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Agronomic and Energetic Potential of Biomass Sorghum Genotypes

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Abstract

The biomass sorghum [*Sorghum bicolor* (L.) Moench], is an interesting crop considering the necessity to invest in alternative sources to generate renewable energy. The objective of this experiment was to identify sorghum biomass genotypes with greatest agronomic and energetic potential, and verify if there is phenotypic association between agronomic and technological properties in the hybrids. The study was conducted in three cities of the Minas Gerais State, Brazil (Lavras, Uberlândia and Sete Lagoas). We evaluated 16 genotypes of sorghum biomass, being 14 of them sensitive hybrids to photoperiod and two cultivars, as control, insensitive to photoperiod. The experimental design was a triple lattice 4 × 4, with plots formed by four linear rows of 5.0 m. The morphoagronomic traits evaluated for the three environments were: days to flowering (FLOW), plant height (PH), number of stalks (NS) and green mass production (GMP). In the experiment conducted in Lavras, we also evaluated the agronomic traits: stalk diameter (SD) and dry mass production (DMP) besides the technological traits: higher heating value (HHV), crude fiber (CF), neutral detergent fiber (NDF) and acid detergent fiber (ADF). The genotype × environment interaction was significant for all traits. The hybrids had superior performance compared to the control genotypes. Biomass sorghum hybrids, sensitive to photoperiod, when compared with commercial hybrids of forage sorghum, insensitive to photoperiod, had an average production of 34 t ha^{-1} dry mass with 62% humidity and higher heating value of 4.400 Kcal/Kg. There was no phenotypic correlation between agronomic and technological traits evaluated.

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Keywords

***Sorghum bicolor*, Bioenergy, Alternative Source, Phenotypic Correlation**

1. Introduction

The rising demand for electric power in Brazil due to the demographic and industrial progress, associated with the concern for environmental issues, such as the impact of climatic changes in the energy production and supply, led to the creation of a Program for Stimulation of Alternative Sources of Electrical Power (Proinfa). This program aims to increase the use of renewable sources such as wind energy, biomass and small hydropower plants (PCH) in the National Interconnected Electric System (SIN), promoting the Brazilian energetic matrix diversification, ensuring the supply chain and enhance the local and regional potential for energy production.

Since then, there was a strong emphasis on plant resources for biomass. These species are cultivated to be used as raw material in the biofuel market, generating renewable energy.

In this context, the sorghum [*Sorghum bicolor* (L.) Moench], exemplifies an energy crop that has being studied for this purpose for a considerable time. In 1984, studies [1] highlighted desirable traits in this crop that made it a strong candidate to be one of the most used crops for energy generation. Nevertheless, only in the last decades a reasonable financial support has been applied in genetic breeding to the development of a specific hybrid with this purpose, called as biomass sorghum genotypes.

Among sorghum genotypes, the biomass-sorghum has the distinction of being sensitive to photoperiod, which means that it has a longer vegetative growing period and consequently greater production of green and dry mass. Furthermore, when compared to other potential biofuel crops, the sorghum stands out for meeting the market demands as: low implementation cost, short cycle, wide adaptability, mechanized management, low humidity and high calorific value in boilers. Thereby, the cultivation of energy crops such as biomass-sorghum becomes a great option for farmers, especially in areas with low suitability for food production, allowing the business diversification and increase of production.

Considering the breeding program to high biomass yield, several features are taken into account during the process of plant selection, but it is important to emphasize that the correlations between traits may have a positive or negative effect in the selection. Therefore, these correlations should be evaluated in order to help the breeder in the adoption of breeding strategies and contribute with the identification of ideotypes.

The estimation of correlations allows the evaluation of the response in a target trait when the selection is done considering another correlated trait, in other words, it is possible to select plants using traits of easy evaluation aiming to get increase in another trait which has a harder evaluation methodology or low heritability [2].

With this study we aim to identify biomass sorghum hybrid genotypes which present higher agronomic and energetic potential, and clarify the phenotypic correlations between agronomic and technological traits.

2. Material and Methods

2.1. Experimental Sites

Three experiments were conducted in Minas Gerais state during the crop season of 2013/2014. The first experiment was conducted in Lavras, from 11/29/2013 to 05/20/2014 at a Federal University of Lavras, in the Center for Scientific and Technological Development in Agriculture—"Muquém" Experimental Farm, located at 21˚14'S, 45˚00'W and altitude of 918 m, with annual average temperature of 19˚C and annual average rainfall of 1529.7 mm [3]. The second experiment was conducted in Sete Lagoas, from 11/21/2013 to 03/11/2014 at Embrapa Milho e Sorgo experimental area, located at 19˚27'S e 44˚14'49"W, with annual average temperature around 23˚C annual and average rainfall of 1403 mm [4]. The third experiment was conducted from 03/13/2014 to 06/26/2014 at "Capim Branco" farm in Uberlândia, located at 18˚56'56"S e 48˚12'21"W with annual average temperature of 22˚C and annual average rainfall of 1500 mm [4].

