Assessment of phenolic compounds and antioxidant activity in different plants parts of sorghum landraces

Evaluación de compuestos fenolicos y actividad antioxidante en diferentes partes de plantas de variedades de sorgo

Avaliação dos compostos fenolicos e atividade antioxidante em diferentes partes da planta de variedades de sorgo

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Abstract

The field of animal feed production it is consider one of the most important areas in livestock production. Given that the livestock sector in Algeria faced many problems, such as water scarcity and the high cost of traditional feed, it is important to find other local sources to overcome those difficulties. This study aimed to determine the content of secondary metabolites, including total phenolic compounds, tannins, and flavonoids, and the antioxidant activity in different parts (leaves, stems, and panicle residues) of ten landraces of sorghum found in the Algerian desert and cultivated in the Bordj Bou Arreridj region of Algeria. The results showed significant differences between the contents of the studied samples, as well as among the three different parts of the plant, namely the leaves, stems, and panicle residues. The total phenolic content ranged from 122.33 to 1344.44 mg EAG.100 g^{-1}, with tannin levels from 4.84 to 927.78 mg EAG.100 g^{-1}, while the flavonoid values ranged from 0.24 to 558.25 mg EQ.100 g^{-1}. The antioxidant activitie also showed a significant variation, with DPPH values between 46.10 and 1481.68 mg AAE.100 g^{-1}, FRAP from 31.76 to 1145.92 mg AAE.100 g^{-1}, and ABTS values ranging from 28.89 to 459.92 mg AAE.100 g^{-1}. These results confirmed that the sorghum plants not only represented a source of primary metabolic compounds such as fibers, starch, proteins, and energy materials used as animal feed, but they could also be utilized as a rich source of phenolic compounds with effective value in the health field.

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Resumen

El campo de la producción de piensos para animales se considera una de las áreas más importantes en la producción ganadera. Dado que el sector ganadero en Argelia ha enfrentado muchos problemas, como la escasez de agua y el alto costo de los piensos tradicionales, es importante encontrar otras fuentes locales para superar esas dificultades. Este estudio tuvo como objetivo determinar el contenido de metabolitos secundarios, incluyendo compuestos fenólicos totales, taninos y flavonoides, y la actividad antioxidante en diferentes partes (hojas, tallos y residuos de panículas) de diez variedades de sorgo encontradas en el desierto argelino y cultivadas en la región de Bordj Bou Arreridj de Argelia. Los resultados mostraron diferencias significativas entre los contenidos de las muestras estudiadas, así como entre las tres partes diferentes de la planta, a saber, las hojas, los tallos y los residuos de las panojas. El contenido total de fenoles osciló entre 122,33 y 1.344,44 mg EAG.100 g^{-1}, con niveles de taninos de 4,84 a 927,78 mg EAG.100 g^{-1}, mientras que los valores de flavonoides variaron de 0,24 a 558,25 mg EQ.100 g^{-1}. La actividad antioxidante también mostró una variación significativa, con valores de DPPH entre 46,10 y 1.481,68 mg AAE.100 g^{-1}, FRAP de 31,76 a 1.145,92 mg AAE.100 g^{-1}, y valores de ABTS que oscilaron entre 28,89 y 459,92 mg AAE.100 g^{-1}. Estos resultados confirmaron que las plantas de sorgo no solo representan una fuente de compuestos metabólicos primarios como fibras, almidón, proteínas y materiales energéticos utilizados como alimento para animales, sino que también podrían ser utilizadas como una rica fuente de compuestos fenólicos con un valor efectivo en la salud humana.

Palabras clave: piensos, metabolitos secundarios, taninos, flavonoides, actividad antioxidante.

Resumo

O campo da produção de ração animal é considerado uma das áreas mais importantes na produção pecuária. Dado que o setor pecuário na Argélia enfrentou muitos problemas, como a escassez de água e o alto custo dos alimentos tradicionais, é importante encontrar outras fontes locais para superar essas dificuldades. Este estudo teve como objetivo determinar o conteúdo de metabólitos secundários, incluindo compostos fenólicos totais, taninos e flavonoides, e a atividade antioxidante em diferentes partes (folhas, caules e resíduos de panícula) de dez variedades de sorgo encontradas no deserto argelino e cultivadas na região de Bordj Bou Arreridj, na Argélia. Os resultados mostraram diferenças significativas entre os conteúdos das amostras estudadas, bem como entre as três partes diferentes da planta, a saber, as folhas, os caules e os resíduos da panícula. O conteúdo total de fenólicos variou de 122,33 a 1.344,44 mg EAG.100 g^{-1}, com níveis de taninos de 4,84 a 927,78 mg EAG.100 g^{-1}, enquanto os valores de flavonoides variaram de 0,24 a 558,25 mg EQ.100 g^{-1}. A atividade antioxidante também mostrou uma variação significativa, com valores de DPPH entre 46,10 e 1481,68 mg AAE.100 g^{-1}, FRAP de 31,76 a 1.145,92 mg AAE.100 g^{-1}, e valores de ABTS variando de 28,89 a 459,92 mg AAE.100 g^{-1}. Esses resultados confirmaram que as plantas de sorgo não apenas representavam uma fonte de compostos metabólicos primários, como fibras, amido, proteínas e materiais energéticos usados como ração animal, mas também poderiam ser utilizadas como uma rica fonte de compostos fenólicos com um valor efetivo na saúde humana.

