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CHEMICAL AND ENERGETIC CHARACTERISTICS OF AFRICAN SWEET SORGHUM AS A SOURCE OF BIOENERGY

José C. Caraschi[1], Ronaldo da S. Viana[2], Bruno R. de A. Moreira[2], Glaucia A. Prates[3*]

[3*]Corresponding author. Universidade Estadual Paulista - UNESP/ Itapeva - SP , Brasil.
E-mail: g.prates@unesp.br | ORCID ID: https://orcid.org/0000-0002-8916-3441

KEYWORDS

Green Energy, Bioenergy, Biofuel, Renewable energy.

ABSTRACT

The aim of this study was to evaluate the energetic potential achieved by the application of phyto-regulators to sweet sorghum cultivars. A randomized complete block design was used. Experiments were conducted using two sweet sorghum cultivars (BRS 508 and BRS 509), four phyto-regulators (ethephon, ethyl-trinexapac, glyphosate, and sulfometuron-methyl), and a control; four replicates were performed 70 days after sowing, at the beginning of the flowering phase of the plants, with the aid of a CO_2-pressurized coastal sprayer. The plants were harvested after 40 days, with the stems being cleared at the height of the apical bud, and were subjected to grinding for the extraction of broth. The following analyses were carried out: chemical (total extractives, lignin, and holocellulose contents), proximate (volatile matter, fixed carbon, and ash contents), and energetic (higher heating value). Multiple comparison (Tukey) and linear correlation (Pearson) analyses were carried out at a 5% significance level. The phyto-regulators positively and significantly influenced the chemical attributes and contents of lignin and fixed carbon. It was concluded that glyphosate, sulfometuron-methyl, and ethephon enhanced the biomass/bioenergy potential of sweet sorghum cultivars.

INTRODUCTION

Originating from the African continent, the genus *Sorghum* spp. (sorghum) tolerates water deficit and is extremely adaptable to tropical climatic conditions. In addition, the genus is rustic and exhibits high photosynthetic rate and mechanization performance in all its agricultural processes. According to data from Companhia Nacional de Abastecimento (CONAB, Brasil, 2017), the production area of sorghum was 43 million ha worldwide in 2015/2016 and North America was the largest producer globally. The production of sorghum in Brazil reached 2 million tons during the 2016/2017 harvest year. Sorghum, grain, forage, grazing, biomass, and saccharin are fundamental to Brazil's agroeconomic scenario (May et al., 2016). However, rice straw, elephant grass, coffee, corn, coconut fibers, banana, and sisal rachis present high bioenergetic potential (García et al., 2015; Silva et al., 2015).

Sweet sugar broth is commonly used in the production of first-generation ethanol in the sugar energy and micro-distillery industries. Bagasse, straw, and sweet sorghum are partially used in the cellulosic ethanol industry and, occasionally, in the cogeneration of energy in the form of heat or bioelectricity. Therefore, in the absence of any immediate or predetermined application of biomass in the agricultural and/or industrial sectors, its physical volume must be strategically managed for subsequent use with increasingly sustainable technologies, thereby mitigating the negative impacts of the final disposal of waste on the environment (Paula et al., 2011; Faria et al., 2016).

Sorghum bagasse can be reused by means of briquetting, which is a densification technique that adds commercial, ecological, and social value to agroindustrial waste. Compared with wood, briquettes considerably reduce the need for expensive transportation, do not require direct mobilization of forest areas for the extraction of raw material, emit less amounts of greenhouse gases that are harmful to human and animal health, and are approximately five times denser (Amorim et al., 2015).

During their production cycles, agricultural crops undergo numerous quantitative and qualitative changes in their morphophysiological characteristics owing to the contiguous actions of biotic and abiotic factors, such as pests, diseases, weed competition, photoperiod, frost, and temperature and water regime including the timing and duration of cultural practices, such as the application of

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[1] Universidade Estadual Paulista - UNESP/ Itapeva - SP, Brasil.

[2] Instituição: Faculdade de Ciências Agrárias e Tecnológica, Universidade Estadual Paulista - UNESP/ Dracena - SP, Brasil.

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phyto-regulators, which can either improve or compromise the raw material quality, thereby directly influencing the energy potential of solid biofuels (May et al. 2016; Viana et al., 2016). Phyto-regulators are synthetic compounds that perform functions analogous to those of plant hormones; despite their benefits, phyto-regulators damage plant physiology and cause reductions in sucrose, lignin, and cellulose contents (Meschede et al. 2011; Viana et al., 2015; Muhwiridzwa et al., 2016).

