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BIOLOGY

Agronomic performance, adaptability and stability of biomass sorghum genotypes in different regions of Brazil, using the Annicchiarico method

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ABSTRACT: This study assessed the agronomic performance and estimate the adaptability and stability of biomass sorghum genotypes in different regions of Brazil. Twenty-five sorghum genotypes were evaluated in experiments conducted in Goiânia (Goiás State-GO), Sobral (Ceará state-CE), Jaguariúna (São Paulo State-SP), Nova Porteirinha (Minas Gerais State-MG), Planaltina (GO), Sete Lagoas (MG), Narandiba (SP), Vilhena Rondônia State (RO) and Terra Rica (Paraná State-PR), in the 2021/2022 growing season. A randomized block design was used, with three repetitions. Pooled analysis of variance was conducted for the traits plant height, flowering, dry and fresh matter yield, and dry matter content. The adjusted means were grouped by the Scott-Knott test ($P < 0.05$). Adaptability and stability were evaluated using Annicchiarico's method. Biomass sorghum genotypes have a longer cycle, greater height and higher yields than their forage sorghum counterparts. The experimental hybrids 202129B014 and 202129B016 and commercial hybrid BRS 716 exhibited high dry and fresh matter yields, general adaptability and high stability for all the environments studied.
Key words: *Sorghum bicolor*, plant breeding, G-E interaction, forage, bioenergy.

Desempenho agronômico, adaptabilidade e estabilidade de genótipos de sorgo biomassa em diferentes regiões do Brasil, pelo método de Annicchiarico

RESUMO: O objetivo do presente estudo foi avaliar o desempenho agronômico e estimar a adaptabilidade e estabilidade de genótipos de sorgo biomassa em diferentes regiões brasileiras. Foram avaliados 25 genótipos de sorgo, conduzidos em Goiânia/GO, Sobral/CE, Jaguariúna/SP, Nova Porteirinha/MG, Planaltina/GO, Sete Lagoas/MG, Narandiba/SP, Vilhena/RO e Terra Rica/PR, na Safra 2021/2022. O delineamento experimental foi em blocos casualizados, com três repetições. Foram realizadas as análises de variância conjuntas para as características altura de plantas, florescimento, produtividade de matéria verde e matéria seca, e teor de matéria seca. Com os valores de médias ajustadas, foram obtidos os agrupamentos de médias pelo teste de Scott-Knott ($P < 0.05$). O método utilizado para avaliar a adaptabilidade e estabilidade foi o de Annicchiarico. Os genótipos de sorgo biomassa apresentam maior ciclo, bem como altura e produtividade de biomassa que os genótipos de sorgo forrageiro. Os híbridos experimentais 202129B014 e 202129B016, bem como o híbrido comercial BRS 716, apresentam alta produtividade de matéria verde e seca, adaptabilidade geral e alta estabilidade para todos os ambientes estudados.
Palavras-chave: *Sorghum bicolor*, melhoramento de plantas, interação GxA, forragem, bioenergia.

INTRODUCTION

In Brazil, biomass sorghum [*Sorghum bicolor* (L). Moench] is a raw material with considerable potential for use in biofuel production and energy cogeneration (MAY et al., 2016; DELGADO et al., 2019). As such, photoperiod-sensitive sorghum genotypes that only flower under photoperiods shorter than 12 hours and 20 minutes are desirable because they ensure greater biomass production throughout the cycle (PARRELLA et al., 2014; CASTRO et al., 2015).

Known as "biomass sorghum", in addition to its suitability for bioenergy production, recent studies have revealed its potential in producing large volumes of high-quality silage for ruminant livestock, replacing forage sorghum (RAMOS et al., 2021; ROSA et al., 2022; QUEIROZ et al., 2022). CASTRO et al. (2015) reported that the average fresh matter production of biomass sorghum genotypes was

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20 tones greater than that of forage cultivars, reaching yields up to 124 t ha^{-1}.