Palavras-chave: ração, metabólitos secundários, taninos, flavonoides, atividade antioxidante.

Introduction

The sorghum plant (*Sorghum bicolor* (L.) Moench) is a rich source of phenolic compounds, flavonoids and tannins. It is a plant known for its ability to adapt to harsh environmental conditions such as low rainfall, saline soil, and high temperatures, and others (Hossain *et al*., 2022). These characteristics make sorghum an ideal crop for sustainable agricultural practices in areas with water scarcity or poor soils quality (Chauhan *et al*., 2025), or for use as an additional crop alongside grasses and fodder during the summer after harvesting wheat, barley, and other crops. In light of the Algerian government's commitment to environmental sustainability and its search for alternatives to traditional fodder, national research projects are focusing on investing in food, health, and energy security. This research contributes to providing food resources for human nutrition and animal feed (Taylor *et al*., 2006), particularly during the hottest and driest periods of the year.

Sorghum is mostly cultivated in the dry and semi-arid tropical regions of Asia and Africa (Charyulu *et al*., 2024), while it is grown in marginal environments in the Algerian desert by some local farmers in small areas for self-consumption or as barriers to protect summer crops from winds and sandstorms. The grasses of these plants are exploited as a main fodder crop for animal feed due to their significant nutritional and functional capabilities. The vegetative part of sorghum is characterized by its density and mainly consists of stems, leaves, and panicles. Panicles include parts like the rachis, glumes, and grains. During the harvesting process, the panicles undergo threshing, winnowing, and grain cleaning. Their residues are then either randomly discarded in nature or disposed of by burning (Estrada-Angulo *et al*., 2019). They are also used as low-value animal feed (Duke *et al*., 2024).

Sorghum plants produce active compounds during their growth stages, that are beneficial for treating various diseases (Dykes and Rooney, 2006). They contain a very large number of medically active compounds, particularly those produced in primary and secondary metabolic processes (More *et al*., 2024). Phenolic compounds are produced in small quantities, which depending on the plant organ and growth stage. While these compounds do not have directly affect basic plant activity such as growth, development and reproduction, they help the plant adapt to its external environment. Various scientific studies and recent statistical analyses have confirmed the effectiveness of phenolic compounds in preventing and resisting diseases due to their antioxidant capabilities and structural diversity (Mérillon and Ramawat, 2025). They also exhibit various biological activity, including anti-inflammatory, antibacterial, antiviral, vasodilatory, anti-cardiovascular, immunomodulatory, and anticancer activity properties, which may be associated with their antioxidant activity (Mérillon and Ramawat, 2025).

This study aims to extract and estimate the phenolic compounds and antioxidant activity present in the leaves, stems, and panicle residues of ten sorghum landraces cultivated in Algeria's Bordj Bou Arreridj province during the 2022 agricultural season. This approach highlights the importance of the phenolic compounds found in sorghum weeds and encourages stakeholders in the agricultural sector, including farmers and growers, to recognise thiss. It also highlights

the importance of these compounds to government bodies, such as research centers, agricultural institutes and pharmaceutical institutes specialising in the cultivation of such promising crops.

Materials and methods

Study location

The study was carried out in sorghum plants in the Algerian desert. All the plants were cultivated in El Hamadia (35°59'59"N, 4°46'59"E, 874m) wilaya of Bordj Bou Arreridj in the year 2022. Bordj Bou Arreridj is a high plateau region located in the northeastern part of Algeria. The area is characterized by hilly terrain and vast plains, and is a significant agricultural and economic hub for the region as a whole. After planting, we observed the growth stages of the plants until flowering and seed formation occurred

Sample preparation

The study samples consisted of nine landraces of sorghum that originated in the Algerian desert, specifically in the Tidikelt, Touat, and Ahaggar regions. The tenth sample was a hybrid from Niger (Table 1).

Table 1. List of common name sorghum accessions, origin and their status.