In Brazil, phyto-regulators classified as inhibitors (glyphosate and sulfometuron-methyl) and retarders (ethephon and ethyl-trinexapac) have been used and tested mainly in sugarcane and sweet sorghum cultivations, and hence there is limited scientific information on the impact of these products on other crops of agronomic interest (Cesarin et al., 2016, Moreira et al., 2018).

The aim of the present study was to evaluate the energetic potential achieved by the application of phyto-regulators to sweet sorghum cultivars in terms of their influence on the chemical and energetic properties of the latter.

MATERIAL AND METHODS

The experiment was carried out at the Paulista Agency of Agribusiness Technology (APTA), Andradina, located in the northwest region of the state of São Paulo, Brazil, at the following geographical coordinates: latitude of 20º55'23"S, and longitude of 51°23'37"W. The characteristic climate of the region is Aw, according to the Köppen-Geiger classification, and the soil in the area is dystrophic red-yellow latosol. The seeds of the sweet sorghum cultivars, BRS 508 and BRS 509, were donated by Embrapa-Brazilian Agricultural Research Corporation, Ministry of Agriculture, Livestock, and Food Supply, Corn and Sorghum, located in the municipality of Sete Lagoas, state of Minas Gerais, Brazil.

A randomized complete block design was used: two sweet sorghum cultivars (BRS 508 and BRS 509), four phyto-regulators (ethephon, ethyl-trinexapac, glyphosate, and sulfometuron-methyl) and a control were employed, with four replicates being performed.

After the 70-day interval, at the beginning of the flowering phase of the sorghum cultivars BRS 508 and BRS 509, the phyto-regulators ethephon, ethyl-trinexapac, glyphosate, and sulfometuron-methyl were applied in dosages of $0.07\ L{\cdot}ha^{-1}$, $0.05\ L{\cdot}ha^{-1}$, $0.08\ L{\cdot}ha^{-1}$, and $0.02\ kg{\cdot}ha^{-1}$, respectively. The phyto-regulators were not applied to the control.

The applications were performed in the morning, from 8:00 a.m. to 11:00 a.m., at a temperature of 25°C ± 2.5°C and relative humidity of 70% ± 5%. The phyto-regulators were sprayed using a CO_2-pressurized sprayer with six flat nozzles (AXI-11002) spaced at intervals of 0.5 m along the spray boom (Viana et al., 2016). There was no subsequent rainfall.

Forty days after spraying, the cultivars were harvested from three central rows of the experimental plots. After the leaves were removed, the stems were cleared at the height of the apical bud and transported to the Caeté Plant, located in the municipality of Paulicéia, state of São Paulo, for the extraction of broth. The specimens were individually ground in a mechanical hydraulic press, and the bagasse was collected and stored in bags of low-density polyethylene for subsequent laboratory analysis.

Prior to the chemical analysis, the bagasse was defibrated and processed in a Wiley mill. The sawdust obtained was classified in overlapping sieves (40/60 mesh), according to TAPPI T 257 sp 14 (TAPPI, 2014).

The biomass specimens of the sweet sorghum cultivars, BRS 508 and BRS 509, treated with phyto-regulators, were characterized according to the following analyses: chemical analysis for total extractive content in accordance with TAPPI T 264 cm-87 (TAPPI, 2007), holocellulose content (sodium chlorite method), and lignin content according to TAPPI T 222 om-02 (TAPPI, 2011); proximate analysis for volatile matter content according to the ASTM E872 - 82 standard (ASTM, 2013), ash content according to the ASTM D1102 - 84 standard (ASTM, 2013), and fixed carbon content (determined as the difference between 100 and the sum of percentage moisture, ash, and volatile matter); and energetic analysis for higher heating value (HHV) according to the ASTM D5865 - 04 standard (ASTM, 2013).

The data set was submitted to inferential analysis: normality (Jarque-Bera), analysis of variance (Fisher), multiple comparisons (Tukey), and linear correlation (Pearson), each at the 5% significance level. In addition, the dispersion measures, such as mean and standard deviation, were determined. To interpret the magnitude of the correlation coefficient, Figueiredo Filho & Silva Junior (2010) suggested the following scores: $0.1 \leq r < 0.3$ (weak); $0.3 \leq r < 0.7$ (moderate); and $0.7 \leq r < 1.0$ (strong), in which "r" is the correlation coefficient. We adapted this methodology for more careful deductions, and employed the following stratified scores in the case of Pearson's correlation coefficient: $0.1 \leq r < 0.3$ (negligible); $0.3 \leq r < 0.5$ (weak); $0.5 \leq r < 0.7$ (median); $0.7 \leq r < 0.9$ (strong); and $0.9 \leq r < 1.0$ (very strong). The statistical software used was Software R version 3.3.1. (R Core Team, 2017).

