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ABSTRACT

Energy potential and thermochemical characterization of *Sorghum bicolor* and *Pennisetum purpureum* compartments for bioenergy generation

This study evaluated the chemical and energetic characteristics of two agricultural biomasses, *Sorghum bicolor [L.]* Moench and *Pennisetum purpureum* Schum., across three compartments: leaves, stems, and whole plants. The research was motivated by the need to identify resilient bioenergy sources for the Southern Hemisphere, aiming to meet rural thermal demands and mitigate dependence on fossil fuels in regions such as Sub-Saharan Africa. The samples were analyzed, in accordance with standardized methods, for extractives content, lignin, holocellulose, volatile matter, ash, fixed carbon, and calorific value. The data were subjected to analysis of variance, and, when differences were identified, Tukey's test at the 5% probability level was applied, along with Pearson's correlation test to assess the relationships among the properties. The results showed that sorghum exhibited a higher calorific value in all compartments, in addition to lower ash contents, whereas elephant grass stood out for its higher ash content, especially in the leaves (9.27%), which may limit its use in direct combustion. The stems were, for both species, the compartment with the highest calorific value. A strong positive correlation was observed between lignin content and calorific value (r = 0.92), and a strong negative correlation between ash content and calorific value (r = −0.95). It is concluded that both crops have energy potential for bioenergy purposes; however, sorghum presents advantages for combustion due to its higher energy content and lower ash content, whereas the use of elephant grass requires forest management strategies. The results validate these crops as strategic alternatives for energy security and the sustainable development of agricultural communities.

Keywords: Biomass. Energy. Biofuels. Energy security. Family forestry.

1. INTRODUCTION

The substantial increase in the global population in recent years has significantly influenced worldwide energy demand, which, when derived from non-renewable fossil fuels, is strongly associated with environmental degradation, pollution, global warming, greenhouse gas emissions, and the depletion of finite energy resources. In this context, intensifying the search for alternative energy sources based on renewable resources becomes essential [1][2].

A set of actions aimed at reducing dependence on fossil fuels includes the establishment of the 17 Sustainable Development Goals (SDGs) during the United Nations General Assembly in 2015. Among them is SDG 7, Affordable and Clean Energy, which aims to ensure access to affordable, reliable, sustainable, and modern energy for all, as well as to significantly increase the share of renewable sources in the global energy mix and improve energy efficiency gains by 2030 [3][4].

One of the main renewable energy sources with the potential to support and facilitate the achievement of the SDGs is biomass, an energy alternative that encompasses environmental, social, and economic benefits [5]. It should be noted that the use of biomass contributes both to reducing dependence on fossil fuels and to lowering greenhouse gas emissions by utilizing agricultural, forestry, and organic residues for energy generation, thereby promoting environmental sustainability [6]. In addition, the conversion of biomass into bioenergy can stimulate local economic development by generating employment and income in associated production chains and by promoting a more efficient circular economy [7].

In Southern Brazil, the expansion of bioenergy derived from short-cycle agricultural biomass plays a strategic role in maintaining productive activities on family-based farms. The expansion of bioenergy from lignocellulosic biomass has been playing a strategic role in diversifying the energy matrix, especially in countries with a strong agro-industrial base [8]. In Sub-Saharan Africa, historically, dependence on fossil fuels and limited access to modern electricity represent critical barriers to development [9]. In this region, solid biomass remains the main energy source for cooking and small agro-industries; however, the unsustainable exploitation of native forests has generated severe environmental impacts [10]. In this context, the identification of fast-growing crops that can be integrated into small-scale systems emerges as a vital solution for energy sovereignty and the mitigation of deforestation on the African continent.

Biomass offers high technological flexibility, as it can be converted through different pathways, such as combustion, pyrolysis, gasification, anaerobic digestion, among others, which broadens its potential applications in energy systems [11]. Moreover, when managed sustainably, biomass may present a carbon balance close to neutrality, since the CO_2 released during conversion processes tends to be offset by the carbon fixed during plant growth, thereby reinforcing its role as a viable alternative in the context of global climate change mitigation targets [12].

Among the various types of biomass, the use of agricultural residues for bioenergy production has become increasingly widespread, mainly due to its potential as an alternative for waste management [13].

Due to the large-scale production of these by-products, there is a significant environmental risk, as the decomposition of organic residues contributes to atmospheric pollution through the generation of gases such as CH_4. In addition, soil and water contamination may also occur, further intensifying climate change [14].

The potential use of agricultural biomass as fuel, as well as forestry crops, is strongly related to its chemical, physical, and energy properties. Therefore, a detailed understanding of these properties is essential to assess its performance, possible impacts, and issues arising from energy conversion processes [15]. The lignocellulosic composition of these biomasses, particularly the fractions of cellulose, hemicellulose, and lignin, is linked to key aspects of thermochemical conversion, where lignin tends to increase the higher heating value, in contrast to cellulose and hemicellulose, which are more closely associated with volatile release and thermal reactivity [16].

For rural producers, crops such as sorghum and elephant grass serve as an immediate energy supply, filling fuel availability gaps while long-cycle forest plantations, such as eucalyptus, have not yet reached harvest maturity. This complementarity is essential to ensure the energy required in critical thermal processes, such as grain drying and tobacco production.

