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Ceratotheca sesamoides Endl.: Chemical Diversity and Potential for Bioactive Compounds in Modern Pharmacological Applications

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Ceratotheca sesamoides is a plant species having notable nutritional and medicinal properties, but it remains unexplored in West Africa, despite its importance in traditional agro-food systems. This study aimed to characterize the genetic, agromorphological and biochemical diversity of local accessions in Burkina Faso and propose sustainable valorization strategies for the species. Forty-nine samples were collected from different agro-ecological zones. Genetic diversity was analyzed using simple sequence repeat (SSR) markers, with data processed by GenAiEx version 6.501, revealing significant variation among accessions. Genetic structuring was examined using the Neighbor-Joining method, identifying three distinct genetic groups. Agromorphological, physico-chemical and biochemical diversity were assessed using statistical tools in R version 4.3.3. The analysis of variance indicated significant differences in traits between groups. Pearson correlation coefficients were computed to study the relationships between key bioactive compounds like polyphenols, flavonoids, alkaloids and essential minerals, such as magnesium, copper and sodium. These findings suggest substantial potential for the species in therapeutic and nutritional applications, supporting its sustainable valorization.

Keywords: *Ceratotheca sesamoides*, Bioactive compounds, Genetic diversity, Sustainable valorization.

INTRODUCTION

Ceratotheca sesamoides Endl. is a plant from the Pedaliaceae family, endemic to West Africa, widely used in traditional practices for its medicinal and nutritional properties. It is primarily consumed as a leafy vegetable and is traditionally used to treat various ailments, including gastrointestinal disorders, skin infections and inflammatory pains [1]. Despite its significance in traditional medicine, this plant remains relatively under-researched in a scientific context, particularly regarding its genetic diversity and bioactive properties [2]. The lack of comprehensive studies on *C. sesamoides* limits the valorization of its promising pharmacological and chemical properties. This study aims to address this gap by providing an original analysis of the genetic diversity of *C. sesamoides* using simple sequence repeats (SSR) markers, which are powerful tools widely used to assess genetic variability and population structure in plants [3]. SSR markers allow for precise detection of genetic diversity within plant populations and their application to this species represents an innovative approach in analyzing its genetic traits [4]. Moreover, this research explores the physico-chemical characterization of *Ceratotheca sesamoides* extracts to identify and quantify the bioactive compounds present in the plant and evaluate their therapeutic and nutritional potential.

The bioactive properties of medicinal plants are often linked to secondary metabolites such as alkaloids, flavonoids and polyphenols, whose production can vary depending on genetic and environmental factors [5]. The assessment of bioactive compounds in *C. sesamoides* is part of an approach aimed at determining the pharmacological properties of this species and exploring its potential for industrial applications in the pharmaceutical and food sectors [6]. The primary objective of this study is to investigate that *C. sesamoides* can be considered an untapped chemical reservoir, highlighting the diversity of its bioactive compounds and the genetic variability within its populations. Such an approach lays the foundation for the scientific and commercial valorization of this underutilized plant. Furthermore, this study aims to provide data that could open new perspectives for its inclusion in pharmacology and

nutrition research and development programs [7]. The use of SSR markers to analyze this genetic diversity is an innovative approach for this plant and represents a first in the systematic evaluation of its chemical and pharmacological potential. Therefore, this study contributes to identifying *C. sesamoides* as a potential source of bioactive compounds for both traditional medicine and industrial applications in the pharmaceutical and food industries [8].

EXPERIMENTAL

The plant material consists of 49 samples of *Ceratotheca sesamoides*, collected from four administrative regions of Burkina Faso, spanning two agroclimatic zones.

Microsatellite markers used for genetic diversity study: A total of 12 microsatellite primers, originally developed for sesame (*Sesamum indicum* L.), a closely related species, since no SSR primers had yet been developed for *C. sesamoides* at the time of this study, were used for the genetic diversity study of the 49 *C. sesamoides* samples. These markers consist of tandem repeats of mono-, di-, tri- or tetranucleotide motifs. These repeats are found in both coding and non-coding regions [9] and are typically characterized by a high degree of length polymorphism [10]. The most common of these microsatellites are (A)n, (TC)n, (TAT)n and (GATA)n (Table-1). The "n" value can range from a few units to several tens [11].