Code	Common name	Origin and status
T01	Tafsout Beida	In Salah – Landrace
T02	Tafsout Beida	In Salah – Landrace
T03	Tafsout Beida	Tamanrasset – Landrace
T04	Tafsout Hamra	In Salah – Landrace
T05	Tafsout Beida	In Salah – Landrace
T06	Tafsout Beida	Adrar – Landrace
T07	Sorgho Khortal	Niger – Hybridvarity
T08	Tafsout Beida	In Salah – Landrace
T09	Tafsout Beida	In Salah – Landrace
T10	Tafsout Hamra	Tamanrasset – Landrace

Once the plants had completed their vegetative growth stages, were harvested three from each landrace. Each plant was divided into three main parts: leaves, stems, and panicle residues. Was then dried all of these parts in a dark, dry room, away from sunlight. After several days, was ground all the materials using an electric grinder (CRAFT Electronics grinder (Model BT9100), P.R.C) and stored them in paper bags, assigning them appropriate codes: LeaT: for leaves, SteT: for stems, and PanT: for panicle residues.

Extraction

Phenolic compounds were extracted from various samples using 0.25 g of powder in 20 mL of an acetone–distilled water mixture (70:30 % v/v) under the same experimental conditions, relying on a digital ultrasonic cleaner (DAIHAN Scientific (Model WUC-D06H), South Korea) device for 45 minutes with a temperature set at 30 °C in closed reactors. After extraction, the various extracts were dried from the solvent in a laboratory drying oven (Memmert, UM400, Germany) at a temperature of 40 °C. After complete drying, they were re-dissolved in 5 mL of pure methanol.

Determination of active compounds

Determination of total phenolic compounds (TPC)

The total phenolic compounds (TPC) were determined according to the method of Singleton *et al*. (1999) using the Folin-Ciocalteu reagent. The gallic acid was used as a standard solution. Was express the phenolic compounds in milligrams of gallic acid equivalents per 100 grams (mg EAG.100 g^{-1}) of dry weight.

Determination of tannin compounds (TC)

To determine tannins, we adopted the polyvinyl poly pyrrolidone (PVPP) method (Silanikove *et al*., 2001). The tannins were determined by calculating the difference between the total phenolic compounds and the phenolic compounds remaining after treatment with PVPP. We express tannins as milligrams of gallic acid equivalents per 100 grams (mg EAG.100 g^{-1}) of dry weight.

Determination of flavonoid compounds (FC)

To determine flavonoids, the colorimetric aluminum chloride method described by Chang *et al*. (2002) and the Woisky and Salatino (1998) method were adopted. Was express the flavonoid compounds in milligram equivalents of quercetin (mg EQ.100 g^{-1}) per 100 grams of the sample dry weight.

Determination of antioxidant capacity

Determination of the free radical scavenging activity (DPPH)

To determine the DPPH free radical scavenging activity (2,2-diphenyl-1-picrylhydrazyl), the method by Sánchez-Moreno *et al*. (1998) was adopted. The value contained in 100 g of the dry weight equivalent to one gram of ascorbic acid for DPPH free radical inhibition was calculated.

Determination of the ferric reducing antioxidant power (FRAP)

The principle of this test involves reducing the ferric iron (Fe^{3+}) to the ferrous iron (Fe^{2+}) by antioxidants in the presence of the TPTZ (2,2,6 Tri (2-pyridyl)-s-triazine) in an acidic medium (Benzie and Strain, 1996). The reducing power of iron is calculated by the value contained in 100 g of the dry weight equivalent to the inhibition of one gram of ascorbic acid.

Determination of the radical scavenging activity (ABTS)

The ABTS (2,2′-azino-bis 3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging capacity was also determined using the ABTS radical cation decolorization method described by Yousfi *et al*. (2009). The value contained in 100 g of the dry weight equivalent to the inhibition of one gram of ascorbic acid is calculated using the cationic radical ABTS.

Experimental design and statistical analysis

Sorghum landraces were raised in a randomized complete block design with three replicates. The experiment site dimension was 13,5 m length and 5,8 m width (75.6 m^2 in total) with 0.5 m spacing between micro-plots and 1m between blocks. Micro-plot area was 1.08 m^2 (1.2 m x 0.9 m), row and plant spacing were 30 cm to get 12 plants per micro-plot (Figure 1).

The results were processed utilizing SPSS statistical software, version 26 (SPSS, 2019). The univariate statistical analysis method was employed to estimate the mean, standard deviation, maximum value, minimum value, and variance. Data were subjected to multivariate analysis of variance (ANOVA) using Tukey's significant differences ($p < 0.05$). The various results were represented using superimposed bar diagrams. Pearson's correlation matrix between phenolic compounds and their antioxidant activity was examined.