Although this study was conducted under the edaphoclimatic conditions of Southern Brazil, the selected species, sorghum and elephant grass, exhibit broad adaptability and are already cultivated in several regions of Africa for forage purposes [17]. Redirecting these crops toward the energy sector may transform biomass residues and surpluses into a high-quality fuel for rural thermal demand. Therefore, this work seeks to provide chemical and energy parameters that support the transfer of these crops as resilient bioenergy sources capable of meeting agricultural processing needs and heat generation in African communities and in other contexts of family-based farming worldwide.

2. MATERIALS AND METHODS

2.1 PLANT MATERIAL

This study evaluated two agricultural biomasses, *Sorghum bicolor* [L.] Moench, cultivar BRS 716, and *Pennisetum purpureum* Schum., cultivar BRS Capiaçu, originating from the municipality of Santa Cruz do Sul, located on the lower northeastern slope of the state of Rio Grande do Sul, Brazil, at geographic coordinates 29°43'59" S and 52°24'52" W, with an average altitude of 122 meters. The municipality has a total area of 734.516 km² and an average annual precipitation of 1,420 mm [18][19].

Sorghum was planted in June 2022, with a spacing of 0.5 m × 0.5 m, totaling 40,000 plants per hectare. Elephant grass was planted on the same date, but with a spacing of 0.6 m × 0.8 m, corresponding to 20,833 plants per hectare. The experimental areas were selected as they represent the edaphoclimatic conditions typical of small rural properties in the region, where these crops are integrated as a complementary energy source. Harvesting was carried out using five replicates of 8 linear meters each for both species. Sorghum was harvested in May 2023, while elephant grass was harvested in July of the same year.

2.2 CHEMICAL AND ENERGY CHARACTERIZATION

The collected samples intended for chemical and energy analyses were separated into compartments (whole plant, leaves, and stems), converted into sawdust using a Wiley-type knife mill, and subsequently classified through vibrating sieves with a 40/60 mesh.

The structural chemical composition and proximate analysis of both biomasses were carried out at the Wood Chemistry Laboratory (LAQUIM), at the Federal University of Santa Maria, RS, Brazil, following technical standards, all in triplicate.

For the determination of total extractives content, TAPPI standard T264 cm-97 was used, and the final content was calculated using Equation 1.

$$EX = \frac{P1-P2}{P1} X\ 100\ (1)$$

Where: EX: total extractives content (%); P1: initial sample weight (g); and P2: weight of the extractive-free sample, oven-dried (g).

For the determination of Klason lignin content, TAPPI standard T222 om-98 was followed, in which all polysaccharides are removed from the sample through acid hydrolysis, leaving lignin as the residue. The final lignin content was obtained using Equation 2. Holocellulose, cellulose, and hemicellulose contents were then obtained by difference, as given in Equation 3.

$$LIG = \frac{P1}{P2} X\ 100\ (2)$$

Where: LIG: lignin content (%); P1: weight of the residual sample (g); and P2: initial weight of the sample, absolutely dry and extractive-free (g).

$$HOLO = 100 - (CZ + EXT + LIG)\ (3)$$

Where: HOLO: holocellulose content (%); CZ: ash content (%); EXT: total extractives content (%); and LIG: lignin content (%).

The calculation of holocellulose by difference is a well-established practice that provides an integrated view of the biomass thermal degradation potential.

Proximate analysis was based on ASTM D1762-84, with the aim of determining the contents of volatile matter, ash, and fixed carbon in the samples. The volatile matter content was calculated using Equation 4:

$$MV = \frac{P1-P2}{P1} X\ 100\ (4)$$

Where: MV: volatile matter content (%); P1: initial sample weight (g); and P2: sample weight after incineration of volatile matter (g).

The ash content was calculated according to Equation 5:

$$CZ = \frac{PC}{P} X\ 100\ (5)$$

Where: CZ: ash content (%); PC: ash weight (g); and P: initial sample weight (g).

Fixed carbon (CF) content was calculated according to Equation 6:

$$CF = 100 - MV - CZ \quad (6)$$

Where: CF: fixed carbon content (%); MV: volatile matter content (%); and CZ: ash content (%).

The gross calorific value (GCV) analysis was carried out at the Laboratory of Ruminant Bromatology and Nutrition (LABRUMEN), at the Federal University of Santa Maria, RS, Santa Maria, Brazil. The processed biomass material was formed into briquettes with an approximate weight of 0.8 grams and subsequently analyzed using a Parr 6400 bomb calorimeter, in accordance with technical standard NBR 8633 (ABNT, 1984). The use of briquettes ensures combustion uniformity within the calorimeter, minimizing experimental errors in the determination of energy potential.

2.3 STATISTICAL ANALYSIS

A completely randomized design (CRD) was adopted in the experimental design. Assumptions for analysis of variance (ANOVA) were tested using the F-test at a 5% significance level ($p \leq 0.05$), the Shapiro–Wilk test for normality, and Bartlett's test for homoscedasticity of variances. In the case of significant analysis of variance, multiple comparisons of means were adopted using Tukey's test. All data were subjected to statistical analysis using the R statistical software.

The relationship between chemical and energy properties was assessed using Pearson's correlation test, considering all values of the analyzed variables. The adopted level of statistical significance was $p < 0.05$. These correlations allow the identification of whether variations in chemical properties are associated with changes in the energy properties of crops.