2.2. Experimental Planning and Conduction

The experiments were laid out in a 4 × 4 triple lattice design (**Figure 1**). The hybrids utilized in this study were

Replication1			
10	11	16	15
1	6	5	4
2	9	3	14
8	7	13	12

Replication 2			
10	1	2	8
11	6	9	7
16	5	3	13
15	4	14	12

Replication 3			
10	6	3	12
1	9	13	15
2	7	16	4
8	11	5	14

Figure 1. The experimental design, 4 × 4 triple lattice, with the 16 treatments.

from biomass sorghum breeding program of the Embrapa Maize and Sorghum, located in Sete Lagoas, Minas Gerais state, Brazil. From the 16 studied genotypes, 14 were photoperiod-sensitive hybrids (CMSXS7012, BRS716, CMSXS7016, CMSXS7021, CMSXS7022, CMSXS7023, CMSXS7024, CMSXS7025, CMSXS7026, CMSXS7027, CMSXS7028, CMSXS7029 CMSXS7030, CMSXS7031) and two cultivars photoperiod insensitive, used as control (VOLUMAX e BRS655).

The experimental plot consisted in four rows, 5 m long, 0.6 m between rows, considering the two central rows the effective area. The direct sowing was done since the no-tillage system was adopted. An early desiccation was performed with glyphosate (3 L ha^{-1}). The operation of pré-sowing soil preparation and the fertilization with NPK 08:28:16 (450 Kg ha^{-1}) was mechanized. Nevertheless, the seeds were sown by hand, with the sowing density of 8 plants/m. The thinning was done 20 days after the sowing, keeping 5 plants/m. The topdressing manuring was applied around 30 days after sowing and consisted of 200 kg/ha of urea.

2.3. Morpho-Agronomic and Technological Traits

The evaluated morpho-agronomic traits according to Parrella *et al.* [5], were: days to flowering (FLOW), number of days in which 50% of plants start the pollen liberation, plant height (PH), plant height average in each plot measured from the soil surface to the top of the panicle, stalk diameter (SD), measured with a digital caliper in the bottom of the steam from five random plants, average number of stalks in a linear meter (NS), number of plants in each effective row divided by the row length, total green mass production (GMP), determined in kg/plot weighing all plants from the effective plot area, harvested at the plant physiological maturity, total dry mass production (DMP), consisted in the GMP sample submitted to a drying process at 60˚C. The GMP and DMP data were converted to t ha^{-1}.

Regarding the experiments located at Sete Lagoas and Uberlândia the only features evaluated were: days to flowering, number of steams, plant height and green mass production.

The technological evaluations were performed just in the experiment located at the city of Lavras. After the plant material being harvested and stored in paper bags, the samples were submitted to a pre-drying process in an oven for 3 to 4 days at 60˚C. After that, it was milled and stored in plastic bags. The dry mass content (DM, %) was determined by drying the material in an oven at 105˚C until the samples achieve constant weight [6]. Based on the dry mass we determined the percentage of crude fiber (CF) using the Kjedal method, according to Silva [6], neutral detergent fiber (NDF), acid detergent fiber (ADF), according to Van Soest *et al.* [7], e higher heating value (HHV) measured by a calorimeter (Parr®), accordance with the ABNT directive 8633 [8].

2.4. Statistical Analysis

The data was submitted to analysis of variance considering deinterblocks information recovery using SAS software [9]. The experimental precision was measured by estimation of selective accuracy [10] and by the coefficient of environmental variation [11].

The adjusted phenotypic means were clustered by Scott-Knott test [12] at 5% significance level. We compute the Pearson's phenotypic correlations among measured traits. The statistical analysis was performed by GENES software [13].

3. Results

3.1. Sorghum Morpho-Agronomic Traits in Lavras, Sete Lagoas and Uberlândia

The range of variation among accuracy values was 23.80% considering number of steams at the experiment in Uberlandia and 97.67% regarding flowering (GMP) at the experiment in Sete Lagoas. The coefficient of variation presented low values for SD and PH (7.81%, 10.45%), medium values for FLOW and NS (13.96%, 17.84%) and high values for DMP and GMP (24.93%, 25.64%) (**Table 1**).

The analysis of variance for agronomic traits showed differences between environments and between genotypes for all evaluated traits with the exception for stalk diameter. The differences between environments reinforce the existence of environmental diversities, and between genotypes show the variability between them regarding the studied agronomic traits. The genotype × environment interaction was significant for all traits (**Table 1**).

Considering the GMP, FLOW, NS and PH it was possible to notice a different pattern among genotypes and superiority of the hybrids compared to the control. The mean values for GMP varied from 36.39 t ha^{-1} to 70.69 t ha^{-1}; considering the FLOW the means varied from 74.07 days to 128.12 days; to PH the minimum was 2.01 m and the maximum was 3.84 m and the NS varied from 6.27 to 9.01 (**Table 2**).

Due to the variation between environments and among evaluated genotypes we verify the formation of groups by Scott e Knott test [12] for the distinct environments. The green mass production and number of stalks were higher in Lavras, and the traits days to flowering and plant height were higher in Sete Lagoas and Lavras. The evaluated genotypes in Uberlândia had the smaller values for all evaluated traits, probably because it was cultivated off-season. The hybrids showing the highest GMP in each environments were: CMSXS7022, CMSXS7024 and CMSXS7016 in Lavras, presenting average production above 100 t ha^{-1}, CMSXS 7016 in Uberlândia, presenting average production around 51 t ha^{-1}, CMSXS 7016 and CMSXS 7024 in Sete Lagoas, with average production above 50 t ha^{-1} (**Table 3**).