The Embrapa Maize and Sorghum breeding program conducts annual biomass sorghum value for cultivation and use (VCU) testing in different regions of the country to identify and select superior genotypes suitable for energy production and/or animal feed. Knowledge of genotype x environment (G-E) interaction is vital in releasing new biomass sorghum cultivars because it enables the selection of genotypes with production stability in a set of environments or adapted to a specific environment (DIAS et al., 2018). Assessing genotype adaptability and stability via ANNICCHIARICO's method (1992) facilitates the interpretation of G-E interaction using a recommendation index, which makes it possible to easily identify a group of superior genotypes in relation to their mean in each environment (CRUZ et al., 2014).In this respect, the present study assessed the agronomic performance and estimate the adaptability and stability of biomass sorghum genotypes in different Brazilian regions using ANNICCHIARICO's method (1992).

MATERIALS AND METHODS

Twenty-five biomass sorghum genotypes were evaluated, namely four commercial hybrids (two forage (BRS 658 and Volumax) and two biomass (BRS 716 and AGRI002-E) varieties) used as controls, and twenty-one experimental genotypes developed and selected by the Embrapa Maize and Sorghum breeding program.

The experiments were carried out in nine locations: Jaguariúna and Narandiba in São Paulo State (SP); Nova Porteirinha and Sete Lagoas in Minas Gerais State (MG); Sobral in Ceará State (CE); Terra Rica in Paraná State (PR); Vilhena in Rondônia State (RO); Goiânia in Goiás State (GO); and Planaltina in the Federal District (DF).

The experimental design in each environment was randomized blocks, with three repetitions. The plots consisted of two 5-meter-long rows, spaced 0.45 m apart in Terra Rica, 0.6 m in Vilhena and 0.7 m at the remaining sites. The density used was 5 plants per meter. Supplementary irrigation was performed throughout the cycle, using a conventional sprinkler system. Base and topdressing were carried out based on soil analyses and crop and pesticide treatments according to crop needs in each location. Experiments at all the sites were conducted in November and December 2021, except for Sobral (CE), where planting was performed in the second growing season (February/2022).

The following traits were assessed: average height of six competitive plants, measured from the ground to the tip of the panicle at harvest (PH); number of days from planting to the date on which 50% of plants in the plots displayed pollen-releasing flowers on the upper third of the panicle (FLOW); fresh matter yield (FMY), determined by weighing the shoots of all the plants in the plot, cut 10 cm above ground and collected at grain physiological maturity, with values converted into tones per hectare (t ha^{-1}); dry matter content in percentage (DM%), obtained by the ratio between the final weight of 0.5 kg fresh samples after drying in a forced air oven at 65 °C for 48 hours, and their initial weight before drying; and dry matter yield (DMY) in t ha^{-1}, obtained by multiplying FMY by % DM.

Due to the inherent difficulty of testing in multiple locations, some traits were not assessed at all sites, namely FLOW in Narandiba, Sete Lagoas and Terra Rica, and DMY and %DM in Goiânia, Narandiba, Terra Rica, and Vilhena.

Pooled analyses were conducted for the five traits in the different locations. The genetic-statistical model used was $Y_{ijk} = m + G_i + B/A_{jk} + A_j + GA_{ij} + E_{ijk}$, with genotype as the fixed effect and environment as the random effect, where Y_{ijk} is the observed value of the trait in the k^{th} block, in the j^{th} environment for the i^{th} genotype; m the overall mean; G_i the effect of the i^{th} genotype; B/A_{jk} the effect of the k^{th} block in the j^{th} environment; A_j the effect of the j^{th} environment; GA_{ij} the effect of interaction between the i^{th} genotype and the j^{th} environment; and E_{ijk} the experimental error. The adjusted means were grouped by the Scott-Knott test ($P < 0.05$). Pearson's correlation was performed to assess the phenotypic correlation between all the variables studied. Statistical analyses were carried out using GENES® statistical software (CRUZ, 2013).

Adaptability and stability were analyzed using the method proposed by ANNICCHIARICO (1992), which involves estimating a confidence index (W_i) for a given genotype in showing relatively superior behavior, whereby the higher the index, the greater the confidence in recommending the cultivar. Based on this method, the averages of each cultivar in each environment are transformed into an average percentage for the environment (Y_{ij}), followed by estimating the standard deviation (σ_i) and mean (Y_i) of the percentages for each cultivar (CRUZ et al., 2014). These estimates were used to calculate the confidence index as follows: $W_i = Y_i – Z_{(1-\alpha)}\sigma_i$, where $Z_{(1-\alpha)}$ = the value in standardized normal distribution at which the function reaches (1-α), with significance predetermined by the author at 0.25 (SCHMILDT et al., 2011). Agronomic performance and stability are measured simultaneously because the highest recommendation indices are obtained for the genotypes with the largest average percentage (Y_i) and lowest deviation σ_i. Thus, W_i expresses both adaptability and stability (CRUZ et al., 2014).