3. RESULTS AND DISCUSSION

According to the analysis of variance, significant differences in extractive content were observed among sorghum compartments, with leaves differing from stems and whole plants. The mean values indicated that leaves presented a higher extractive content, as shown in Figure 1. These results corroborate those reported by Pimentel et al. [20], who, when characterizing the chemical and energetic properties of different agronomic groups of sorghum, also found higher levels of this component in leaves, although those values were higher than those obtained in the present study. This elevated concentration of extractives in leaves may influence the ignition rate of the biomass, since these compounds typically exhibit high volatility and thermal reactivity during the initial stages of the combustion process [21].

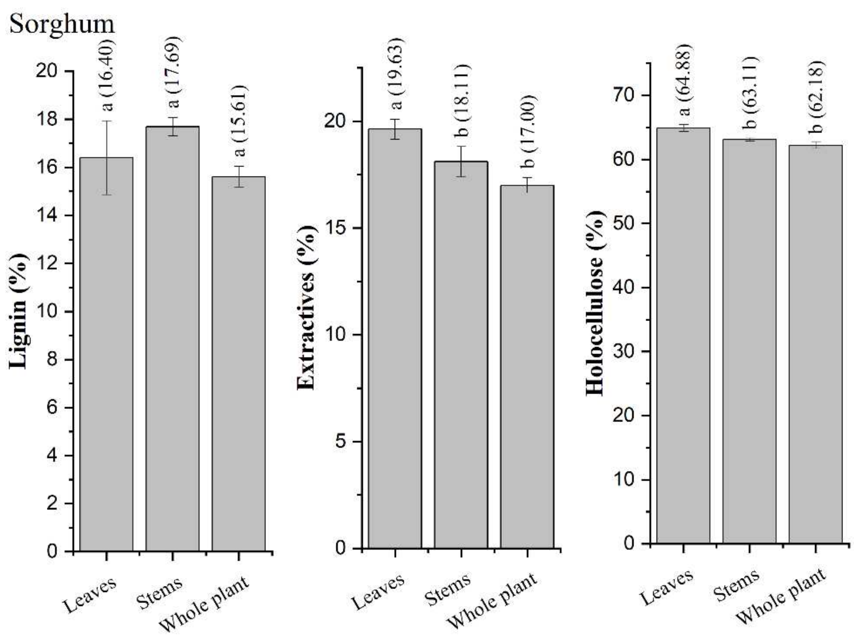
Holocellulose content also showed significant differences in the leaf fraction compared to stems and whole plants, as shown in Figure 1. This result is consistent with that obtained by Pimentel et al. [20], who also reported higher holocellulose content in the leaves of sorghum BRS 716 (62.17%) when compared to other plant compartments.

For elephant grass, significant differences were observed in lignin and holocellulose contents among the three compartments (Figure 2). For lignin, the highest content was found in the stems, differing from both the whole plant and leaves. Higher lignin contents in the stem fraction indicate a strong potential for its use in direct combustion processes. From an energy efficiency perspective, this pattern is highly desirable, as lignin has a higher energy density than polysaccharides due to its lower oxygen content and greater thermal stability, which enhances the final energy balance during direct combustion [16].

For the cultivar BRS Capiaçu, Beber et al. [22], when analyzing the effect of plant part and age on biomass characteristics, also found higher lignin content in stems (12.23%), followed by the whole plant (10.56%) and leaves (7.72%); however, these values are lower than those obtained in the present study.

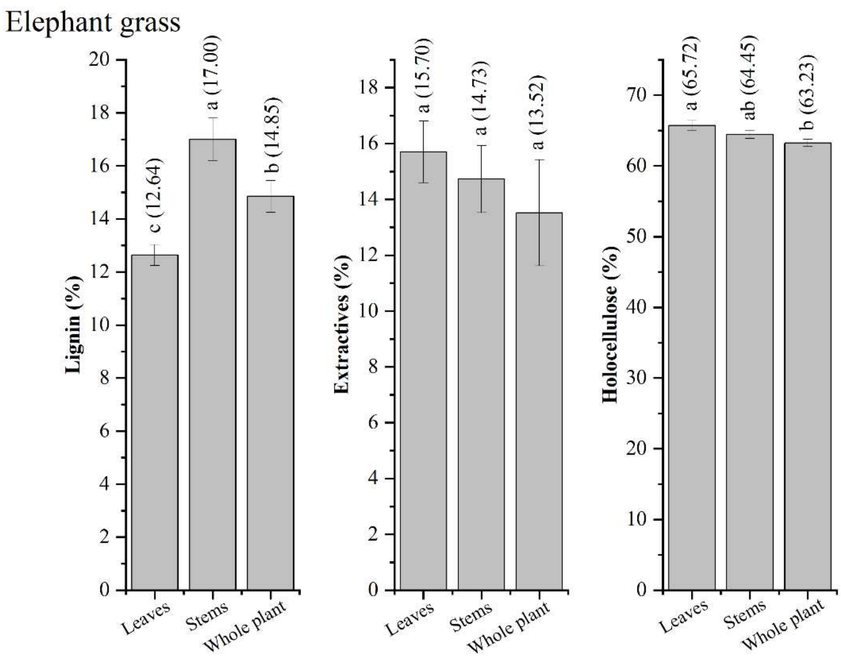
Regarding holocellulose content, as observed for sorghum, the highest values were found in the leaves and stems. It is known that, in energy generation processes, raw materials with higher holocellulose content present a high volatile matter content, resulting in faster combustion and an intense release of gases during the initial heating phase [23]. This behavior may favor ignition; however, it leads to a shorter duration of energy retention within the solid during the process. In this context, for applications aimed at higher energy yield, biomass with lower holocellulose content is preferable.