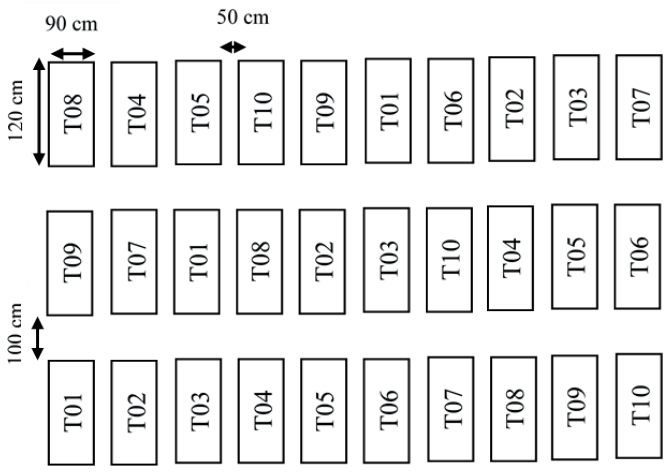

Figure 1. Experimental design.

The Ward method was employed as a multivariate statistical technique for hierarchical cluster analysis (HCA). All experiments were conducted in triplicate, when significant differences were detected ($p < 0.05$).

Results and discussion

The results obtained in the determination the active compounds are show in table 2.

Table 2 indicates that the studied samples contain total phenolic compounds ranging from 122.33 to 1,344.44 mg EAG.100 g^{-1}, with a mean value estimated at 433.86 mg EAG.100 g^{-1} and a very high dispersion with a significant variance of 70,255.09. The tannin content ranges from 4.84 to 927.78 mg EAG.100 g^{-1}, with a mean value of 281.82 mg EAG.100 g^{-1} and a substantial variance of 42,600.74. Flavonoid content varied from 0.24 to 558.25 mg EQ.100 g^{-1}, with a mean value of 82.52 mg EQ.100 g^{-1} and a variance of 11,364.34.

Table 2. Total Phenolic compound contents and antioxidant activity of leaves, stems, and panicles of sorghum plant samples.

	Phenolic Compounds (mg.100 g^{-1})			Antioxidant Activity (mg.100 g^{-1})		
	TPC	**TC**	**FC**	**DPPH**	**FRAP**	**ABTS**
LeaT01	830.48^{j}	441.42^{i-k}	121.72^{b-g}	500.84^{ghi}	413.10^{c-f}	162.23^{a-f}
LeaT02	668.65^{ij}	462.88^{jkl}	96.68^{a-f}	584.04^{e-j}	393.44^{c-f}	160.38^{a-f}
LeaT03	425.81^{b-g}	225.96^{b-g}	153.50^{c-g}	502.48^{c-i}	475.49^{d-g}	204.5^{def}
LeaT04	1197.28^{k}	808.21^{m}	464.83^{h}	1265.47^{k}	724.85^{g}	253.29^{fg}
LeaT05	463.22^{d-i}	246.82^{b-h}	195.28^{fg}	888.62^{ijk}	419.36^{c-f}	223.86^{d-g}
LeaT06	622.09^{g-j}	392.13^{g-k}	174.73^{efg}	878.97^{ijk}	588.72^{fg}	253.95^{fg}
LeaT07	448.15^{c-g}	294.25^{f-j}	73.40^{a-d}	340.15^{a-g}	254.06^{a-d}	196.43^{c-f}
LeaT08	610.18^{f-j}	437.51^{i-k}	152.84^{c-g}	771.85^{hij}	503.86e^{fg}	264.16^{fg}
LeaT09	507.36^{d-i}	288.47^{e-j}	218.86^{g}	661.69^{g-j}	587.11f^{g}	233.54^{efg}
LeaT10	786.47^{j}	629.02^{lm}	156.81^{d-g}	629.68^{f-j}	558.70f^{g}	313.33^{g}
SteT01	612.60^{f-j}	517.82^{kl}	95.56^{a-f}	99.55^{ab}	274.67^{a-e}	126.71^{a-e}
SteT02	423.01^{a-h}	257.25^{b-i}	22.63^{ab}	243.41^{a-f}	196.04^{abc}	119.95^{a-e}
SteT03	239.97^{a-d}	139.90^{a-f}	58.44^{a-d}	99.55^{ab}	143.60^{ab}	125.65^{a-e}
SteT04	268.62^{a-e}	173.94^{a-f}	32.95^{ab}	109.80^{abc}	74.01^{a}	68.92^{ab}
SteT05	188.81^{ab}	101.54^{a-d}	23.78^{ab}	83.53^{ab}	136.49^{ab}	62.16^{ab}
SteT06	167.75^{a}	84.18^{ab}	14.91^{a}	77.21^{ab}	85.03^{a}	76.48^{ab}
SteT07	409.93^{a-h}	273.53^{c-i}	54.93^{abc}	217.41^{a-e}	234.47^{a-d}	227.97^{efg}
SteT08	495.38^{e-i}	422.11^{h-l}	34.13^{ab}	509.66^{d-i}	222.82^{abc}	193.25^{c-f}
SteT09	237.87^{a-d}	121.32^{a-f}	15.17^{a}	162.28^{a-d}	133.74^{ab}	83.10^{abc}
SteT10	369.69^{a-f}	286.92^{d-j}	30.25^{ab}	178.62^{a-d}	282.06^{a-e}	171.38^{b-f}
PanT01	209.74^{abc}	36.94^{a}	17.47^{a}	142.22^{a-d}	90.84^{a}	73.56^{ab}
PanT02	182.22^{ab}	102.01^{a-b}	15.01^{a}	73.93^{a}	82.95^{a}	49.97^{a}
PanT03	281.74^{a-e}	141.98^{a-f}	27.82^{ab}	142.22^{a-d}	177.88^{abc}	167.14^{b-f}
PanT04	282.88^{a-e}	142.79^{a-f}	29.18^{ab}	280.67^{a-g}	189.24^{abc}	109.21^{a-d}
PanT05	212.70^{abc}	94.07^{abc}	9.33^{a}	81.75^{ab}	103.96^{a}	88.27^{abc}
PanT06	169.03^{a}	91.01^{abc}	14.76^{a}	70.96^{a}	84.47^{a}	71.31^{ab}
PanT07	182.08^{ab}	102.55^{a-e}	11.71^{a}	70.46^{a}	103.49^{a}	68.52^{ab}
PanT08	509.34 $^{e-i}$	381.73^{g-k}	49.19^{ab}	472.88^{b-h}	352.83^{b-f}	177.87^{b-f}
PanT09	383.35^{a-g}	216.37^{a-g}	92.96^{a-e}	324.64^{a-g}	303.82^{a-e}	129.36^{a-e}
PanT10	639.11^{h-j}	539.89^{kl}	16.67^{a}	949.45^{jk}	231.08^{a-d}	234.73^{efg}
Minimum	**122.33**	**4.84**	**0.24**	**46.10**	**31.76**	**28.89**
Maximum	**1,344.44**	**927.78**	**558.25**	**1,481.68**	**1,145.92**	**459.92**
Moyenne	**433.86**	**281.82**	**82.52**	**380.47**	**280.74**	**156.38**
Variance	**70,255.09**	**42,600.74**	**11,364.34**	**145,929.44**	**48,925.03**	**8,936.49**