ANNICCHIARICO's method (1992) also makes it possible to obtain an environmental index, which measures the quality of the site and is the difference between the overall mean of an environment and that of all the environments. Thus, environments with a positive index are considered favorable and a negative index unfavorable (CRUZ et al., 2014; SILVA et al., 2016).

RESULTS AND DISCUSSION

Analysis of variance revealed that G-E interaction was significant for all the traits assessed at 1% significance (Table 1). These results indicated genetic variability between the sorghum genotypes investigated and the possibility of selecting genotypes of interest.

Most of the experimental genotypes analyzed exhibited a larger or similar average height than that of the photosensitive commercial controls AGRI002E and BRS716, with values greater than 4 m (except the genotypes CMSXS7200, CMSXS7500, CMSXS7501 and CMSXS7502). Some experimental hybrids were more than 5 m tall, such as 202129B006, which obtained the highest overall mean for this trait, with 5.44 m in Planaltina; 5.79 m in Sete Lagoas; 5.62 m in Nova Porteirinha; 5.63 m in Vilhena; and 5.77 m in Goiânia. PH is directly correlated with yield in biomass sorghum, facilitating indirect FMY and DMY selection and making it a highly relevant trait in selecting new cultivars (WIGHT et al., 2012).

In all the environments studied, the forage controls BRS 658 and Volumax were the smallest, with average heights of 2.49 and 2.39 m, respectively. This is likely due to their insensitivity to photoperiod, meaning that they flower when days are still long and their vegetative cycle ends early, making the plants smaller. Similarly to the present study, CASTRO et al. (2015) also reported that photoperiod-sensitive biomass hybrids were almost twice as tall as photoperiod-insensitive forage sorghum cultivars.

Hybrids with delayed flowering are desirable in terms of greater biomass production because they accumulate more biomass throughout the cycle (CASTRO et al., 2015). The number of days to flowering was evaluated in six locations. The latest genotypes were 202129B002, 202129B005, 202129B006, 202129B011, 202129B014, 202129B015, 202129B017, CMSXS7200, CMSXS7500 and CMSXS7501, which flowered an average of 120 days after planting (DAP) and were similar to the photoperiod-sensitive

Table 1 - Analysis of variance summary with the respective mean squares (MS), degrees of freedom (DOF), and estimated coefficients of variation (CV) for the traits flowering (FLOW, days), plant height (PH, meters), fresh matter yield (FMY, t ha^{-1}), dry matter yield (DMY, t ha^{-1}) and dry matter content (%DM) of biomass sorghum in VCU testing in the 2021/2022 growing season in nine locations.

CV	DOF[1/]	MS	DOF[2/]	---------------MS--------------		DOF[3/]	----------------MS----------------	
		FLOW		PH	FMY		DMY	%DM
Block/Env	12	9.59	18	0.24	3437.75	10	34.27	11.70
Block	2	12.56	2	0.17	2817.45	2	104.87	21.91
Block x Env	10	8.99	16	0.25	3515.28	8	16.62	9.14
Genotype (G)	24	5576.66**	24	14.28**	9191.48**	24	470.43**	90.62**
Environment (E)	5	34579.3**	8	27.34**	85462.85**	4	3776.30**	1854.32**
G x E	120	830.46**	192	0.47**	1272.00**	96	66.94**	41.88**
Residual	288	8.46	432	0.07	330.77	240	4485.86	2.96
Mean		115.18		4.23	78.74		21.20	30.80
CV (%)		2.52		6.20	23.10		20.39	5.59

*, **Significant according to the F test at 5 and 1% probability, respectively.[1/]Trait assessed in Nova Porteirinha, Planaltina, Sobral, Jaguariúna, Vilhena and Goiânia.[2/] Traits assessed in Nova Porteirinha, Planaltina, Sete Lagoas, Sobral, Narandiba, Jaguariúna, Goiânia, Terra Rica and Vilhena.[3/] Trait assessed in Planaltina, Sete Lagoas, Sobral, Jaguariúna and Nova Porteirinha.

commercial controls (BRS716 and AGRI002E). Of the locations investigated, Sobral exhibited the lowest number of days to flowering for the photoperiod-sensitive genotypes. At the remaining sites flowering in biomass sorghum occurred between 110 and 152 DAP, while in Sobral it varied from 72 to 80 DAP for the same genotypes. For the forage sorghum genotypes (BRS 658 and Volumax), flowering in Sobral occurred at 64 DAP.