The equipment used included an oven for drying leaves, a precision balance for weighing, a pH meter and Whatman filters for pH measurement and a titration apparatus for titratable acidity. Water activity was measured with an AquaLab 4TE and a rotary shaker ensured homogeneous polyphenol extraction, with an OASIS cartridge used for solid-phase purification. Glycosides were separated by HPLC, terpenes extracted *via* steam distillation and ash content determined using a muffle furnace. Minerals and trace elements (Mg, K, Na, Ca, Fe, Cu) were estimated by flame atomic absorption spectrometry after sample digestion.

Genomic DNA extraction: Genomic DNA was extracted from 0.2 g of 21-day-old leaves using a modified CTAB protocol, including TES buffer during tissue grinding and an extended incubation at 60 ºC. The final DNA pellet was rinsed with 70% ethanol, resuspended in TE buffer and stored at -20 ºC.

PCR amplification: PCR reactions (25 µL) were prepared with 40 ng/µL genomic DNA, 10 µM primers and a commercial PCR mixture containing Taq polymerase. The thermal profile consisted of an initial denaturation at 94 ºC for 3 min, followed by 45 cycles (94 ºC, 1 min; 48 ºC, 2 min; 72 ºC, 2 min) and a final extension at 72 ºC for 15 min.

Electrophoretic migration and band reading: Amplified products were separated on 2% agarose gels in Tris-borate-EDTA (TBE) buffer, stained with ethidium bromide and visualized under UV light. Fragment sizes were estimated by comparison with a molecular weight marker (50-2000 bp).

Determination of physico-chemical characteristics: Leaf moisture content was determined by oven-drying at 105 ºC until constant weight, a standard and widely used method for plants [12]. The dry matter percentage of the leaves was calculated by subtracting the moisture content from 100%, which allowed the determination of the dry matter content in each leaf sample [13]. Leaf pH was measured by dissolving 10 g of leaves in 100 mL of distilled water, filtering and reading with a calibrated pH meter, a method widely used in plant studies [14]. Titratable acidity of *C. sesamoides* leaves was determined

TABLE-1
CHARACTERISTICS OF THE MICROSATELLITE PRIMERS USED

Primer	Sequence	Melting temperature (ºC)	Repeated Motif and number	Size (bp)
AY838905	F: GGAGAAATTTTCAGAGAGAAAAA R: ATTGCTCTGCCTACAAATAAAA	53.0	(AG)17	155-164
AY838921	F: CCATTGAAAACTGCACACAA R: TCCACACACAGAGAGCCC	55.7	(AT)11, (TC)18, (TG)12	221-259
AY838907	F: CCCAACTCTTCGTCTATCTC R: TAGAGGTAATTGTGGGGGA	55.9	(CT)18	217-231
AY838909	F: TTTTCCTGAATGGCATAGTT R: GCCCAATTTGTCTATCTCCT	53.2	(AG)24	263-275
JL328139	F: AGAGATCCAATCAAATGTGC R: CACCAATAGGAACAAATACTCG	54.8	TA	215
JL331244	F: AGTCCCACCGTCTTGTCT R: GAGGTGGAGTGCCTATATTCT	56.9	TC	184
JL332475	F: GGACTAGATATCGGTGATCCT R: GGTTAAACAAGTCCGTCTTTC	56.9	GGT	216
JL335867	F: CCTGACTTTCACAAGAACTGA R: TGCCACATTTTGTTACACAC	54.5	ATC	203
JL336321	F: TACAAAACTCAGCAGCAACA R: GCAGAAACGATGAAGAGAAG	54.2	CCTTTG	193
HQ236491	F: AGGAAGAACAACGGTGGAGA R: CGCCCTTTTACGTTTCTCTG	57.3	(AG)4, (GAA)2, (AG)7	200
HQ236492	F: TGGGAAATAGGATTGCCACT R: GGGTTTCAATAAGGGGGAGA	56.3	(TTC)2, (CCTTT)2	185
HQ224876	F: CACCGCTCGAACTCTCTCTCCTT R: GACTTGTCCGACCATCCATC	59.4	(TC)7, (AC)10	217

by titration with 0.1 N NaOH using 2% phenolphthalein, a standard method for plant acids [15]. Leaf water activity was measured at 35 ºC using a calibrated AquaLab 4TE, a key parameter for metabolite preservation and bioactive compound stability [16].