Fig. 1 Mean values of extractives, lignin, and holocellulose contents for sorghum compartments. Means followed by the same lowercase letters do not differ among compartments at the P < 0.05 level, based on Tukey's test. Error bars represent the standard deviation



Source: Author (2026)

Fig.2 Mean values of extractives, lignin, and holocellulose contents for elephant grass compartments. Means followed by the same lowercase letters do not differ among compartments at the P < 0.05 level, based on Tukey's test. Error bars represent the standard deviation



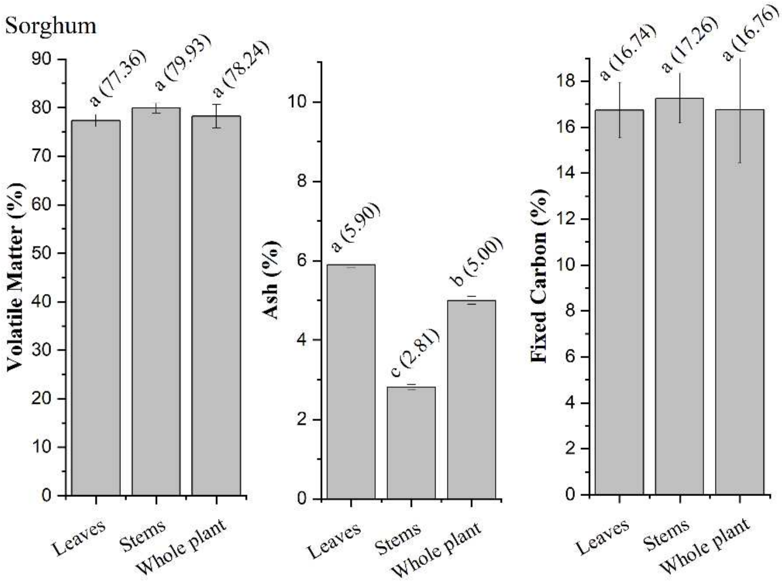
Source: Author (2026)

Regarding fixed carbon content, an important variable in relation to energy properties, no significant differences were observed among sorghum compartments (Figure 3), whereas for elephant grass, the highest content was found in the stem fraction (Figure 4). Macedo, Rousset, and Vale [24], when evaluating the energy potential of the crop, obtained a fixed carbon content similar to that of the present study (17.2%), although for the whole-plant compartment. This result reinforces the suitability of stems for combustion processes that require longer thermal residence time, a key characteristic for heat stability in drying furnaces.

In contrast, ash content differed significantly among the three compartments of both species, with the highest values observed in the leaves of sorghum and elephant grass, as shown in Figures 3 and 4.

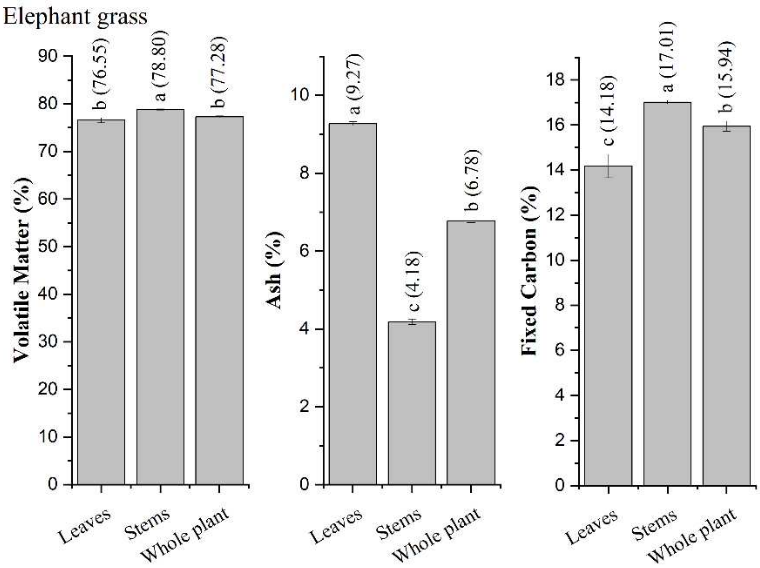
Ferreira et al. [25] obtained a high ash content of 8.07%, as did Lee et al. [26] and De Conto et al. [27], who reported values of 9.68% and 8.26%, respectively, for elephant grass. In addition, these authors observed the influence of high ash content on the reduction of the gross calorific value. Depending on its level, large amounts of ash reduce the available energy in the material and, consequently, its conversion efficiency [28]. The value of 9.27% observed in the leaves of elephant grass in the present study exceeds the technical limits recommended to avoid slag formation in boilers, suggesting that, for small-scale producers, the preferential use of stems or blending with eucalyptus wood would be a safer strategy to preserve equipment.