Biomass sorghum is photoperiod sensitive, flowering only when days are less than 12 hours and 20 minutes long, which generally occurs between March and September in most of Brazil (PARRELA et al., 2014). However, when sorghum is planted from October to December, when days are longer than 12 hours and 20 minutes, flowering only begins on March 21 the following year, increasing its vegetative cycle and; consequently, height and biomass production, when compared to photoperiod insensitive cultivars (PARRELA et al., 2014). Short-day plants reduced their cycle in low latitude areas and as such, the early flowering observed in Sobral (CE) for the biomass sorghum genotypes is partly due to the low latitude of this location (3° 40′ 58″ S) in relation to the other sites and the planting time, which occurred in the off-season, in February.

Average FMY in the environments varied from 32.29 to 100.09 t ha^{-1} for the controls BRS 658 and BRS 716, respectively (Table 2). Of the experimental genotypes, hybrids 202129B006, 202129B007, 2021B014, 202129B015 and 202129B016 were among the most productive at all the locations studied, with overall means greater than 90 t ha^{-1}. The experimental genotypes 202129B006 and 202129B012 in Planaltina, 202129B006, 202129B008, 202129B014, 202129B016 and CMSXS7500 in Narandiba, and 202129B013 in Terra Rica obtained higher FMY values than those of the commercial biomass sorghum controls (BRS 716 and AGRI002E).

The highest FMY values were recorded in Goiânia (Table 2), with an overall mean of 150.83 t ha^{-1} and the largest yields obtained by the controls AGRI002E (211.48 t ha^{-1}) and BRS716 (205.62 t ha^{-1}) and the experimental hybrid 202129B005 (187.14 t ha^{-1}).The forage hybrids BRS 658 and Volumax obtained the lowest FMY. This can be justified by their insensitivity to photoperiod, which results in earlier flowering, generally within 60 to 70 days regardless of photoperiod. This early sorghum cycle produces smaller plants, negatively affecting FMY, behavior also observed by other authors in tests with photoperiod sensitive and insensitive sorghum (CASTRO et al., 2015; DELGADO et al., 2019).

Selecting biomass sorghum genotypes based on DMY is important because this variable is directly related to second generation ethanol production (DAHLBERG et al., 2011), silage production (ROSA et al., 2022), and energy cogeneration. Among the experimental genotypes, hybrids 202129B006, 202129B007, 202129B014, 202129B015, 202129B016 and 202129B017 obtained similar DMY values to those of the controls (BRS716 and AGRI002E) in most of the environments assessed (Table 3), with average values greater than 25 t ha^{-1}, reaching 28.50 t ha^{-1} for 202129B014.

The photoperiod sensitive biomass sorghum controls BRS716 and AGRI002E achieved the highest DMY values and the insensitive forage controls Volumax and BRS 658 the lowest (Table 3). MEKI et al. (2017) a decline of up to 76 % in dry biomass production in photoperiod-insensitive sorghum genotypes when compared to their sensitive counterparts. The DMY values recorded here were similar to those reported by DELGADO et al. (2019), with 17 to 25 t ha^{-1} for experimental biomass sorghum genotypes and 7 to 11 t ha^{-1} for the forage controls BRS 655 and Volumax, respectively.

In general, CMSXS7200, CMSXS7500, CMSXS7501 and CMSXS7502 obtained the lowest average FMY and DMY values. This can be justified by the genetic composition of these genotypes, which contain the bmr (brown midrib) gene. Sorghum bmr plants are mutants and phenotypically characterized by the brown leaf midrib and stem. Bmr genotypes are relevant in silage production due to their low lignin content and greater cell wall digestibility when compared to non-mutant sorghum plants, thus exhibiting better ruminal degradability (RODRIGUES et al., 2021). However, despite this agronomically interesting trait, bmr genotypes are inferior to normal sorghum plants, especially in terms of fresh and dry matter yield (AGUILAR et al., 2015).