Determination of macronutrients: Alkaloids were extracted using ethanol, methanol and chloroform and their content was quantified by spectrophotometry, a widely validated method for medicinal plants [17]. Flavonoids were extracted with ethanol, methanol and acetone and quantified by spectrophotometry, a standard method for medicinal plants [18]. Tannins were extracted with distilled water and ethanol and quantified by spectrophotometry, a simple and sensitive method widely used for plants [19]. Saponins were extracted with ethanol and methanol and quantified using the foam test, a rapid and effective method for plant saponins [20]. Terpenes were extracted by steam distillation using hexane or chloroform and quantified by gas chromatography, the standard method for essential plant oils [21]. Glycosides were extracted using methanol, acetone and ethanol, then analyzed by HPLC, a reference method for glycoside analysis [22]. Polyphenols were extracted with methanol and acetic acid and quantified by spectrophotometry, a common, accurate and easy method for plant extracts [23].

Mineral and trace element quantification: Minerals (Mg, K, Na, Ca) and trace elements (Fe, Cu) in the leaves were determined by atomic absorption spectrometry. This method, widely used for the quantification of mineral elements in plant tissues, allows for precise measurement of element concentrations [24]. After dissolving the samples in HCl and decomposing the organic matter in a muffle furnace at 450 ºC for 2 to 4 h, the elements were quantified after appropriate dilution. This organic matter combustion step is crucial to prevent interference in the measurement of metallic elements [25].

Statistical data analysis: The statistical analysis was conducted to assess the genetic, agro-morphological and biochemical structuring of *C. sesamoides* accessions. The molecular data obtained from SSR markers were processed using GenAlEx 6.501 software, allowing the calculation of several genetic diversity parameters. To visualize the genetic structuring of the accessions, a simple matching dissimilarity matrix was generated and analyzed in DARwin 6.0 software using the Neighbor-Joining grouping method. All additional statistical analyses were performed using R software, version 4.3.3. Analysis of variance (ANOVA), conducted under R, was used to test the significance of differences between genetic groups concerning agromorphological, physico-chemical and biochemical variables, with a significance threshold set at 5% ($p < 0.05$). The concentrations of bioactive compounds were compared across groups and effect sizes (Eta^2) were calculated to determine the contribution of each compound to differentiation. In parallel, a Pearson correlation analysis was carried out to explore the relationships between bioactive compounds and mineral elements. The results of these correlations were represented in the form of a heatmap, providing an intuitive visualization of the positive and negative relationships between the different variables. Medicinal and mineral potentials of *C. sesamoides* groups were quantified using a normalized scoring system. Each variable (bioactive compound or mineral) was scaled between 0 and 1 based on its minimum and maximum values across all groups. Group scores were calculated as the mean of normalized values:

$$\text{Medicinal score} = \frac{1}{n}\sum_{i=1}^{n}\frac{X_i - X_{min,i}}{X_{max,i} - X_{min,i}}$$

$$\text{Mineral score} = \frac{1}{m}\sum_{j=1}^{m}\frac{Y_j - Y_{min,j}}{Y_{max,j} - Y_{min,j}}$$

X_i and Y_j are the values of bioactive compounds and minerals, $X_{min,i}$, $X_{max,i}$, $Y_{min,j}$, $Y_{max,j}$ are the minimum and maximum values across groups and n and m are the numbers of bioactive compounds and minerals considered. The total score represents the sum of medicinal and mineral scores. scores approaching 1 indicate high potential, scores near 0 indicate low potential and intermediate values represent moderate performance.

RESULTS AND DISCUSSION

Genetic groups descriptions: Table-2 presents the genetic parameters of the three genetic groups obtained using the Neighbor-Joining method. Genetic group 1 has the highest genetic parameters, with an effective allele number of 1.88, a polymorphism of 100%, an observed heterozygosity of 0.27, an expected heterozygosity of 0.26, a Shannon diversity index of 0.72, an inbreeding coefficient of 0.31 and a polymerphism information content (PIC) of 0.45. Genetic group 3 showed an effective allele number of 1.97, a polymorphism of 83.34%, an observed heterozygosity of 0.29, an expected heterozygosity of 0.38, a Shannon diversity index of 0.69, a PIC of 0.45 and an inbreeding coefficient of 0.24. Genetic group 2 had the lowest genetic parameters, with an effective allele number of 1.82, a polymorphism of 83.34%, an observed heterozygosity of 0.28, an expected heterozygosity of 0.37, a Shannon diversity index of 0.63, a PIC of 0.41 and an inbreeding coefficient of 0.24.