Fig.3 Mean values of volatile matter, ash, and fixed carbon contents for sorghum compartments. Means followed by the same lowercase letters do not differ among compartments at the $P < 0.05$ level, based on Tukey's test. Error bars represent the standard deviation



Source: Author (2026)

Fig.4 Mean values of volatile matter, ash, and fixed carbon contents for elephant grass compartments. Means followed by the same lowercase letters do not differ among compartments at the P < 0.05 level, based on Tukey's test. Error bars represent the standard deviation

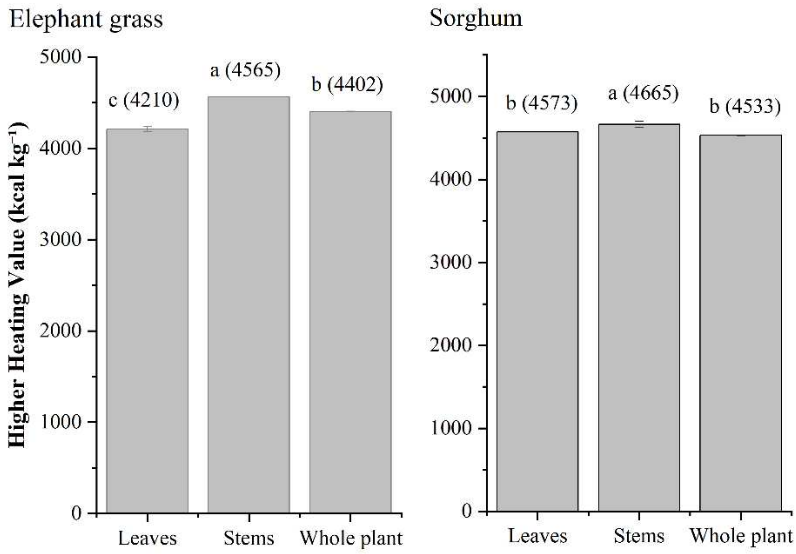


Source: Author (2026)

Regarding calorific value, for both species, the stem compartment exhibited the highest values, as shown in Figure 5. Beber et al. [22], analyzing the same elephant grass cultivar, also obtained a higher gross calorific value for stems (4,299 kcal/kg) and a lower value for leaves (4,280 kcal/kg).

Fig.5 Mean values of gross calorific value for sorghum and elephant grass compartments. Means followed by the same lowercase letters do not differ among compartments at the P < 0.05 level, based on

Tukey's test. Error bars represent the standard deviation



Source: Author (2026)

When comparing the chemical composition between species, significant differences in extractive content were observed across all compartments, with sorghum showing the highest values for leaves, stems, and whole plant, as shown in Table 1. The higher values in sorghum may be associated with environmental factors or the crop's developmental stage. Some studies have reported similar contents of this component in sorghum and elephant grass, which may be related to patterns of accumulation of soluble compounds and to shared structural and biological defense functions common to these Poaceae grasses [29][30]. Depending on the types of extractives present in the crops, they may directly influence the energy characteristics of biofuels, favoring an increase in calorific value due to their higher carbon proportion, which can enhance both the calorific value and the fixed carbon content present in the fuel [31].

For lignin and holocellulose contents, only the leaf compartment showed a significant difference, with higher values observed for sorghum. It can be stated that biomass with higher lignin content tends to exhibit higher calorific values, since lignin is the most relevant component for energy generation, as its energy yield is directly related to its proportion in the biomass [32].

In addition, lignin contains proportionally less oxygen than holocellulose, which contributes to a higher calorific value in biomass with elevated levels of this component, as materials with lower oxygen content tend to release more energy per unit mass during combustion [16][33]. This biochemical basis explains why sorghum, with higher lignin content in leaves compared to elephant grass, exhibited superior energy performance in this study. Higher lignin content leads to slower decomposition and lower gas yield as a product, which is advantageous for energy biomass applications [34].

In contrast, high holocellulose contents may negatively influence combustion processes. Lower values of this chemical component are desirable when the biomass is intended for energy generation, since holocellulose exhibits an unstable and weak profile under thermal degradation processes; therefore, it does not contribute positively to biomass use for this purpose [35][32].

Regarding the analysis of energy properties, sorghum presented the highest calorific value in all compartments when compared to elephant grass. This result may be associated with the higher ash content in elephant grass, since ash reduces the available energy in the material and, consequently, decreases conversion efficiency [28]. High ash contents, such as those observed in the leaf compartment of elephant grass, impair the combustion process. This elevated content in leaves, compared to stems, may be mainly related to mineral transport processes, as minerals are predominantly deposited in the leaves [36].

Regarding sorghum, in addition to its higher calorific value, it also presented a higher lignin content, which likely contributed to a greater fixed carbon content in the leaves. During combustion, lignin decomposes gradually over a wide temperature range, promoting the formation of condensed aromatic carbon structures, resulting in a higher fixed carbon content [37].

Furthermore, a lower ash content was observed in all sorghum compartments, particularly in the stems, when compared to elephant grass, as shown in Table 1. Ashes are composed of inorganic elements that do not contribute to the energy value of the fuel and, at high levels, cause fouling, corrosion, and a reduction in calorific value. Thus, biomass with lower ash content, such as sorghum, is preferable when the objective is energy generation [38][39].