RESULTS AND DISCUSSION

The results obtained in the chemical-energetic characterization of the biomass specimens of the sweet sorghum cultivars, BRS 508 and BRS 509, with and without the application of phyto-regulators are presented in Table 1.

TABLE 1. Chemical-energetic characterization of sweet sorghum biomass cultivars, BRS 508 and BRS 509, with and without application of phyto-regulators.

Analysis	Chemical[1] (%)			Proximate[2] (%)			Energetic[3] ($MJ \cdot kg^{-1}$)
	Lig	Hol	Ex	Ash	FC	VM	HHV
Cultivar	BRS 508						
Control	9.78	62.72	27.50	2.65	18.25	79.10	18.42
Glyphosate	14.95	68.12	16.93	2.96	19.60	77.44	18.62
Sulf.-methyl	15.71	57.03	27.26	3.35	19,04	77.61	18.61
Ethephon	10.12	52.62	37.26	2.60	18,29	79.11	18.57
Ethyl-trinexapac	11.20	59.80	29.00	2.65	18.27	79.08	18.50
Mean	12.35	60.06	27.59	2.84	18.69	78.47	18.54
Standard deviation	5.84	2.78	7.23	0.32	0.61	0.86	0.08
Cultivar	BRS 509						
Control	8.82	53.04	38.14	2.68	18.21	79.11	18.53
Glyphosate	12.83	59.64	27.53	2.81	20.26	76.93	18.70
Sulf.-methyl	13.57	57.20	29.23	2.84	19.76	77.40	18.54
Ethephon	10.67	52.94	36.39	2.74	19.49	77.77	18.56
Ethyl-trinexapac	12.14	58.25	29.61	2.87	18.22	78.91	18.51
Mean	11.61	56.21	32.18	2.79	19.19	78.02	18.57
Standard deviation	3.07	1.89	4.75	0.08	0.93	0.95	0.08

(1) Chemical composition: lignin content (Lig), holocellulose content (Hol), total extractive content (Ex); (2) Proximate analysis: ash content (Ash), fixed carbon content (FC), volatile matter content (VM); and (3) Energetic analysis: higher heating value (HHV).

The analysis of variance and multiple comparisons of the ash contents are presented in Table 2.

TABLE 2. Residual ash content (%) of sweet sorghum biomass cultivars, BRS 508 and BRS 509, managed with phyto-regulators.

Cultivar	Phyto-regulator						
	C	G	S-m	E	E-t	Mean	F Test
BRS 508	2.65 BC	2.96 B	3.35 aA	2.60 C	2.65 BC	2.84	12.38^{*}
BRS 509	2.68	2.81	2.84 b	2.74	2.87	2.79	0.76^{ns}
Mean	2.66	2.90	3.10	2.67	2.76		
F test	0.02^{ns}	1.44^{ns}	16.25^{*}	1.17^{ns}	2.99^{ns}		

F test phyto-regulator = 7.94^{*}

F test cultivar = 1.02^{ns}

F test phyto-regulator x cultivar = 5.21^{*}

Variation coefficient = 6.38

Mean values followed by the same letter in upper case in the row and in lower case in the column, do not differ, based on the Tukey test ($p < 0.05$); p-value = 0.24; *significant based on Fisher's test ($p < 0.05$); control (C), glyphosate (G), sulfometuron-methyl (S-m), ethephon (E), and ethyl-trinexapac (E-t).

At the cultivar level, the BRS 508 biomass treated with sulfometuron-methyl showed significantly higher ash content than that of BRS 509. There was no significant difference between the two cultivars in terms of other treatments.

As revealed by the analysis of variance, at the BRS 509 cultivar level, there was no rejection of the null hypothesis among the specimens treated with the phyto-regulators. However, the plants sprayed with ethyl-trinexapac, sulfometuron-methyl, glyphosate, and ethephon had, on average, 8%, 6%, 5%, and 3%, respectively, more residual ash compared to that of the control. Among the BRS 508 cultivar specimens, the use of sulfometuron-methyl increased the ash content of the raw material by 20% in comparison to that of the control, and this increase was statistically significant.