There were no significant differences between genotypes for stalk diameter (SD), this trait was evaluated only in Lavras. The stalk diameter mean values were 21.7 mm for the control genotypes and 23.1 mm considering the hybrids (**Figure 2**). In relation to dry mass production, the genotypes may be grouped in two clusters. For this trait, the mean values varied from 13 t ha^{-1}, control genotype BRS655, to 47 t ha^{-1}, hybrid CMSXS7024 (**Figure 2**).

Despite the significant difference among genotypes for dry mass production, it is interesting to know the genotype with higher percentage of dry mass, in other words, the individual with lower water content. Such data is valuable when we consider a raw material with no demand for a pre-treatment, suitable for being used as a biofuel without any drying process. The genotypes with outstanding dry mass content were CMSXS7012, CMSXS7026 and CMSXS7023, presenting 42% of dry mass. Generally, the genotypes presented an average of 62% of water content (**Figure 2**).

3.2. Sorghum Technological Traits in Lavras

The experimental precision verified by the accuracy varied from 50.92% for CF, to 79.61% for ADF. The

Table 1. Analysis of variance for the agronomic traits: stalk diameter (SD) and dry mass production (DMP) in Lavras-MG and joint analysisof variance for the agronomic traits: plant height (PH), number of stalks (NS), green mass production (GMP) and days to flowering (FLOW) corresponding to the evaluation of biomass-sorghum genotypes in Lavras-MG, Sete Lagoas-MG and Uberlândia-MG during the crop season of 2013/2014.

SV(1)	DF(2)	F value					
		SD(3) (mm)	DMP(3) (t ha^{-1})	FLOW (days)	PH (m)	NS	GMP (t ha^{-1})
Environments	2	-	-	311.82**	164.17**	79.64**	128.07**
Genotypes	15	1.30	2.62*	6.2**	22.36**	2.77**	5.55**
Genotypes × environments	30	-	-	1.68*	3.00**	1.93*	2.4**
Effective error	63 (21#/20¨)	3.20	70.82	239.05	0.13	1.91	192.16
Minimum accuracy (%)		-	-	73.99	91.99	23.80	80.1
Maximum accuracy (%)		48.04	78.63	97.67	96.33	84.17	94.07
CV (%)		7.81	24.93	13.96	10.45	17.84	25.64

(1)Source of variation, (2)Degrees of freedom, (3)Agronomic traits evaluated only in Lavras-MG, #, ¨Degrees of freedom from SD e DMP, respectively, *, **Significant at 5% and 1% probability, respectively by F test, CV: Coefficient of Variation.

Table 2. Mean values fortotal green mass production (GMP), days to flowering (FLOW), plant height (PH) and number of stalks (NS) corresponding to the evaluation of biomass-sorghum genotypes in Lavras-MG, Sete Lagoas-MG and Uberlândia-MG, during the crop season of 2013/2014.

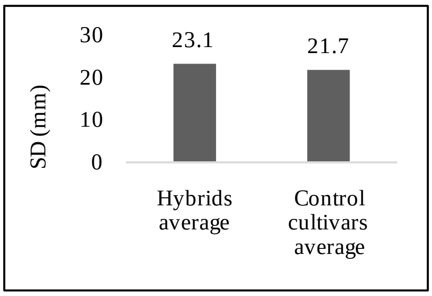
Genotypes	GMP (t ha^{-1})	FLOW (days)	PH (m)	NS
CMSXS7024	70.69 a	123.55 a	3.80 a	8.82 a
CMSXS7016	68.99 a	128.12 a	3.81 a	8.52 a
CMSXS7022	65.48 a	108.54 a	3.63 a	8.05 a
BRS716	61.77 a	116.14 a	3.84 a	7.70 a
CMSXS7025	59.91 a	111.85 a	3.82 a	8.14 a
CMSXS7029	58.93 a	113.81 a	3.49 b	8.17 a
CMSXS7030	58.65 a	115.50 a	3.46 b	6.83b
CMSXS7021	58.11 a	117.68 a	3.44 b	9.01 a
CMSXS7027	55.17 a	117.19 a	3.80 a	8.04 a
CMSXS7028	54.95 a	115.51 a	3.69 a	7.66 a
CMSXS 7012	48.60 b	113.55 a	3.57 a	6.27 b
CMSXS7023	47.38 b	107.99 a	3.67 a	6.87 b
CMSXS7026	41.29 b	108.19 a	3.26 b	8.22 a
CMSXS7031	41.08 b	110.72 a	3.18 b	7.03 b
BRS655	37.54 b	74.07 c	2.01 c	7.17 b
Volumax	36.39 b	89.35 b	2.12 c	7.42 b
Hybrids Mean	56.50 (1.41)¨	114.88 (1.41)	3.60 (0.04)	7.81 (0.13)
Control Mean	36.96 (3.35)	81.71 (3.66)	2.07 (0.09)	7.30 (0.33)

Means followed by the same letter in columns belong to the same group by Scott Knott test (1974), at 5% probability; ¨Standard deviations.