LeaT: leaves, SteT: stems, PanT: panicle residues.

The highest values were recorded for the leaves compared to the stems and panicle residues, especially the leaves of the LeaT04 sample. These results revealed the richness of sorghum plants in phenolic compounds and the clear diversity among the different studied samples and their parts. These findings are considered low compared to the results obtained by (Abugri *et al.*, 2015; Tugli *et al.*, 2019; Yi *et al.*, 2025) for the red and brown sorghum leaves.

With regard to antioxidant activity, the results shown in Table 2 also indicated that the highest antioxidant activity was in the leaf samples (LeaT), where the samples LeaT04, LeaT05, and LeaT06 recorded very high values, while the stem samples (SteT) and panicle residue samples (PanT) had relatively lower values. We observed that the ability to inhibit the DPPH ranges between 46.10 and 1,481.68 mg.100 g^{-1}, with a mean value estimated at 380.47 mg.100 g^{-1} and a very strong dispersion with 145,929.44 of variance.

The values of FRAP ranged between 31.76 and 1,145.92 mg.100 g^{-1}, with a mean value of 280.74 mg.100 g^{-1} and a large dispersion measure of 48,925.03. The values of the ABTS ranged between 28.89 and 459.92 mg.100 g^{-1}, with an average value of 156.38 mg.100 g^{-1}, which is considered weak compared to the DPPH and FRAP activity values. The ABTS test also exhibited a low dispersion measure compared to the previous values, estimated at 8,936.49.

Due to the variation in the levels of phenolic compounds and their antioxidant activity, significant differences were observed among the various samples studied. This enable us to conduct a study to determine whether there were statistically significant differences among the various parts of the plant (leaves, stems, and panicle residues), and among the sorghum samples sources.

ANOVA variance analysis showed significant statistical differences at a significance level of less than 0.05 among the three parts of the plant (Table 3).

This indicates significant difference in the distribution of phenolic compounds and variations in antioxidant activity between different parts of sorghum plants.

Figure (2) shows a comparison of the average phenolic content and its antioxidant activity for leaves, stems, and panicle residues using superimposed bar diagrams.