Dry matter content is an important factor in using raw material to generate energy because raw material with a high moisture content demands additional energy expenditure to evaporate this water, thus reducing the efficiency of energy generation. Boilers in suspension-firing cogeneration systems, which use biomass as fuel, generally operate at moisture contents of up to 50 %. In silage production, high moisture contents compromise silage quality due to the multiplication of undesirable bacteria and wastewater production, while low dry matter levels hinder silage compaction and oxygen elimination, increasing the aerobic phase of the ensiling process, which is also not ideal (MACHADO et al., 2012). According to MARTINKOSKI & VOGEL (2013), the ideal dry matter

Table 2 - Decomposing of fresh matter yield (FMY), in ha^{-1}, in 25 sorghum genotypes assessed in nine locations in the 2021/2022 growing season.

Genotypes	--PLA--		---SL----		---NA----		----NP---		--VIL--		--JAG--		--SOB--		---GOI---		-----TR-----		Mean
202129B001	41.74	Cb	82.97	Ba	98.02	Bb	90.38	Ba	81.11	Ba	44.09	Ca	54.36	Ca	152.29	Ac	91.60	Bb	81.84
202129B002	40.63	Cb	60.23	Cb	134.32	Ab	59.05	Cb	76.11	Ba	41.22	Ca	44.84	Ca	154.45	Ac	89.85	Bb	77.86
202129B003	39.59	Cb	71.87	Bb	124.59	Ab	81.00	Ba	48.89	Cb	32.55	Ca	43.26	C	150.43	Ac	72.48	Bb	73.85
202129B004	44.92	Db	56.63	Db	128.04	Bb	75.05	Cb	85.56	Ca	44.65	Da	51.96	Da	176.10	Ab	112.67	Bb	86.17
202129B005	50.16	Db	54.20	Db	118.62	Bb	70.81	Cb	80.56	Ca	37.46	Da	43.57	Da	187.14	Aa	108.10	Bb	83.40
202129B006	102.70	Ba	100.40	Ba	163.11	Aa	99.57	B	88.89	Ba	35.19	C	43.36	Ca	179.33	Ab	38.87	Cc	94.60
202129B007	60.63	Db	90.17	Ca	107.74	Bb	111.81	Ba	80.56	Ca	45.76	Da	60.89	Da	159.10	Ab	98.22	Bb	90.54
202129B008	57.46	Db	93.15	Ca	159.69	Aa	59.00	Db	65.00	Da	39.42	Da	49.50	Da	125.48	Bd	86.71	Cb	81.71
202129B009	52.22	Cb	73.15	Cb	126.11	Ab	90.14	Ba	67.22	Ca	35.13	Ca	50.55	Ca	123.43	Ad	104.24	Bb	80.24
202129B010	52.38	Cb	92.38	Ba	121.29	Ab	92.76	Ba	70.00	C	40.37	Ca	48.75	Ca	145.86	A	92.84	Bb	84.07
202129B011	43.43	Db	101.21	Ba	110.93	Bb	95.90	Ba	81.11	C	34.27	Da	59.87	Da	164.33	Ab	83.34	Cb	86.04
202129B012	87.30	Ba	87.67	B	133.24	Ab	90.71	B	73.89	Ba	37.49	Ca	43.19	Ca	138.10	Ac	53.12	Cc	82.74
202129B013	51.90	Cb	77.93	Ca	128.47	Bb	62.14	Cb	59.44	Ca	34.81	Ca	43.62	Ca	119.86	Bd	197.00	Aa	86.13
202129B014	60.08	Db	111.28	Ca	141.28	Ba	114.38	Ca	76.67	Da	40.33	D	49.34	Da	172.81	Ab	103.55	Cb	96.63
202129B015	59.84	Db	108.61	Ca	127.45	Bb	102.19	Ca	91.67	Ca	39.47	Da	54.89	Da	159.00	Ab	92.86	Cb	92.89
202129B016	62.92	Cb	101.48	B	145.57	Aa	92.10	Ba	73.89	Ca	48.10	Ca	51.23	C	162.00	Ab	92.81	Bb	92.23
202129B017	49.62	Cb	81.05	Ba	134.00	Ab	91.43	Ba	81.11	Ba	58.52	Ca	61.92	Ca	142.48	Ac	94.52	Bb	88.29
CMSXS7200	25.08	Cb	51.20	Bb	128.13	Ab	58.62	Bb	-		22.42	C	44.01	Ba	71.62	Be	30.15	Cc	53.90
CMSXS7500	42.54	Cb	59.70	Bb	151.92	A	73.48	Bb	54.44	Bb	31.97	C	44.41	C	133.95	Ad	72.77	Bb	73.91
CMSXS7501	45.87	Cb	76.90	Ba	115.64	Ab	79.14	B	54.44	Cb	37.09	Ca	47.27	Ca	112.14	A	41.78	Cc	67.81
CMSXS7502	44.61	Cb	64.66	Cb	124.93	Ab	51.90	Cb	52.78	Cb	29.63	Ca	41.25	Ca	122.10	Ad	93.25	Bb	69.46
BRS716	60.98	Db	99.09	Ca	127.71	Bb	116.19	Ba	87.78	C	49.66	Da	62.57	Da	205.62	Aa	91.22	Cb	100.09
AGRI002E	44.00	Db	108.10	B	118.46	Bb	80.05	Ca	86.11	Ca	44.85	Da	53.27	Da	211.48	Aa	78.61	Cb	91.66
BRS658	20.79	Ab	32.14	Ab	58.77	Ac	33.60	Ac	22.22	Ac	24.68	Aa	25.72	Aa	-		40.44	Ac	32.29
Volumax	27.94	Ab	33.62	Ab	54.99	Ac	34.50	Ac	30.56	A	25.76	Aa	31.78	Aa	-		28.11	Ac	33.41
Mean(VCU)	50.77		78.79		123.32		80.24		69.58		38.20		48.22		150.83		83.56		79.27
Mean (GE)	53.12		80.80		129.67		82.93		72.17		38.57		49.14		145.33		88.13		82.11
Mean (T)	38.43		68.24		89.98		66.08		56.67		36.24		43.33		208.55		59.60		64.36

Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ according to the Scott-Knott test (1974) at 5 % probability.

content of silage is between 28 and 35%. The average dry matter levels (% DM) reported in the present study varied from 26 to 34% in the biomass sorghum genotypes and 25 to 30 % in the forage sorghum controls. The highest % DM values were recorded in Sete Lagoas for the genotypes AGRI002E, 202129B004 and 202129B005, with 40, 41 and 43%, respectively.

Correlation estimates make it possible to predict a trait when selection is based on another related trait. Thus, it allows the selection of an easily measured trait to achieve improvements in another that is difficult to measure or has low heritability (LOMBARDI et al., 2013). In our study, Pearson's correlation indicated positive and significant correlation coefficients for all the traits assessed (Table 4).

The strongest correlation observed for DMY was with FMY (Table 4). The correlation results obtained here demonstrate that biomass sorghum breeding programs for energy, biofuel or silage production focused on selecting high FMY genotypes will therefore select genotypes with high DMY production.

The G-E interaction observed in the present study for all the traits analyzed (Table 1) is a major challenge in the selection or recommendation of new cultivars. Alternatives to mitigate the effects of this interaction include recommending cultivars according to their response in each environment; however, the high costs involved makes this unfeasible for research institutions. Additionally, any unforeseen change in the environment may prevent cultivars from responding like more adapted varieties. Another option is to recommend cultivars with broad adaptability and high phenotypic stability to ensure a certain degree of predictable production (BARROS et al., 2010; MENEZES et al., 2015).

In the present study, FMY was considered the most important trait for superior genotype selection, since it was assessed in all the environments and

Table 3 - Decomposing interaction for dry matter yield (DMY) in t ha^{-1} for 25 sorghum genotypes assessed in four locations in the 2021/2022 growing season.