TABLE-2
DIVERSITY PARAMETERS OF THREE GENETIC GROUPS

Groups	Ne	I	Ho	He	PIC	FIS	P (%)
G 1	1.88	0.72	0.26	0.39	0.45	0.31	100
G 2	1.82	0.63	0.27	0.36	0.41	0.24	83.34
G 3	1.97	0.69	0.28	0.38	0.45	0.24	83.34
Averages	1.89	0.68	0.27	0.38	0.44	0.26	88.89

Legend: Ne: Number of effective alleles; I: Shannon Diversity Index; Ho: Observed heterozygosity; He: Expected heterozygosity; FIS: Departure from panmixia in a subpopulation; PIC: Polymorphism Information Content; P: Percentage of polymorphic loci

Genotypic structure of accessions based on Neighbor-Joining method: The Neighbor-Joining tree constructed from molecular data reveals a clear structure of the 49 accessions into three distinct genetic groups (Fig. 1). Group 1 consists of the largest and most branched accessions, with high internal cohesion. Group 2 exhibits intermediate characteristics and greater variability. Group 3, distinctly separated from the other two, consists of smaller and less branched accessions.

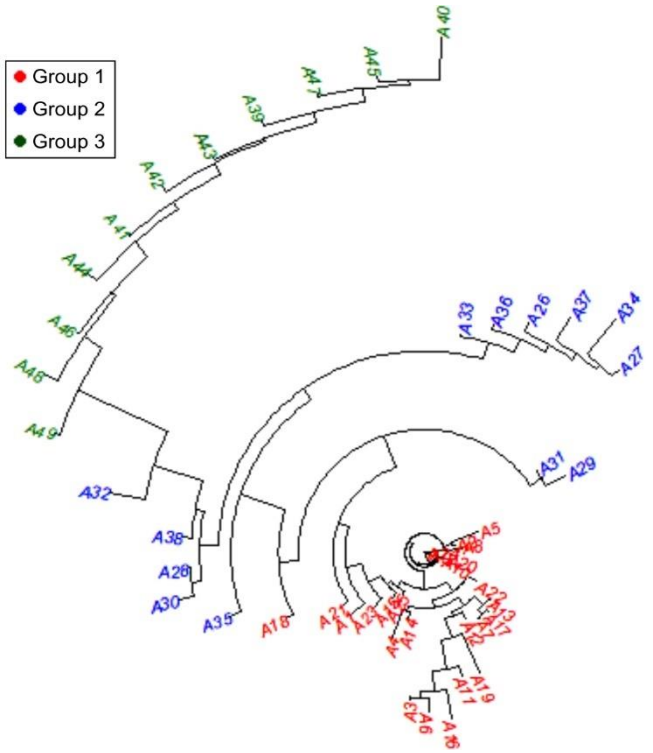

Fig. 1. Phylogenetic tree of 49 *C. sesamoides* accessions constructed using SSR marker data.

Variation in physico-chemical characteristics of accessions: Table-3 shows that moisture, dry matter, total acidity, pH and water activity varied slightly between groups. However, none of these differences were statistically significant (Pr > F > 0.3).

Variation in bioactive compound concentrations in accession groups: Table-4 shows that Group 1 has a significantly higher concentration of alkaloids compared to Groups 2 and 3. Regarding flavonoids, Group 1 has a significantly higher concentration than Group 3, while Group 2 is intermediate, with a significant difference (Pr > F = 0.014). For glycolsides, Groups 1, 2 and 3 show similar concentrations and the P-value of 0.682 indicates no significant difference between the groups for this compound. For polyphenols, Group 1 has the highest concentration, followed by Group 2 and Group 3, with a significant difference observed (Pr > F = 0.035). Saponins have similar concentrations across the groups, with 5% for Group 1, 4% for Group 2 and 3% for Group 3 and the P-value of 0.485 shows no significant difference. For tannins, Groups 1 and 3 have higher concentrations than Group 2 and the difference is significant (Pr > F = 0.041). Finally, for terpenes, Groups 1, 2 and 3 have similar concentrations and the P-value of 0.145 shows no significant difference between the groups.