Figure (2a) shows that the highest total phenolic compound content is found in the leaves, followed by the stems and then the panicle residues with similar values. Phenolic compounds are distributed in different parts in the same pattern, with total phenolic compound content being the highest, followed by tannin content, and finally flavonoid content.

Figure (2b) illustrates the distribution of antioxidant activity in the three parts of plants. It is evident that the antioxidant activity of the phenolic compounds are more closely related to the DPPH than to the FRAP activity, followed by the ABTS scavenging.

These compounds are usually found in high concentrations in the leaves, as they play an important role in defending against environmental stresses such as drought, salinity, among others (Kumar *et al*., 2023).

These results are consistent with those reported in many other studies. The active compounds present in sweet sorghum stems play an important role in inhibiting the growth of certain pathogenic bacteria (Chen *et al*., 2022). The compounds found in the panicle residues also help to maintain grain quality and improve resistance to insects and fungi (Awika and Rooney, 2004).

The results of the ANOVA analysis indicated significant statistical differences between the different sorghum landraces at a significance level of less than 0.05 (Table 4). This suggests that there is biochemical diversity among the sorghum landraces studied.

Figure 3 illustrates the distribution of mean values for phenolic compounds and their antioxidant activity from ten sorghum landraces.

Table 3. Homogeneous subsets of phenolic compounds and their antioxidant activity by different sorghum plant parts.

Part of the plant	Phenolic Compounds			Antioxidant Activity		
	(mg.100 g^{-1})					
	TPC	TC	FC	DPPH	FRAP	ABTS
Leaves	656.0±26.9^{b}	422.7±22.6^{b}	180.9±13.8^{b}	702.4±36.3^{b}	491.9±22.4^{b}	226.6±8.2^{b}
Panicle residues	305.2±19.2^{a}	184.9±17.4^{a}	28.4±4.3^{a}	260.9±39.4^{a}	172.1±15.7^{a}	117.0±8.2^{a}
Stems	340.4±20.7^{a}	237.9±18.8^{a}	38.3±3.2^{a}	178.1±15.8^{a}	178.3±11.9^{a}	125.6±9.0^{a}

TPC: total phenolic compounds, TC: tannin compounds, FC: flavonoid compounds,DPPH: radical scavenging activity, FRAP: ferric reducing antioxidant power, ABTS: radical scavenging activity. Different letters indicate statistically Tukey's significant differences ($p< 0.05$).

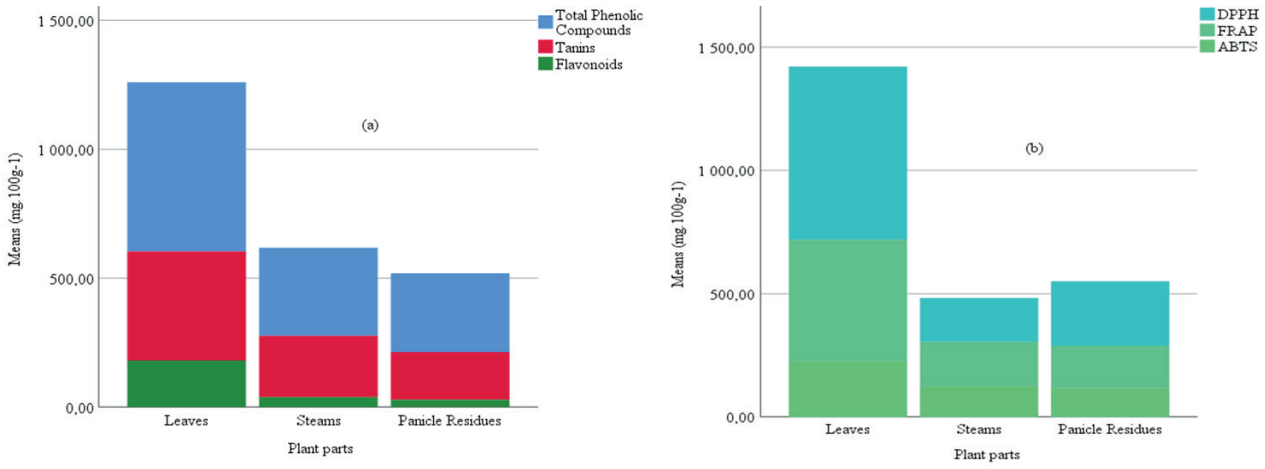

Figure 2. A bar diagram superimposed with phenolic compounds (a) and antioxidant activity (b) among leaves, stems, and panicles.

Table 4. Homogeneous subsets of phenolic compounds and their antioxidant activity by sorghum plant landraces.