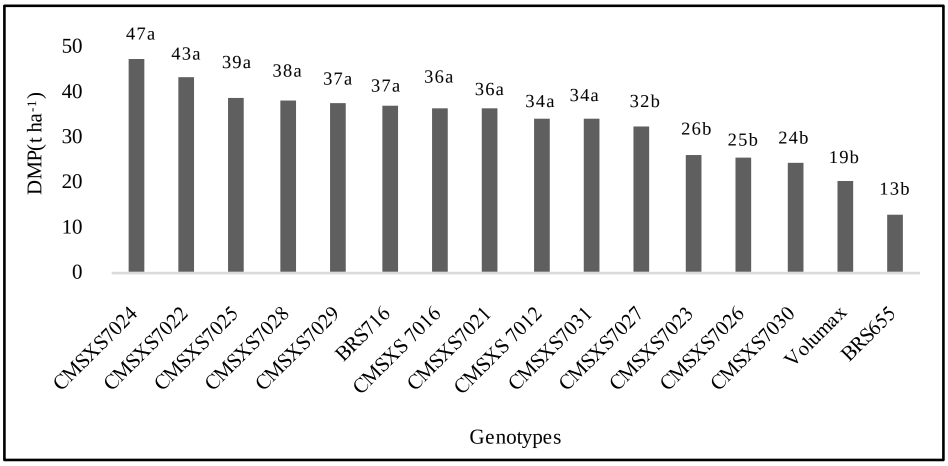
Table 3. Mean values of green mass production (GMP), days to flowering (FLOW), plant height (PH) and number of stalk (NS) corresponding to the evaluation of biomass-sorghum genotypes in Lavras-MG, Sete Lagoas-MG and Uberlândia-MG, during the crop season of 2013/2014.

Genotypes	GMP (t ha^{-1})			FLOW (days)			PH (m)			NS		
	LV	SL	UB	LV	SL	UB	LV	SL	UB	LV	SL	UB
CMSXS7022	124.28 a	35.23 a	36.93 a	149.98 a	107.32 b	68.32 a	4.58 a	3.66 b	2.66 a	11.71 a	6.29 a	6.14 a
CMSXS7024	120.82 a	51.98 a	39.26 a	145.76 a	157.59 a	67.31 a	4.59 a	4.50 a	2.30 a	12.66 a	8.08 a	5.73 a
CMSXS7016	101.73 b	53.93 a	51.30 a	147.71 a	165.64 a	70.99 a	4.29 a	4.31a	2.54 a	10.01 a	8.56 a	6.99 a
CMSXS7030	98.72 b	46.11 a	31.12 a	134.44 a	144.08 a	67.99 a	4.20 a	3.94 b	2.23 a	8.07 b	6.62 a	5.80 a
CMSXS7028	95.40 b	35.85 a	33.60 a	135.56 a	143.98 a	66.99 a	4.39 a	4.26 a	2.43 a	10.68 a	6.27 a	6.04 a
BRS716	93.87 b	44.42 a	47.01 a	145.00 a	138.37 a	65.03 a	4.37 a	4.58 a	2.57 a	10.01a	6.10 a	6.99 a
CMSXS7029	92.59 b	49.78 a	34.42 a	135.48 a	143.96 a	61.99 a	3.80 b	4.39 a	2.29 a	9.46 b	8.57 a	6.48 a
CMSXS7025	92.24 b	44.43 a	43.07 a	133.61 a	138.27 a	63.68 a	4.43 a	4.59 a	2.43 a	11.30 a	6.40 a	6.72 a
CMSXS7021	90.05 b	43.98 a	40.31 a	138.70 a	151.01 a	63.33 a	4.12 a	3.67 b	2.53 a	12.22 a	7.74 a	7.06 a
CMSXS7027	82.97 b	42.12 a	40.41 a	137.24 a	148.35 a	65.99 a	4.42 a	4.49 a	2.49 a	10.28 a	6.89 a	6.84 a
CMSXS7012	78.70 b	26.72 a	40.38 a	135.09 a	140.57 a	64.99 a	4.17 a	4.12 a	2.43 a	7.50 b	4.69 a	6.63 a
CMSXS7023	69.19 c	40.87 a	32.09 a	128.36 a	134.59 a	61.03 a	4.27 a	4.34 a	2.40 a	7.11 b	6.52 a	6.99 a
Volumax	56.51 c	22.79 a	29.85 a	114.70 b	93.05 b	60.31 a	2.62 c	2.00 c	1.75 b	8.89 b	6.38 a	6.99 a
CMSXS7026	56.29 c	33.39 a	34.20 a	131.99 a	130.92 a	61.67 a	3.99 b	3.39 b	2.39 a	10.99 a	7.27 a	6.41 a
BRS655	48.91 c	33.86 a	29.84 a	83.40 c	82.79 b	56.02 a	2.21 c	2.13 c	1.68 b	9.48 b	5.07 a	6.96 a
CMSXS7031	47.45 c	33.53 a	42.28 a	130.32 a	141.51 a	60.34 a	3.44 b	3.76 b	2.34 a	8.05 b	6.20 a	6.84 a