Table 1 – Mean values of extractives, lignin, holocellulose, volatile matter, ash, fixed carbon, and calorific value for sorghum and elephant grass by compartment. Means followed by the same lowercase letters within each column do not differ between species at the $P < 0.05$ level, based on Tukey's test

Species	**Extractives (%)**	**Lignin (%)**	**Holocellulose (%)**
	Leaves		
Sorghum	19,63 a	16,39 a	64,45 a
Elephant grass	15,70 b	12,63 b	62,18 b
	Stems		
Sorghum	18,10 a	17,68 a	63,12 a
Elephant grass	14,73 b	17,00 a	63,23 a
		Whole plants	
Sorghum	17,00 a	15,60 a	65,72 a
Elephant grass	13,52 b	14,85 a	64,88 a
	Volatile matter (%)	**Ash (%)**	**Fixed carbon (%)**
	Leaves		
Sorghum	77,36 a	5,90 b	16,74 a
Elephant grass	76,55 a	9,27 a	14,18 b
	Stems		
Sorghum	79,93 a	2,81 b	17,26 a
Elephant grass	78,80 a	4,18 a	17,01 a
	Whole plants		
Sorghum	78,24 a	5,00 b	16,76 a
Elephant grass	77,28 a	6,78 a	15,94 a
	Calorific value (kcal/kg)		
	Leaves		
Sorghum	4.573 a		

Elephant grass	4.210 b
	Stems
Sorghum	4.665 a
Elephant grass	4.565 b
	Whole plants
Sorghum	4.533 a
Elephant grass	4.402 b

Source: Author (2026)

Pearson's correlation analysis allows the identification of possible associations between the chemical and energy properties of the agricultural biomasses studied, as shown in Table 2. A strong positive correlation was observed between lignin content and gross calorific value (r = 0.92), as well as between lignin content and fixed carbon content (r = 0.72). In addition, fixed carbon content also showed a direct correlation with calorific value (r = 0.76). These results indicate that higher lignin and fixed carbon contents contribute significantly to the energy content of sorghum and elephant grass biomasses. This relationship has already been reported in comparative analyses of plant biomass chemical composition, in which lignin showed a positive correlation with gross calorific value and fixed carbon, in contrast to the negative effect of ash content [31][40].

Table 2 – Pearson's correlation between the chemical and energy properties of the agricultural crops studied

Variable	**EXT**	**HOLO**	**PCS**	**CF**	**MV**	**CZ**
LIG	0.33^{ns}	-0.41^{ns}	0.92*	0.64*	-0.63*	-0.9*
EXT		-0.65^{*}	0.46^{ns}	0.22^{ns}	0.18^{ns}	-0.28^{ns}
HOLO			-0.47*	-0.51*	-0.27^{ns}	-0.54*
PCS				0.72*	-0.69*	-0.95*
CF					0.23^{ns}	-0.69*
MV						-0.72*

Source: Author (2026)

Regarding extractives content, no significant correlation was observed with calorific value, indicating that in the sorghum and elephant grass cultivars analyzed, extractives do not influence the energy value of the biomass.

Holocellulose content showed a negative correlation with calorific value (r = −0.47), as did volatile matter content (r = −0.69). Lower holocellulose values are desirable when biomass is intended for energy generation, since this component exhibits an unstable and weak profile under thermal degradation processes; therefore, it does not contribute positively to biomass use for energy purposes [34]. Volatile matter, in turn, is beneficial in facilitating biomass ignition at lower temperatures; however, its high content makes combustion control difficult, causing the fuel to be consumed too rapidly in the combustion chamber and thus reducing process efficiency [41][42].

Ash content showed a strong negative correlation with calorific value ($r = -0.95$), highlighting the importance of species selection to identify those with lower levels of this component, which negatively affects the combustion process.

4. FINAL CONSIDERATIONS

The results obtained in the present study highlight the potential of agricultural biomass as an alternative source of renewable energy, particularly in agricultural systems that require supplementary energy sources while forest plantations are being established. Sorghum exhibited higher energy value and lower ash content, indicating greater suitability for direct combustion. Elephant grass, despite its considerable calorific value, presents leaves with high ash contents, which may cause operational problems during combustion and reduce process efficiency, requiring careful forest management and processing of this biomass.

The choice of material, species, and compartment should consider the intended application (combustion, gasification, among others) as well as the operational limitations of the equipment. The use of stems is recommended for thermal energy generation due to their higher calorific value and lower ash content; however, plant fractionation may not always be a feasible option. In this sense, alternatives such as blending agricultural biomass with wood could be explored, since wood generally presents lower ash content, which may help reduce operational issues.

In this context, detailed chemical characterization is essential to guide technological and economic decisions in the implementation of bioenergy supply chains. Short-cycle crops, such as sorghum and elephant grass, offer a viable and efficient solution when properly managed, contributing to the reduction of pressure on other natural resources while promoting greater flexibility and energy security.

5. CONCLUSIONS

The chemical and energy characterization of the compartments of *Sorghum bicolor* and *Pennisetum purpureum* reveals that both biomasses have potential for the rural energy matrix, although they exhibit distinct behaviors that influence their thermal efficiency. Sorghum biomass stands out due to its superior energy performance across all compartments, driven by higher lignin contents combined with lower mineral content. These properties confer greater combustion stability to sorghum, positioning it as a high-performance fuel for processes requiring rapid temperature rise and lower ash residue.

In the context of South–South cooperation, these results validate sorghum as a strategic crop for technological transfer between Brazil and African nations, where the species is already well adapted to agricultural conditions.

On the other hand, the use of elephant grass for bioenergy purposes requires strategic management of its compartments. Although it presents a competitive and viable calorific value, its high ash content acts as a severe technical limitation, capable of inducing corrosion and clogging in thermal systems. Therefore, to enable the use of this crop, the segregation of fractions or the adoption of blending techniques with low-mineral-content forest biomass is recommended, aiming to balance inorganic load and preserve the service life of conversion equipment.