Landraces	Phenolic Compounds			Antioxidant Activity		
	(mg.100 g^{-1})					
	TPC	TC	FC	DPPH	FRAP	ABTS
T01	550.9±56.9^{bcd}	332.1±47.3^{b-e}	78.3±12.2^{a}	247.5±44.3^{ab}	259.5±35.6^{a}	120.9±9.9^{a}
T02	419.2±46.3^{a-d}	274.1±36.2^{a-d}	44.8±8.5^{a}	300.45±46.6^{abc}	224.1±26.0^{a}	110.1±12.6^{a}
T03	318.0±21.8^{a}	169.3±11.9^{a}	79.9±12.6^{a}	248.1±44.7^{ab}	265.7±36.1^{a}	165.8±14.9^{abc}
T04	582.9±86.7^{cd}	375.0±61.5^{cde}	175.7±41.4^{b}	552.0±100.4^{bc}	329.4±56.2^{a}	143.81±16.3^{bc}
T05	288.2±25.2^{a}	147.5±14.6^{a}	76.1±17.2^{a}	351.3±76.4^{abc}	219.9±30.7^{a}	124.7±14.6^{a}
T06	319.6±42.5^{a}	189.1±28.5^{ab}	68.1±14.9^{a}	342.4±74.5^{abc}	252.7±46.9^{a}	133.9±17.5^{a}
T07	346.7±30.0^{ab}	223.4±23.1^{abc}	46.7±7.1^{a}	209.3±34.7^{a}	197.3±19.2^{a}	164.3±19.5^{abc}
T08	538.3±42.9^{bcd}	413.8±32.3^{de}	78.7±11.9^{a}	584.8±65.9^{c}	359.8±42.5^{a}	211.8±21.6^{bc}
T09	376.2±44.1^{abc}	208.7±28.3^{ab}	109.0±30.2^{ab}	382.9±81.0^{abc}	341.6±67.3^{a}	148.6±21.4^{ab}
T10	598.4±36.3^{d}	485.3±30.1^{e}	67.9±12.4^{a}	585.9±95.2^{c}	357.3±34.9^{a}	239.8±16.3^{c}

TPC: total phenolic compounds, TC: tannin compounds, FC: flavonoid compounds, DPPH: radical cavenging activity, FRAP: ferric reducing antioxidant power, ABTS: radical scavenging activity. Different letters indicate statistically Tukey's significant differences ($p< 0.05$).

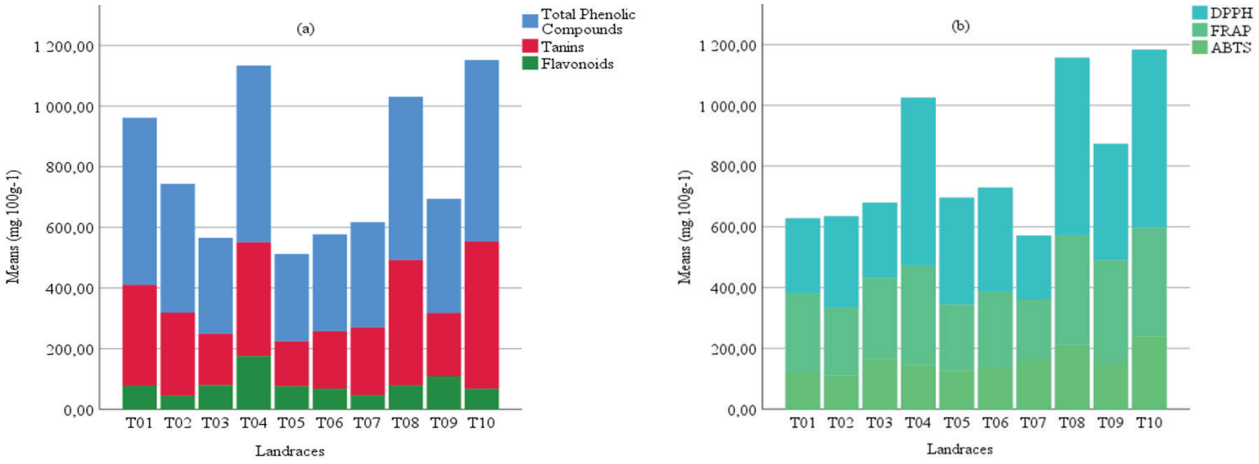

Figure 3. A bar diagram superimposed with phenolic compounds (a) and antioxidant activity (b) among sorghum landrace samples

The graph shows that the distribution of phenolic compounds in landraces matches their distribution in the different parts of the plant. The results indicate a significant variation between the landraces. It can be observed that the landraces (T01, T04, T08, T10) have the highest mean values for total phenolic content (Figure 3.a). While the landraces (T04, T08, T10) have the highest values in DPPH scavenging (Figure 3.b), the effect of ABTS scavenging remains relatively limited compared to DPPH and FRAP activity. Generally, this variation may be due to the influence of genetic differences or the impact of environmental factors and climatic conditions.