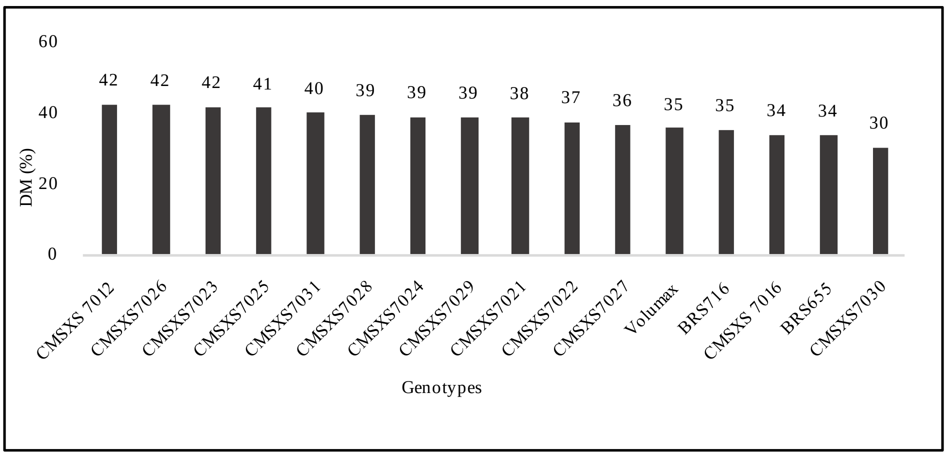
Means followed by the same letter in columns belong to the same group by Scott Knott test (1974), at 5% probability.



(a)



(b)



(c)

Figure 2. (a) General stalk diameter mean value (SD) from hybrids and control genotypes evaluated in the city of Lavras during the crop season of 2013/2014; (b) Mean values of dry mass production (DMP) considering each evaluated the city of Lavras during the crop season of 2013/2014, means with the same letter belong to the same group by Scott-Knott test (1974), at 5% probability; (c) Dry mass (DM) mean values considering the genotypes evaluated the city of Lavras during the crop season of 2013/2014.

coefficient of variation indicates high precision for all traits (below 20%). Considering the technological traits, we found differences among genotypes only for the acid detergent fiber (ADF) (**Table 4**).

The neutral detergent fiber mean value based on the control genotypes was 72.1% and for the hybrids it was 71.7%. Considering crude fiber it was 36.1% for the control genotypes and 36.6% for the hybrids. For ADF, Despite the analysis of variance indicates significant differences for ADF, it has not been possible to cluster the

Table 4. Summary of analysis of variancefor the technological traits: higher heating value (HHV), neutral detergent fiber (NDF), acid detergent fiber (ADF) e crude fiber (CB), corresponding to the evaluation of biomass-sorghum genotypes in Lavras-MG, Sete Lagoas-MG and Uberlândia-MG, during the crop season of 2013/2014.

		Mean squares			
FV	DF	HHV (Kcal/Kg)	NDF (%)	ADF (%)	CB (%)
Genotypes	15	2845.01	37.99	38.22*	11.6
Error	20	3262.67	17.31	13.98	8.57
Relative efficiency (%)		95	92.39	109.56	98.47
Accuracy (%)		-	73.85	79.61	50.92
CV (%)		1.30	5.80	7.99	8.02

genotypes in groups using the Scott-Knott test [12] at 5% probability. The mean values varied from 38.7% (CMSXS7026) to 51.9% (BRS716) (**Figure 3**).

3.3. Phenotypic Correlations between Morpho-Agronomic and Technological Traits

It was possible to detect significant differences for some of the analyzed combinations (GMP × DMP, GMP × NS, GMP × FLOW, GMP × PH, DMP × NS, DMP × FLOW, DMP × PH, FLOW × PH, CF × NDF, CF × ADF, ADF × NDF) suggesting that there is an association between variables (**Table 5**).

The highest positive correlation values were observed between GMP × DMP (0.9318) and FLOW × PH (0.9038). Despite the low correlation values presented between NS × DMP (0.5254) e NS × GMP (0.4984), it suggest a positive correlation. This correlation could be due to the genotypes sensitivity to photoperiod, which promote an increase in the vegetative cycle, leading to a increment in the amount of days to flowering and also in the other agronomic traits (NS, PH, DMP, GMP). The technological trait CF shows positive correlation in combination with NDF (0.8477) and ADF (0.880). The traits NDF and ADF also presented a high correlation among them (0.9418). We do not observed significant correlations between technological and agronomic traits for the evaluated genotypes.