Ultimately, the integration of these short-cycle grasses into the energy planning of family-based farms represents a solution of high socioeconomic relevance. In addition to diversifying the renewable energy matrix, the strategic cultivation of sorghum and elephant grass ensures immediate energy security by meeting thermal demands for agricultural product drying during the maturation period of forest stands. In this way, detailed knowledge of the chemical properties of these materials ceases to be merely a laboratory parameter and becomes a tool for autonomy and economic resilience for rural producers.

Thus, the application of these technical results in African and Brazilian contexts promotes rural energy autonomy and reduces pressure on native forests, transforming chemical knowledge into economic resilience for producers.

REFERENCES

1. AMIN, Muhammad et al. Hydrogen production through renewable and non-renewable energy processes and their impact on climate change. **International journal of hydrogen energy**, v. 47, n. 77, p. 33112-33134, 2022.
2. BROCKWAY, Paul E. et al. Estimation of global final-stage energy-return-on-investment for fossil fuels with comparison to renewable energy sources. Nature Energy, v. 4, n. 7, p. 612-621, 2019.
3. ORGANIZAÇÃO DAS NAÇÕES UNIDAS. Os Objetivos de Desenvolvimento Sustentável no Brasil. Energia limpa e acessível, 2025. Disponível em:
https://brasil.un.org/pt-br/sdgs/7.
4. WEILAND, Sabine et al. The 2030 Agenda for Sustainable Development: Transformative Change through the Sustainable Development Goals? Politics and Governance, v. 9, n. 1, p. 90–95, 26 fev. 2021.
5. ALI, Farhad et al. Fueling the future: biomass applications for green and sustainable energy. **Discover sustainability**, v. 5, n. 1, p. 156, 2024.
6. ZHAO, L.; WANG, Y.; ZHANG, Q. Biomass energy and biofuels: Perspectives, potentials, and sustainability challenges. **Sustainability**, v. 16, n. 16, p. 7036, 2025. DOI: 10.3390/su16167036.
7. SARAVANAN, A.; RAGINI, Y. P.; KARISHMA, S.; HEMAVATHY, R. V.; JYOTSNA, M. A review on advancing sustainable energy: The role of biomass and bioenergy in a circular economy. Sustainable Futures, v. 10, p. 100835, 2025. DOI: 10.1016/j.sftr.2025.100835.
8. BAIDOO, Emmanuel Boafo et al. Revolutionizing bioenergy production: a review on sustainable biomass feedstock. **Biomass and Bioenergy**, v. 201, p. 108113, 2025.
9. ADEWUMI, Idowu Olugbenga; IBRAHIM, Rasheed; IBRAHIM, Kudirat. Optimizing Cassava-to-Bioenergy Conversion Using Artificial Neural Networks: a Sustainable Pathway for Africa. **BioEnergy Research**, v. 19, n. 1, p. 20, 2026.
10. TOLESSA, Amsalu. Current status and future prospects of small-scale household biodigesters in Sub-Saharan Africa. **Journal of Energy**, v. 2024, n. 1, p. 5596028, 2024.
11. BALOPI, Babusi et al. Biomass-to-electricity conversion technologies: a review. **Waste Disposal & Sustainable Energy**, p. 1-29, 2025.
12. SELIVANOV, Egor; CUDLIN, Pavel; HORÁČEK, Petr. Carbon neutrality of forest biomass for bioenergy: a scoping review. **iForest-Biogeosciences and Forestry**, v. 16, n. 2, p. 70, 2023.
13. MEENA, Pradeep Kumar et al. Thermochemical conversion of agricultural residue for the production of hydrogen, methane, and biofuels: A comprehensive overview. **Industrial crops and products**, v. 221, p. 119340, 2024.
14. LACKNER, Maximilian; BESHARATI, Maghsoud. Agricultural Waste: Challenges and Solutions, a Review. In: **Waste**. MDPI, p. 18, 2025.
15. SHAHZAD, Hafiz Muhammad Aamir et al. Thermochemical and biochemical conversion of agricultural waste for bioenergy production: an updated review. **Discover Environment**, v. 2, n. 1, p. 134, 2024.
16. ESTEVES, Bruno; SEN, Umut; PEREIRA, Helena. Influence of chemical composition on heating value of biomass: A review and bibliometric analysis. **Energies**, v. 16, n. 10, p. 4226, 2023.
17. BALEHEGN, Mulubrhan et al. Forage conservation in sub-Saharan Africa: Review of experiences, challenges, and opportunities. **Agronomy Journal**, v. 114, n. 1, p. 75-99, 2022.
18. IBGE. INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE.
Levantamento Sistemático da Produção Agrícola Estatística da Produção Agrícola, 2024.
19. INM. INSTITUTO NACIONAL DE METEREOLOGIA - INM. Monitoramento - precipitação, 2025.
20. PIMENTEL, Leonardo Duarte *et al.* Chemical and bioenergetic characterization of sorghum agronomic groups1. **Pesquisa Agropecuária Tropical**, v. 47, n. 4, p. 424– 431, dez. 2017.
21. BRAND, M. A. Energia da biomassa florestal. Rio de Janeiro: **Interciência**, 2010.
22. BEBER, Roberto C. *et al.* Effect of Plant Part and Age on the Proximate, Chemical, and Elemental Characteristics of Elephant Grass Cultivar BRS Capiaçu for Combustion-Based Sustainable Bioenergy. **Sustainability**, v. 17, n. 6, p. 2741, 19 mar. 2025.
23. LIU, Yuan et al. Pirólise rápida de holocelulose para a preparação de precursores de combustíveis de éter de cadeia longa: Efeito dos tipos de holocelulose. **Bioresource technology** , v. 338, p. 125519, 2021.
24. MACEDO, Lucélia Alves; ROUSSET, Patrick Louis Albert; VALE, Ailton Teixeira. Influência da composição da biomassa no rendimento em condensáveis da torrefação de resíduos vegetais. **Pesquisa Florestal Brasileira**, v. 34, n. 80, 26 dez. 2014.
25. FERREIRA, Suelem Daiane *et al.* Use of Biochar Produced from Elephant Grass by Pyrolysis in a Screw Reactor as a Soil Amendment. **Waste and Biomass Valorization**, v. 10, n. 10, p. 3089–3100, out.