Excessive presence of ash in agroindustrial waste can promote corrosion and mechanical wear in equipment by abrasion as well as compromise the heat transfer zones of carbon steel metal sheets, especially in high-temperature furnaces, and this is even more critical when solid biofuels are derived from biomass with ash content exceeding 4% (Shenglei et al., 2014).

The applications of sulfometuron-methyl and glyphosate to BRS 508 and of ethyl-trinexapac to BRS 509 partially limited the energy generation potential of these raw materials, as these treatments were associated with the highest ash percentages of 3.35%, 2.96%, and 2.87%, respectively. The situation became even more restrictive in the case of the BRS 508 bagasse treated with sulfometuron-methyl, because, according to Gravalos et al. (2016), plant biomasses are considered suitable for the production of solid biofuels when their ash contents are less than 3% (Carvalho et al., 2015). The BRS 508 biomass treated with ethephon exhibited a lower percentage of ash mass, which legitimized the synergic effect of this phyto-regulator in terms of ash content.

The analysis of variance and multiple comparisons of the volatile matter contents of the specimens are presented in Table 3.

TABLE 3. Volatile matter content (%) of sweet sorghum biomass cultivars, BRS 508 and BRS 509, treated with phyto-regulators.

Cultivar	Phyto-regulator						
	C	G	S-m	E	E-t	Mean	F test
BRS 508	79.10 A	77.44 aB	77.60 B	79.11 aA	79.08 A	79.47	94.79^{*}
BRS 509	79.11 A	76.93 bC	77.40 B	77.77 bB	78.91 A	78.02	114.73^{*}
Mean	79.10	77.18	77.50	78.44	79.00		
F test	0.01^{ns}	16.56^{*}	2.54^{ns}	114.30^{*}	1.78^{ns}		

F test phyto-regulator = 191.23^{*}

F test cultivar = 62.04^{*}

F test phyto-regulator x cultivar = 18.29^{*}

Variation coefficient = 0.23

Mean values followed by the same letter, in upper case in the row and in lower case in the column, do not differ, based on the Tukey test ($p < 0.05$); p-value = 0.21; *significant or ^{ns}not significant based on Fisher's test ($p < 0.05$); control (C), glyphosate (G), sulfometuron-methyl (S-m), ethephon (E), and ethyl-trinexapac (E-t).

Among the BRS 508 cultivar specimens, those treated with ethephon and ethyl-trinexapac, as well as the control, exhibited the highest volatile matter content with no significant difference between them. By contrast, the biomass of the plants treated with sulfometuron-methyl and glyphosate were associated with lower volatile matter contents. All phyto-regulators barring ethephon reduced the volatile matter content of the feedstock; the reductions achieved by using ethyl-trinexapac, sulfometuron-methyl, and glyphosate were approximately 0.03%, 1.9%, and 2.1%, respectively, compared to the control.

Among the BRS 509 cultivar specimens, the plants treated with ethyl-trinexapac exhibited significantly higher volatile matter than those treated with ethephon, sulfometuron-methyl, and glyphosate. The applications of ethyl-trinexapac, ethephon, sulfometuron-methyl, and glyphosate promoted reductions of 0.25%, 2.16%, 1.70%, and 2.76%, respectively, in the volatile matter content of the bagasse compared to that of the control.

In evaluating the performance of the cultivars treated with the same phyto-regulators, no significant difference was found between the volatile matter contents of the control groups of the two cultivars. However, the BRS 508 plants treated with glyphosate and ethephon presented significantly higher volatile matter contents than those of the BRS 509 plants with identical treatments.

According to Brand (2010), the volatile matter contents of the main agricultural and forestry residues with the potential to generate renewable energy vary in the range 75–85%, and this authenticates the results obtained in the present study. According to Shenglei et al. (2014), the higher the volatile matter content, the lower the reactivity and ignition of the raw material. Therefore, the BRS 508 and BRS 509 plants submitted to glyphosate, sulfometuron-methyl, and ethephon applications showed the highest values of volatile matter content among all the specimens.

The analysis of variance and multiple comparisons of the fixed carbon contents of the specimens are presented in Table 4.

TABLE 4. Fixed carbon content (%) of sweet sorghum biomass cultivars, BRS 508 and BRS 509, managed with phyto-regulators.