Effect sizes of bioactive compounds across groups: Fig. 2 indicate that polyphenols, flavonoids and tannins have the strongest effects, with Eta^2 values of 0.99 and 0.98 and confidence intervals close to 1. Saponins and alkaloids show high effects, with Eta^2 values of 0.90 and 0.84, respectively. Glycosides exhibit a moderate effect with an Eta^2 of 0.65, while terpenes have the lowest effect with an Eta^2 of 0.24.

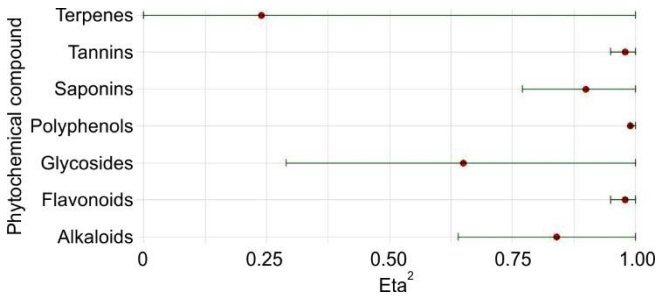

Fig. 2. Strength of differences in bioactive compound concentrations among groups

Analysis of mineral variation and accessions across three groups: The concentrations of mineral elements meas-

TABLE-3
PHYSICO-CHEMICAL PARAMETERS OF DIFFERENT TREATMENT GROUPS

Treatment	Variables				
	Moisture (%)	Dry matter (%)	Total acidity (meq/L)	pH	Water activity
Group 1	10.94	91.06	205.25	6.85	0.52
Group 2	10.88	88.49	212.04	6.59	0.45
Group 3	11.01	90.21	199.58	7.05	0.51
Pr > F	0.586	0.651	0.312	0.724	0.854

TABLE-4
CONCENTRATIONS OF BIOACTIVE COMPOUNDS IN THE ACCESSION GROUPS

Treatment	Variables						
	Alkaloids (%)	Flavonoids (%)	Glycosides (%)	Polyphenols (%)	Saponins (%)	Tannins (%)	Terpenes (%)
Group 1	2 a	4.5 a	3 a	14 a	5 a	10 a	3 a
Group 2	0.5 b	3 ab	2.5 a	10 b	4 a	6 b	2.5 a
Group 3	0.5 b	1.5 b	2 a	8 b	3 a	9 a	2.5 a
Pr > F	0.046	0.014	0.682	0.035	0.485	0.041	0.145

ured in the three treatment groups show significant differences for some elements and no difference for others (Table-5). Copper is significantly higher in Group 1 compared to Groups 2 and 3, with a P-value of 0.0124. Regarding iron, Group 1 also presents the highest concentration, followed by Group 2 and Group 3, with a significant difference (Pr > F = 0.0168). For magnesium, the concentrations differ significantly across the groups, with 79.25 for Group 1, 89.25 for Group 2 and 77.65 for Group 3 (Pr > F = 0.0425). In contrast, for potassium, the concentrations are very similar across the groups and no significant difference was observed (Pr > F = 0.925). Concerning sodium, Group 1 shows the highest concentration (19.87), followed by Group 2 (15.04) and Group 3 (14.35), with a significant difference (Pr > F = 0.029). Finally, for calcium, although variations were observed between the groups, with 387.08 for Group 1, 354.82 for Group 2 and 286.71 for Group 3, no significant difference was found (Pr > F = 0.347).

Effect sizes of mineral concentrations in different groups: Fig. 3 shows that calcium, magnesium and potassium exhibit a maximal Eta^2 of 1.00, with confidence intervals very close to 1. Sodium has an Eta^2 of 0.99, with a confidence interval ranging from 0.98 to 1.00. Iron shows an Eta^2 of 0.81, with a confidence interval from 0.58 to 1.00. Copper has the lowest Eta^2, equal to 0.69, with a confidence interval ranging from 0.36 to 1.00.

