012. 72p. (Dissertation) – Universidade Oeste do Paraná, 2012. Portuguese

37 STURION, J.A; PEREIRA, J. C. D; CHEMIM, M.S; Quality of the wood *of Eucalyptus vimanalis* for energetic purposes according to the spacing and age of cut. Forest Research Bulletin, n. 16, p.55-59, 1988. Portuguese

38 PROTÁSIO, T. P., TRUGILHO, P. F., SIQUEIRA, H. F., MELO, I. C. N. A., ANDRADE, C. R., AND GUIMARÃES JR., J. B. Energetic characterization of in natura and torrified pellets produced with Pinus residual wood. Brazilian Forest Research, v. 35, n. 84, 435-442. 2015. Portuguese

39 MAGALHÃES, M. A.; DONATO, D. B.; CANAL, W. D.; CARNEIRO, A. C. O.; PEREIRA, B. L. C.; VITAL, B. R. Characterization of pellets produced from elephant grass for energy use.. Brazilian Journal of Wood Science, v. 7, n.3, p.155-162, 2016. Portuguese

40 GARCIA, D. P.; CARASCHI, J. C.; VENTORIM, G.; VIERA, F. H. A.; PROTÁSIO, T. P. Comparative energy properties of torrefied pellets in relation to pine and elephant grass pellets. Bioresources, v. 13, n. 2, p.2898-2906. 2018.

41 CHEN, W. H.; PENG, J.; BI, X. T. A state of the art review of biomass torrefaction, densification and applications. Renewable & Sustainable Energy Reviews. 44, 847- 866. 2015.

42 MANOUCHEHRINEJAD, M.; YUE, Y.; MORAIS, R. A. L.; SOUZA, L. M. O. Densification of Thermally Treated Energy Cane and Napier Grass. BioEnergy Research, v11, 3, 538–550. 2018.