Cultivar	Phyto-regulator						
	C	G	S-m	E	E-t	Mean	F test
BRS 508	18.25 B	19.60 bA	19.04 bA	18.29 bB	18.27 B	18.27	23.98*
BRS 509	18.21 C	20.26 aA	19.76 aB	19.49 aA	18.22 C	19.19	64.34*
Mean	18.23	19.93	19.40	18.89	18.24		
F test	0.03^{ns}	22.40*	18.94*	53.94*	0.10^{ns}		

F test phyto-regulator = 77.14*

F test cultivar = 50.72*

F test phyto-regulator x cultivar = 11.17*

Variation coefficient = 1.22

Mean values followed by the same letter, in upper case in the row and in lower case in the column, do not differ, based on the Tukey test ($p < 0.05$); p-value = 0.28; *significant or ^{ns}not significant based on Fisher's test ($p < 0.05$); control (C), glyphosate (G), sulfometuron-methyl (S-m), ethephon (E), and ethyl-trinexapac (E-t).

In the case of the BRS 508 cultivar, the bagasse from the plants submitted to sprays of glyphosate and sulfometuron-methyl showed significantly higher fixed carbon contents than those of the plants subjected to the other treatments, and the latter did not exhibit statistically significant differences. Compared to the control, the applications of glyphosate, sulfometuron-methyl, ethephon, and ethyl-trinexapac provided increases of 7.4%, 4.4%, 0.2%, and 0.2%, respectively, in the fixed carbon content of the biomass.

A similar trend was observed in the specimens of the BRS 509 cultivar, in which the fixed carbon content of the bagasse from the plants treated with glyphosate was significantly higher than those from the plants treated with sulfometuron-methyl, ethyl-trinexapac, and ethephon as well as the control. Compared to the control, the fixed carbon contents of the biomass of the BRS 509 cultivar specimens increased by 11.26%, 8.51%, 7.03%, and 0.05%, with the application of glyphosate, sulfometuron-methyl, ethephon, and ethyl-trinexapac, respectively.

In evaluating the performance of the cultivars treated with the same phyto-regulators, it was observed that the fixed carbon content of the BRS 509 bagasse was significantly higher than that of BRS 508 bagasse in the cases of applications of glyphosate, sulfometuron-methyl, and ethephon. The results obtained agree with the data presented by Brand (2010), Williams et al. (2012), Protásio et al. (2013), and Chen et al. (2015) who mention in their respective researches that the fixed carbon indices of agricultural and forest lignocellulosic residues are in the range 14–30%.

Given that biomass with higher fixed carbon content and lower concentration of volatile matter has a greater propensity to generate briquettes and pellets with higher heating value, the potential of glyphosate-treated BRS 509 sweet sorghum biomass, which is associated with higher fixed carbon content and lower volatile matter content, is validated.

The analysis of variance and multiple comparisons of the HHVs of the two cultivars are presented in Table 5.

TABLE 5. Higher heating value (MJ·kg^{-1}) of sweet sorghum biomass cultivars, BRS 508 and BRS 509, managed with phyto-regulators.

Cultivar	Phyto-regulator					
	C	G	S-m	E	E-t	Mean
BRS 508	18.42	18.62	18.61	18.57	18.50	18,55 b
BRS 509	18.53	18.70	18.54	18.56	18.51	18,65 a
Mean	18.49 B	18.68 A	18.66 A	18.64 A	18.52 B	

F test phyto-regulator = 77.14*

F test cultivar = 39.48*

F test phyto-regulator x cultivar = 1.38^{ns}

Variation coefficient = 0.26

Mean values followed by the same letter, in upper case in the row and in lower case in the column, do not differ based on the Tukey test ($p < 0.05$); p-value = 0.66; *significant or ^{ns}not significant based on Fisher's test ($p < 0.05$); control (C), glyphosate (G), sulfometuron-methyl (S-m), ethephon (E), and ethyl-trinexapac (E-t).

As indicated by the analysis of variance, there was no rejection of the null hypothesis at the level of interaction between the factors, with significant differences appearing only at the level of simple effects. The applications of the phyto-regulators, glyphosate, sulfometuron-methyl and ethephon, endowed the biomass of the cultivars with the highest values of HHV, and differed significantly from the treatments involving ethyl-trinexapac and the control, which were statistically indifferent. At the cultivar level, the HHV of the bagasse of BRS 509 was significantly higher than that of BRS 508.

To evaluate the energy potential of agricultural lignocellulosic residues for the production of briquettes and pellets, it is noteworthy that, on average, the biomass specimens presented HHVs in the range 17–18 $MJ \cdot kg^{-1}$.