4. Discussion

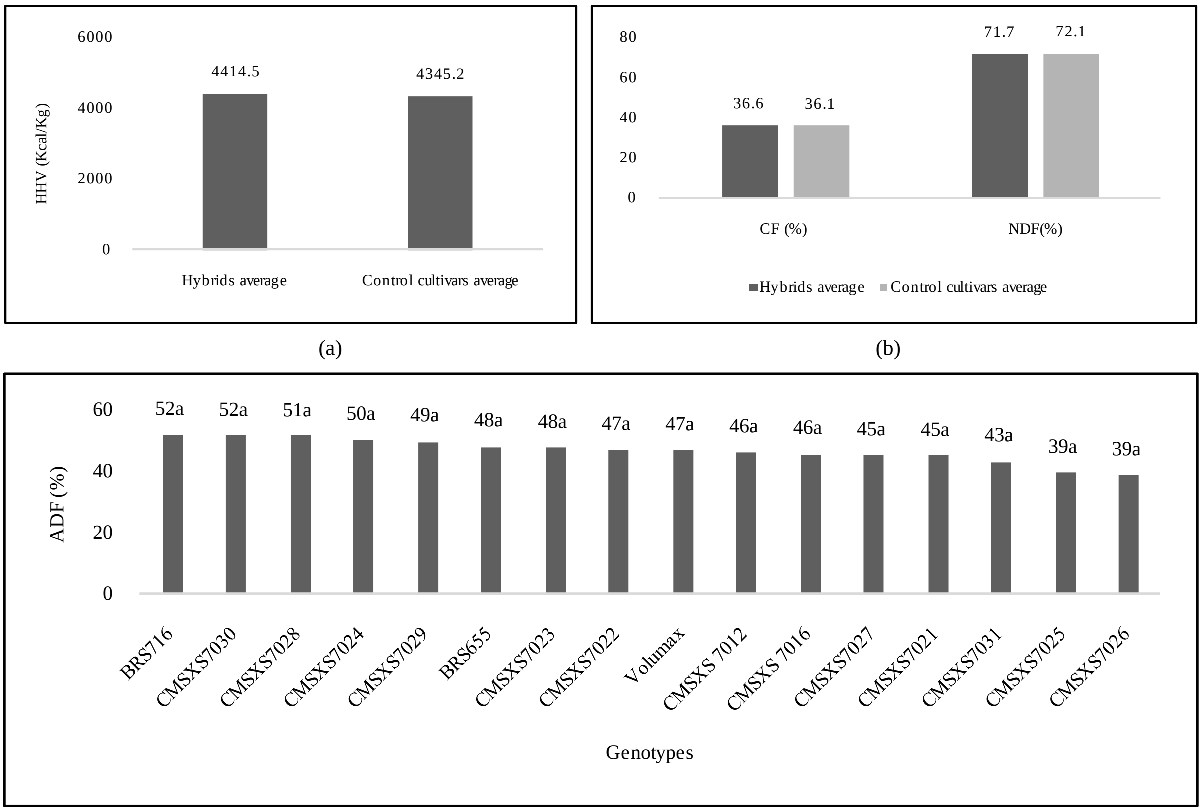
4.1. Morpho-Agronomic Traits

The sorghum breeding programs have been done aiming to develop hybrids with photoperiod sensitivity and dry mass production above 50 t ha^{-1}/cycle [5] [14]. Furthermore, other traits are also desirable for a biofuel crop, for example: low grain yield, resistance to lodging, low water content, biomass quality and others.

The field evaluation of distinct genotypes is recurrent activity in plant breeding programs. Nevertheless, for a successful selection procedure, the existence of genetic variation among individuals is strictly necessary. This fact can be verified observing the differences in the performance of hybrids used in this study, allowing the identification of the most suitable genotypes according to the performance related to those desirable traits (**Table 2**, **Table 3**).

Assuming the significant genotypes × environments interaction for the traits GMP, FLOW, NS and PH, the environment affect the genotypes pattern, it means that the genotypes have different performance for those traits in all evaluated environments.

According to Wight *et al*. [15], the plant height can be used as a useful indicator of dry mass production in sorghum hybrids sensitive to photoperiod. Since these individuals have a longer vegetative period, it favors the plant growth and consequently the green mass production. Nevertheless, very tall plants may increase the lodging index promoting losses. According to Parrella *et al*. [14], the height in sorghum plants is controlled by 4 main genes with two alleles each, with an additive effect, and the combination of alleles responsible for the phenotype (short, medium or tall). The same authors verified a variation in plant height from 2.72 m to 5.60 m in a study aiming to develop hybrids sensitive to photoperiod with high biomass production. Parrella *et al*. [5], evaluating the agronomic performance of biomass-sorghum hybrids, observed hybrid plants with height between 2.77 and 5.50 m, and sorghum varieties with plant height between 2.03 and 5.12, highlighting that, in general,



(c)

Figure 3. Mean values of technological traits: high heating value (HHV), neutral detergent fiber (NDF) and crude fiber (CF) for the control and hybrids genotypes evaluated in the city of Lavras during the crop season of 2013/2014 (a) (b), mean values of acid detergent fiber (ADF) presented by the genotypes evaluated in the city of Lavras during the crop season of 2013/2014, means with the same letter belong to a same group by the Scott-Knott test at 5% probability (c).

Table 5. Estimatives of Pearson phenotypic correlation coefficients (rf_{xy}) between the traits: plant height (PH), number of stalks (NS), green mass production (GMP), dry mass production (DMP), stalk diameter (SD), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude fiber (CF), days to flowering (FLOW) and higher heating value (HHV) evaluated in biomass-sorghum genotypes in the city of Lavras, Minas Gerais state, during the crop season of 2013/2014.