Genotypes	-------PLA------		--------SL--------		-------JAG------		-------SOB------		--------NP-------		Mean
202129B001	12.28	Cc	31.04	Ab	14.44	Ca	20.44	Bc	33.02	Ab	22,24
202129B002	12.26	Bc	21.72	Ac	15.99	Ba	22.28	Ac	22.28	Ac	18,91
202129B003	12.07	Cc	27.91	Ab	11.66	Ca	22.17	Bc	32.08	Ab	21,18
202129B004	14.67	Bc	22.88	Ac	15.10	Ba	20.45	Ac	28.42	Ab	20,30
202129B005	17.01	Bc	22.67	Ac	12.82	Ba	18.16	Bc	27.10	Ab	19,55
202129B006	30.68	Aa	38.41	Aa	11.26	Ca	21.08	Bc	33.59	Ab	27,00
202129B007	17.65	Cb	31.52	Bb	15.65	Ca	28.41	Bb	41.89	Aa	27,02
202129B008	16.06	Bb	33.54	Ab	12.03	Ba	15.78	Bd	19.75	Bc	19,43
202129B009	16.35	Bb	26.24	Ac	10.73	Ba	29.53	Ab	31.85	Ab	22,94
202129B010	15.32	Bb	32.59	Ab	12.33	Ba	25.17	Ab	30.43	Ab	23,17
202129B011	12.78	Cc	38.04	Aa	11.66	Ca	21.72	Bc	35.93	Aa	24,03
202129B012	25.40	Aa	31.88	Ab	13.44	Ba	25.30	Ab	30.96	Ab	25,40
202129B013	15.73	Bb	26.43	Ac	11.34	Ba	24.94	Ab	22.12	Ac	20,11
202129B014	19.11	Cb	40.14	Aa	14.60	Ca	29.52	Bb	39.11	Aa	28,50
202129B015	19.36	Bb	37.85	Aa	13.51	Ba	18.41	Bc	37.88	Aa	25,40
202129B016	20.36	Bb	36.45	Aa	15.19	Ba	30.29	Ab	32.17	Ab	26,89
202129B017	14.46	Cc	25.41	Bc	18.74	Ca	38.72	Aa	31.82	Ab	25,83
CMSXS7200	6.62	Bc	13.77	Ad	8.00	Ba	14.11	Ad	16.49	Ad	11,80
CMSXS7500	12.46	Bc	18.90	Ac	11.02	Ba	13.60	Bd	23.22	Ac	15,84
CMSXS7501	10.87	Bc	19.87	Ac	10.60	Ba	14.10	Bd	19.10	Ac	14,91
CMSXS7502	10.50	Bc	18.38	Ac	8.90	Ba	21.16	Ac	14.74	Ad	14,74
BRS716	18.87	Bb	33.76	Ab	17.24	Ba	37.44	Aa	40.28	Aa	29,52
AGRI002E	16.52	Cb	43.68	Aa	14.41	Ca	20.21	Cc	28.07	Bb	24,58
BRS658	5.96	Ac	11.65	Ad	7.33	Aa	10.99	Ad	13.36	Ad	9,86
Volumax	6.56	Bc	12.53	Bd	6.16	Ba	18.43	Ac	10.85	Bd	10,91
Mean (VCU)	15.20		27.89		12.57		22.50		27.86		21,20
Mean (GE)	15.81		28.36		12.81		22.64		28.76		21,68
Mean (T)	11.98		25.41		11.28		21.77		23.14		18,71

Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ according to the Scott-Knott test (1974) at 5% probability.

showed a high correlation with DMY. The adaptability and stability of the sorghum genotypes for this trait were measured using ANNICCHIARICO's method (1992). Adaptability is the potential ability of genotypes to take full advantage of environmental stimuli, while stability is their capacity to exhibit highly predictable behavior in the face of environmental changes (BORÉM & MIRANDA, 2009). As such, the better the adaptability of a genotype to specific environments and the greater its stability under environmental changes, the lower its selection risk.

In line with ANNICCHIARICO's method (1992), adaptability and stability were measured according to genotype superiority in relation to the average in each environment, based on an estimated confidence index (Wi). Thus, the most stable genotype for a given trait is that which obtains a higher-than-average value (Wi ≥ 100), that is, a response greater than or equal to the average for the cultivar. This method also enabled the identification of favorable and unfavorable environments by calculating the mean of each environment in relation to the overall mean (TAVARES et al., 2017).