Table 5 presents a correlation matrix of the relationships between phenolic compounds and their antioxidant activity.

The matrix indicates a positive correlation between all the variables. A very strong correlation is observed between total phenolic content and tannin content with a correlation coefficient of 0.963.

There are also other strong correlations between total phenolic content and the following variables: flavonoid content (0.747); DPPH (0.778). and FRAP (0.806). The FRAP is strongly correlated with flavonoid content (0.842) and ABTS (0.794). A moderate correlation is observed between ABTS and flavonoid content (0.587). which may explain the relatively weak cationic radical scavenging effect exhibited by these compounds. In general, these results indicate that antioxidant activity is directly related to DPPH and FRAP activity. Additionally, we cannot overlook the ABTS scavenging, which

Table 5. Correlation matrix among total phenols, tannins, flavonoids, and antioxidant activity.

	TPC	TC	FC	DPPH	FRAP
TC	0.963**				
FC	0.747*	0.645			
DPPH	0.778*	0.721*	0.736*		
FRAP	0.806*	0.727*	0.842*	0.812*	
ABTS	0.728*	0.720*	0.587	0.723*	0.794*

TPC: total phenolic compounds, TC: tannin compounds, FC: flavonoid compounds, DPPH: radical scavenging activity, FRAP: ferric reducing antioxidant power, ABTS: radical scavenging activity. *: strong correlation, **: very strong correlation.

serves as an additional indicator of the ability of these plants to perform antioxidant activity. These characteristics make the phenolic compounds of sorghum grasses of health and nutritional value when offered as animal feed, as they can contribute to combating oxidative stress associated with many diseases (Mawouma *et al*., 2022).

The diagram (Figure 4) represents the results of hierarchical cluster analysis (HCA) using the Ward method.

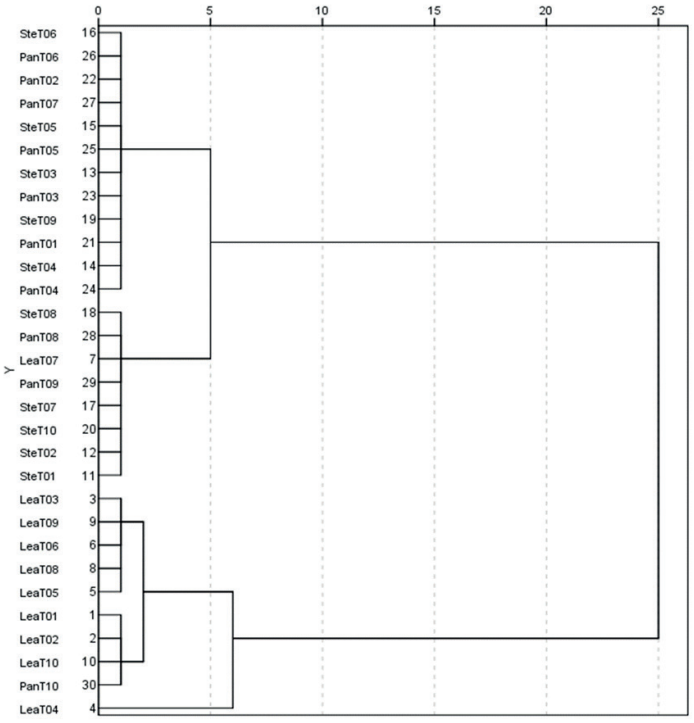

Figure 4. Dendrogram of sorghum samples (Leaves, Stems, Panicle residues) based on Ward's distance.

Was observed the presence of two main clusters originating from a distance of 7. The first cluster includes the most stem and panicle residue samples. except for the sample of the Nigerian leaves (LeaT07). While the second cluster gathers the majority of leaf samples. except for the red panicle sample from the Tamanrasset region (PanT10). These exceptions indicate the presence of both genetic and environmental factors among the studied samples (D'almeida *et al*., 2025). It can be observed that the distance between the distribution of samples within each cluster is very close. indicating a significant similarity in phenolic content and antioxidant activity between leaf samples. on one hand. and stem and panicle residue samples. on the other

Conclusion

The study results indicated a diversity among different sorghum grasses in their secondary metabolite content and antioxidant activity, suggesting a significant biodiversity among sorghum plant landraces found in the Algerian desert. The importance of these results lies in supporting the national economic strategies pursued by the Algerian government to ensure food security, health, and energy sustainability. The study results are promising, and it is recommended to support them with further future studies, such as developing techniques for extracting active compounds and studying some antibacterial, antifungal, and anticancer compounds. In addition to conducting some chromatographic analyses and identified the active compounds, as well as some applications in the nutrition of both humans and animals.

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