Traits	GMP	DMP	HHV	NDF	ADF	CF	FLOW	PH	SD
NS	0.4984*	0.5254*	−0.0413	−0.0884	−0.1481	−0.2689	0.3215	0.3248	−0.3796
GMP		0.9318**	0.0568	0.2134	0.2731	0.2786	0.8511**	0.7697**	−0.0619
DMP			0.2095	0.0257	0.0791	0.1239	0.8365**	0.7694**	−0.0273
HHV				−0.3551	−0.3703	−0.2722	−0.3305	−0.1716	−0.1047
NDF					0.9418**	0.8477**	0.0171	0.0854	−0.0644
ADF						0.8808**	0.0508	0.0300	−0.1623
CF							0.1940	0.1981	0.1019
FLOW								0.9038**	0.1956
PH									0.4292

the hybrids have a taller height comparing to the varieties, due to the heterosisor hybrid vigor, what is the increased vigor observed in a F1 comparing with the parents.

The trait NS has been related to the genotype capacity totillering. Since it was observed differences, it was possible to assume that the evaluated genotypes presents non similar tillering capacity. It is also appropriate to emphasize that this trait is strongly influenced by environmental factors, especially water availability. The highest average of NS were found in Lavras, where was found difference for NS, apparently the differences for tillering among genotypes seems to be caused by environmental and management factors, enabling some hybrids and control genotypes to present an outstanding performance (**Table 3**). Perazzo *et al*. [16], reported that the trait number of stalks per hectare represent the sorghum population per area unit and can be associated with dry mass production when evaluated together with stalk diameter and plant height.

When it is desired to produce biomass, an important feature that should be evaluated is the number of days to flowering (FLOW). This trait is directly related to the potential of green mass production and consequently dry mass, it means biomass. It was expected from genotypes that present more days to flowering to have higher GMP and DMP. Rooney e Aydin [17], highlighted that the flowering date depends on the date of sowing and the day length that varies according to the latitude and seasons. The experiments conducted in Lavras and Sete Lagoas (planted in November of 2013) had higher values of FLOW compared to the experiment in Uberlândia (planted in March of 2014), probably due to the differences in the period that the experiment stayed in the field and the different sowing dates. Such difference affect not only the FLOW, but also the traits GMP and PH that presented lower values in this environment (**Table 3**).

Parrella *et al*. [5] emphasize the sorghum classification regarding the sensitivity to photoperiod as sensitive or insensitive to photoperiod. The sensitive sorghum is a short-day plant, so its shoot apices stay in a vegetative stage until the day length becomes shorter than 12 hours and 20 minutes, this change stimulate the floral induction leading to flowering. This trait represents an advantage for biomass production, because it extend the vegetative cycle and consequently the biomass production per hectare/cycle when compared to long-day genotypes [5]. Murphy *et al*. [18] and Yang *et al*. [19], identified that the dominant alleles were responsible for the differences in the sensitivity to photoperiod and for the flowering timing among sorghum genotypes. Such alleles act delaying the period of flowering induction in the biomass-sorghum hybrids. The evaluated control genotypes in all environments presented early-cycle behavior compared to the other hybrids. Pereira *et al*. [20], reported that the forage sorghum cultivars, BRS655 and Volumax, insensitive to photoperiod have short-cycle (80 to 114 FLOW), reinforcing our results.

The green mass production can be considered as one of the most important traits to be evaluated in the desirable hybrids, it represent the general capacity of a hybrid to produce dry mass, in other words, biomass. Probably, the mean values obtained from some hybrids were higher depending on the experimental site due to the genetic and environmental variations. The distinct conditions favor the biomass production for well-adapted genotypes (**Table 3**). Pereira *et al*. [20] found in their studies that the green mass production of sorghum hybrids varied from 54.84 t ha^{-1} to 104.18 t ha^{-1}, and among varieties varied from 66.24 t ha^{-1} to 72.65 t ha^{-1}. The forage sorghum hybrids BRS655 and Volumax, presented GMP of 45.40 t ha^{-1} and 45.92 t ha^{-1}, considering that these cultivars are insensitive to photoperiod, they have shorter cycle and smaller height, consequently a lower yield value can be seen. Parrella *et al*. [14], reported a green mass production in biomass-sorghum hybrids that varied from 17.72 to 135.28 t ha^{-1}. Parrella *et al*. [5], in a previously mentioned study, found that the GMP varied from 32.45 t ha^{-1} to 161.62 t ha^{-1} considering hybrids and varied from 20.14 t ha^{-1} to 76.42 t ha^{-1} in varieties. Once again, it was possible to verify that in general, hybrids are more productive than varieties, due to the heterosis. According to Olson *et al*. [21], the higher biomass accumulation in hybrids can be attached to the longer vegetative period (photoperiod sensitive), higher leaf area index, higher radiation interception and greater efficiency of use of radiation (C4 plants).