Based on the environmental indices, which indicate the differences between the mean for the genotypes in each location and the overall mean of all the sites, the locations were classified as favorable (Sete Lagoas, Narandiba, Nova Porteirinha, Goiânia and Terra Rica) when the index was positive for FMY, and unfavorable (Planaltina, Vilhena, Jaguariúna and Sobral) when negative (ANNICCHIARICO, 1992).

Overall confidence indices and adaptability indices in favorable and unfavorable environments were

Table 4 - Pearson's correlation between the agronomic parameters of 25 sorghum genotypes assessed in 9 environments.

Trait	FMY	DMY	PH	FLOW	DM
FMY	1	0.9081**	0.9429**	0.8194**	0.5333**
DMY		1	0.8342**	0.5967**	0.4003*
PH			1	0.8486**	0.5546**
FLOW				1	0.4766*
% DM					1

*, **Significant at 5 and 1% probability, respectively.

obtained for all nine locations for FMY, using the overall mean confidence index (Wi ≥ 100). The recommendation index (Wi) revealed that the experimental hybrids 202129B007, 202129B014, 202129B015 and 202129B016 and commercial control BRS716 exhibited the best adaptability and stability for FMY considering all the environments studied. Genotypes 202129B014, 202129B015, 202129B016 and 202129B017 and the control BRS716 showed the greatest adaptability and stability in favorable environments, and 202129B007, 202129B010, 202129B014, 202129B016 and the control BRS716 for unfavorable environments (Table 5).

In general, the experimental hybrids 202129B014 and 202129B016 and commercial

Table 5 - Classification of adaptability and stability in the sorghum genotypes assessed, according to ANNICCHIARICO'S METHOD (1992), considering the mean Wi in favorable and unfavorable environments for fresh matter yield (FMY).2021/2022 growing season.

	---------------Overall---------------		--------------Favorable-------------		-----------Unfavorable----------	
Genotype	mean	Wi	mean	Wi	mean	Wi
202129B001	81.84	86.69	103.05	85.95	55.33	85.51
202129B002	77.86	76.04	99.58	71.46	50.70	79.20
202129B003	73.85	75.89	100.07	86.61	41.07	72.09
202129B004	86.17	81.35	109.70	73.60	56.77	88.85
202129B005	83.40	75.45	107.77	67.60	52.94	85.33
202129B006	94.60	65.49	116.26	64.96	67.53	62.15
202129B007	90.54	100.20	113.41	91.04	61.96	117.41
202129B008	81.71	82.82	104.80	74.75	52.85	95.62
202129B009	80.24	88.15	103.41	85.53	51.28	92.82
202129B010	84.07	98.69	109.03	99.50	52.87	101.12
202129B011	86.04	86.70	111.14	90.96	54.67	79.09
202129B012	82.74	70.51	100.57	72.82	60.47	69.86
202129B013	86.13	46.33	117.08	37.01	47.44	85.42
202129B014	96.63	102.94	128.66	113.86	56.60	100.61
202129B015	92.89	101.85	118.02	101.31	61.47	99.94
202129B016	92.23	107.61	118.79	109.38	59.04	104.23
202129B017	88.29	93.99	108.69	101.35	62.79	95.97
CMSXS7200	47.91	19.73	67.94	33.36	22.88	1.50
CMSXS7500	73.91	73.00	98.36	72.28	43.34	79.29
CMSXS7501	67.81	67.48	85.12	58.08	46.17	81.97
CMSXS7502	69.46	68.97	91.37	66.45	42.07	76.12
BRS716	100.09	108.21	127.96	100.43	65.25	121.18
AGRI002E	91.66	85.30	119.34	81.34	57.06	88.03
BRS658	28.71	18.36	32.99	9.81	23.35	30.38
Volumax	29.69	18.62	30.24	8.69	29.01	45.52

hybrid BRS 716 are the most promising for future recommendations in the nine locations assessed due to their overall adaptability and adaptability to favorable and unfavorable environments for FMY (Table 5). This genotypes also exhibited high stability.

CONCLUSION

Of the biomass sorghum genotypes assessed, the experimental hybrids 202129B014 and 202129B016 and commercial hybrid BRS 716 exhibited high yield, broad adaptability and high stability for fresh matter production and therefore present a low recommendation risk, according to ANNICCHIARICO'S METHOD (1992), for the locations studied.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTIONS

All the authors contributed equally to the manuscript.

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