2019.
26. LEE, Mei-Kuei *et al.* Pyrolysis of napier grass in an induction-heating reactor. **Journal of Analytical and Applied Pyrolysis**, v. 88, n. 2, p. 110–116, jul. 2010.
27. DE CONTO, D. *et al.* Performance of rotary kiln reactor for the elephant grass pyrolysis. **Bioresource Technology**, v. 218, p. 153–160, out. 2016.
28. MARAFON, Anderson Carlos *et al.* Chemical composition and calorific value of elephant grass varieties and other feedstocks intended for direct combustion.
Grassland Science, v. 67, n. 3, p. 241–249, jul. 2021.
29. GOMES, Alanderson Moacir Da Silva Santos *et al.* Emprego de diferentes aditivos na silagem de *Pennisetum purpureum* Schum como alternativa para suplementação animal. *In*: ZUFFO, Alan Mario; AGUILERA, Jorge González (Eds.). **Pesquisas Agrárias e Ambientais: Volume VII**. 1. ed. *[S.l.]*: Pantanal Editora. p. 60–69, 2021.
30. MCKINLEY, Brian A. *et al.* Variation in energy sorghum hybrid TX08001 biomass composition and lignin chemistry during development under irrigated and non- irrigated field conditions. **PLOS ONE**, v. 13, n. 4, p. e0195863, 23 abr. 2018.
31. BONFATTI JÚNIOR, Eraldo Antonio et al. Correlation between the heating value and the chemical characteristics of Eucalyptus biomass. **Ciência Rural**, v. 55, p. e20240100, 2025.
32. SANTOS, Rosimeire Cavalcante Dos *et al.* Influência das propriedades químicas e da relação siringil/guaiacil da madeira de eucalipto na produção de carvão vegetal. **Ciência Florestal**, v. 26, n. 2, p. 657–669, 20 jun. 2016.
33] YANG, Haiping et al. Characteristics of hemicellulose, cellulose and lignin pyrolysis. **Fuel**, v. 86, n. 12-13, p. 1781-1788, 2007. Doi: https://doi.org/10.1016/j.fuel.2006.12.013
34. BURHENNE, Luisa et al. The effect of the biomass components lignin, cellulose and hemicellulose on TGA and fixed bed pyrolysis. **Journal of Analytical and Applied Pyrolysis**, v. 101, p. 177-184, 2013.
35. DOMINGOS, Idalina *et al.* Calorific Power Improvement of Wood by Heat Treatment and Its Relation to Chemical Composition. **Energies**, v. 13, n. 20, p. 5322, 13 out. 2020.
36. MONTI, Andrea; DI VIRGILIO, Nicola; VENTURI, Gianpietro. Mineral composition and ash content of six major energy crops. **Biomass and Bioenergy**, v. 32, n. 3, p. 216–223, mar. 2008.
37. ĐUKANOVIĆ, Nina et al. Comparative Study of Biochar from Different Biomass Feedstocks: Toward Sustainable Resource Utilization and Environmental Applications. **Molecules**, v. 31, n. 1, p. 37, 2025.
38] MORALES, Marina Moura *et al.* Sorghum Biomass as an Alternative Source for Bioenergy. **Biomass**, v. 4, n. 3, p. 1017–1030, 5 set. 2024.
39. VASSILEV, Stanislav V. et al. An overview of the chemical composition of biomass.
Fuel, v. 89, n. 5, p. 913–933, maio 2010.
40. RUIZ-AQUINO, Faustino et al. Effect of chemical components on the energy properties of wood from two forest species. **Results in Engineering**, p. 107816, 2025.
41. ELOY, Elder *et al.* Influence of anatomy on the mechanical resistance of woods in an agroforestry system. **Floresta**, v. 53, n. 1, p. 64-64–71, 1 jan. 2023.
42. GARCÍA, Roberto *et al.* Spanish biofuels heating value estimation. Part II: Proximate analysis data. **Fuel**, v. 117, p. 1139–1147, jan. 2014.

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Competing interest

The authors declare that there are no conflicts of interest and that this work is original. Furthermore, this manuscript is not being submitted simultaneously to any other journal.

Author Contributions

All authors made substantial contributions to the development and execution of this study. Ana Elisa Souza Iop was responsible for manuscript writing, statistical analyses, data analysis, and manuscript revision. Daniele Bernardy contributed to field data collection and laboratory analyses. Pietra Tessele de Paula contributed to field data collection and laboratory analyses. Jorge Antonio de Farias was responsible for study supervision and critical revision of the manuscript. All authors read and approved the final version of the manuscript.

Data Availability

Not applicable.