Regarding the agronomic analyzes done in the experiment in Lavras, it was observed that there was no difference for the trait SD, that is very influenced by environmental factors. Durães *et al*. [22], they also found no variability for diameter between sweet sorghum genotypes. Monteiro *et al*. [23] suggest that the stalk diameter is a meaningful trait for the biomass production in forage sorghum, because not always a higher plant height provides the highest dry mass production, especially if it is not associated with a reasonable stalk diameter. Besides that, this trait is directly related to lodging, especially in case of genotypes with greater plant height. The yield of dry mass is a primary factor, because it generates an immediate response in biomass production, which is one of the major focuses for improving energy production. Silva *et al*. [24], report that the plant DM content are variable according to the genotype × environment interaction that affect the dry mass accumulation by the plant. According to Zago [25], the stalk is the portion of the plant that less contributes to raising the DM content, followed by leaves and panicle. Thereby, the increase of panicle participation in the physical structure of the plant becomes the major modification responsible for the change in the DM content, and consequently for the determination of harvesting time. Not all hybrids that have high green mass productions also presented high dry mass production, probably due to the components into the samples used to perform the DM calculation, because the samples may be together with plant parts that have not a great contribution to the increase of DM content, as reported early. Corroborating with the results obtained in the experiment, Parrella *et al*. [14], working with biomass-sorghum, found mean values of dry mass around 50 t ha^{-1}, and report that in general, such yields are higher than twice of the yield observed in the commercial forage sorghum cultivars available in the market.

4.2. Technological Traits

Besides the dry mass production, before recommending a material as good power generator is necessary to evaluate it and determine its calorific potential. The higher heating value is an important measure for the energetic evaluation of any fueland it was used to evaluate the performance of genotypes under test. When we are comparing the higher heating value obtained from the biomass-sorghum genotypes (4411.37 Kcal/Kg) with other materials that have the same finality as: maize stalk (4211.88 Kcal/Kg), sugarcane bagasse (4274.48 Kcal/Kg), coffee silver skin (4441.74 Kcal/Kg), bean stalk (4291.71 Kcal/Kg), soybean stalk (4504.25 Kcal/Kg), sawdust (4291.71 Kcal/Kg) [26], It is possible to assume that the sorghum biomass has a high calorific value, and thus it can be used to energy generation as a sustainable energy source.

An important fact needs to be observed, the water content in the harvest, so it can be burned without any drying treatment, because the humidity decreases the combustion temperature hindering the burning process. A high proportion of stalks can significantly increase the humidity of the material because they hold the majority of water content in the plant [27]. Therefore, it is necessary to evaluate carefully the plant condition at the harvest time, the environmental conditions, stalk proportion and genotype performance, so the collected material can be readily led to the boiler and have high caloric yields.

In the experiment conducted by Damasceno *et al*. [28], differences among genotypes were reported considering the NDF, showing values from 46.1% to 77.7%, and ADF values ranging from 25.7% to 52.5%. Neumann *et al*. [27], analyzing the proportion of cell wall constituents of stalk fraction, leaves and panicles from several sorghum hybrids, reported the existence of significant variation among genotypes regarding NDF and ADF. It was also reported that the results from the panicle compounds showed the lower FDN and FDA content when compared to stalk and leaves.

There was no significant difference among genotypes considering NDF and CF, suggesting that the evaluated genotypes have the same cell wall constituents regarding the three major compounds (hemicellulose, cellulose and lignin) measured by NDF, according to the described early.

4.3. Phenotypic Correlations

Many traits are taken into consideration to the hybrid selection. The use of correlations might have a positive or a negative effect in this process, but is considered as a useful auxiliary tool in genetic breeding programs.

The correlation estimative permit the behavior prediction of a trait when the selection is done over another trait correlated to it, in other words, allows the selection considering a trait of easy measuring, aiming to get increases in another of hard measuring method or low heritability [29].

It was observed significant positive correlations among the agronomic traits, suggesting that there is an important relation between GMP and DMP, such traits also presented a high correlation with the FLOW and PH, and medium correlation with NS (**Table 5**). This results indicate that breeding programs focused in the development of hybrids with higher values of FLOW, PH and NS will probably select individuals with higher green mass and dry mass production, as predicted before. Monk, Miller and Mcbee [1], studying the uses of correlation analysis, reported the existence of a significant and positive correlation between plant height and total biomass production in sorghum genotypes for energy production. According to Perazzo *et al*. [16], there was significant and positive correlation between DMP and GMP ($r = 0.87$), PH ($r = 0.61$) and NS ($r = 0.57$) considering 32 sorghum cultivars in the Brazilian semiarid region. This results show that the correlation between the sorghum genotypes cycle and the traits PH and GMP were presented in another experiments [30].

Considering the evaluated technological traits, a significant and positive correlation was also found between them, suggesting that the NDF and ADF are highly correlated with themselves and highly correlated with the trait CF, indicating that breeding programs focused in development of genotypes with high or low fiber content, during the selection for one of those traits will affect the others.

The lack of correlation between agronomic and technological traits could be occurred due to the non-interference of the agronomic traits on the composition of sorghum cell wall.

5. Conclusions

The biomass sorghum hybrids, sensitive to photoperiod, when compared to forage sorghum commercial hybrids, insensitive to photoperiod, present an average dry mass production of 34 t ha^{-1}, with 62% humidity and higher heating value of 4.400 Kcal/Kg. Thereby, it can be considered as a raw material with agronomic and energetic potential for bioenergy production.

The agronomic traits plant height, days to flowering and the number of stalks are correlated with the green mass accumulation and consequently dry mass accumulation.

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