Although there was no interaction between the factors, the phyto-regulators positively and significantly influenced the HHV of sweet sorghum bagasse, maintaining it above the international quality standard corresponding to 16.50 $MJ \cdot kg^{-1}$, as recommended by the ISO 17225-1 standard (ISO, 2014) for the production of briquettes and pellets from agricultural and forest residues. The results of the Pearson correlation matrix are presented in Table 6.

TABLE 6. Coefficients of linear associations between the chemical-energetic attributes of sweet sorghum biomass of BRS 508 and BRS 509 cultivars managed with phyto-regulators, aiming at energy production.

Parameter $^{(1)}$	Hol	Ext	ASH	VM	FC	HHV
Lig	0.44^{*}	-0.72^{*}	0.69^{*}	-0.70^{*}	0.54^{*}	0.42^{*}
Hol		-0.94^{*}	0.18^{ns}	-0.23^{ns}	0.17^{ns}	-0.14^{ns}
Ext			-0.39^{*}	0.44^{*}	-0.33^{*}	-0.04^{ns}
Ash				-0.45^{*}	0.18^{ns}	0.32^{ns}
VM					-0.96^{*}	-0.82^{*}
FC						0.82^{*}

*Significant and ^{ns}not significant, based on the Pearson test ($p < 0.05$); lignin (Lig), holocellulose (Hol), total extractives (Ex), ash (Ash), volatile matter (VM), fixed carbon (FC), higher heating value (HHV).

Among the most important associations was that of volatile matter content and HHV, which correlated negatively with a strong degree of linear association, indicating that the presence of volatile matter proportionally reduced the calorific values of the biomass of the BRS 508 and BRS 509 sorghum cultivars.

According to ISO 17225-1 (ISO, 2014), the biological basis of the inverse correlation between volatile material content and HHV is the fact that volatile materials are inert compounds, i.e., unlike fixed carbon, they do not actively participate in the combustion of plant biomass. These results, besides confirming the reports of Vinutha et al. (2014), justified the lower HHV values presented by the BRS 508 and BRS 509 controls, and the specimens treated with ethyl-trinexapac (BRS 508), ethephon (BRS 508), and ethyl-trinexapac (BRS 509), since these were associated with the highest volatile matter contents (Table 3).

The attributes, fixed carbon and HHV, exhibited a positive correlation with a strong degree of linear association, suggesting that the higher the mass percentage of organic carbon, the greater the energy potential of sorghum bagasse; this explains the significant energy yield of the bagasse of the BRS 509 cultivar submitted to the applications of glyphosate and ethephon.

Among the elemental components of biomass, i.e., lignin, holocellulose, and total extractives, only lignin showed a significant correlation with HHV, indicating that value of the raw materials of the cultivars increases with lignin content. It is believed that in comparison with cellulose and hemi-cellulose, lignin content increases the HHV of biomass (Demirbas, 2001; Jung et al., 2015) owing to the high contents of carbon and hydrogen atoms present in its molecular composition, since these are the main chemical elements responsible for the generation of energy. The nature of this correlation justified the highest values of HHV exhibited by the plants treated with applications of glyphosate (BRS 508), glyphosate (BRS 509), and sulfometuron-methyl (BRS 509), as these specimens were associated with the highest percentages of total lignin, as described in Table 7.

TABLE 7. Linear correlation of chemical-energetic biomass parameters for the production of solid biofuels.

Parameter	Ash	Fixed Carbon	HHV
Volatile matter	- 0.57	0.26	0.24
Ash		- 0.94	- 0.89
Fixed Carbon			0.96

Understanding the degrees of linear associations between the physical, chemical, and energetic attributes of the raw materials is fundamental to the development of technologies for the production of solid biofuels, such as briquettes and pellets, because this information enables the definition of agronomic strategies pertaining to plant physiology, genetics, and mineral nutrition of energy crops to improve the technical, economic, environmental, industrial, commercial, and social aspects of the raw materials and, above all, enhance their sustainability.

CONCLUSIONS

The main conclusions that may be drawn from the present study on the heating calorific values of different sweet sorghum biomass for combustion are listed below:

- The energy yield of BRS 509 sorghum cultivar was higher than that of BRS 508.
- The phyto-regulators, glyphosate, sulfometuron-methyl, and ethephon, significantly increased the HHVs of the cultivars BRS 509 and BRS 508.
- The fixed carbon and lignin contents of the sweet sorghum biomass showed positive correlations with HHV.

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