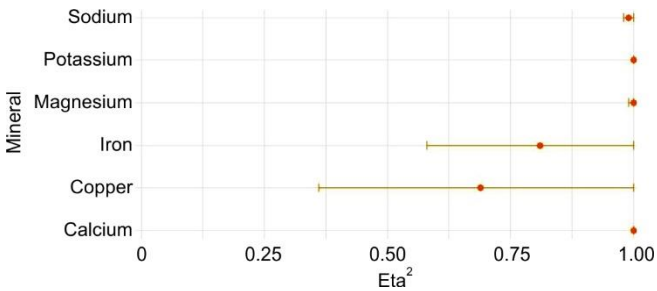

Fig. 3. Importance of differences in mineral concentrations among the groups

Relation between bioactive compounds and minerals: Fig. 4 reveals a strong positive correlation between copper and polyphenols, alkaloids, sodium and magnesium. Magnesium also shows a strong positive correlation with alkaloids, polyphenols, sodium and copper. Sodium is strongly correlated with alkaloids, polyphenols, magnesium and copper. Alkaloids exhibit marked positive correlations with polyphenols, sodium, magnesium and copper. Polyphenols are strongly correlated with alkaloids, sodium, magnesium and copper. In contrast, saponins display a strong negative correlation with copper, magnesium, sodium, alkaloids and polyphenols. Tannins also show a strong negative correlation with copper, magnesium, sodium, alkaloids and polyphenols. Flavonoids are strongly negatively correlated with copper, magnesium, sodium, alkaloids and polyphenols. Iron, terpenes, glycosides, calcium and potassium mainly exhibit moderate correlations with the other variables. Some moderate positive or negative correlations appear depending on the pairs. The hierarchical clustering highlights two main groups. The first group includes minerals such as copper, magnesium and sodium, associated with alkaloids and polyphenols. The second group includes secondary compounds such as saponins, tannins and flavonoids. These groupings reflect the proximities in the observed correlation profiles.

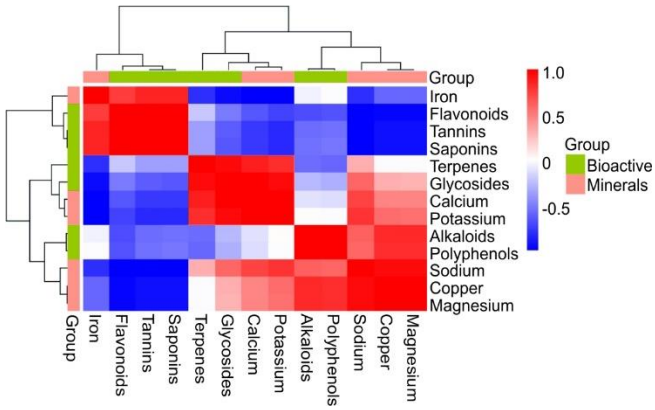

Fig. 4. Relationship between bioactive compounds and mineral elements in *Ceratotheca sesamoides*

Medicinal and industrial potential of *C. sesamoides* through bioactive compounds and mineral scores: Table-6 shows that Group 1 presents a good balance between bioactive compounds and minerals, making it the group with the highest medicinal and industrial potential. It achieves the highest total score, with a average score of 3.06 for bioactive compounds and a mineral score of 19.515, resulting in a total score of 22.575. Group 3, although having the highest average score for bioactive compounds (5.515), has a mineral score of 16.245, making it slightly less mineral-rich than Group 1. However, this group could still be of interest for applications requiring a high potential for bioactive compounds, even though it is less versatile on the mineral side. Finally, Group 2 receives the lowest total score (15.750), with a low average score for bioactive compounds (1.88) and a mineral score of 13.870. This group therefore has lesser potential for both medicinal and mineral applications.

The results of this study provide an in-depth analysis of the genetic and chemical diversity of *C. sesamoides*, revealing

TABLE-5
MINERAL ELEMENT CONCENTRATIONS IN THE DIFFERENT TREATMENT GROUPS

Treatment	Variables					
	Copper (mg/100 g)	Iron (mg/100 g)	Magnesium (mg/100 g)	Potassium (mg/100 g)	Sodium (mg/100 g)	Calcium (mg/100 g)
Group 1	4.232 a	7.25 a	79.25 a	1625.24 a	19.87 a	387.08 a
Group 2	3.612 b	6.67 ab	89.25 b	1601.45 a	15.04 b	354.82 a
Group 3	4.085 ab	6.054 b	77.65 a	1687.69 a	14.35 b	286.71 b
Pr > F	0.0124	0.0168	0.0425	0.925	0.029	0.347

TABLE-6
COMPARISON OF MEDICINAL AND MINERAL SCORES OF DIFFERENT *Ceratotheca sesamoides* GROUPS

Groups	Average medicinal score	Average mineral score	Average total score
Group 1	3.06	19.515	22.575
Group 2	1.88	13.870	15.750
Group 3	5.515	16.245	21.760

several important trends related to adaptation, genetic structuring and the pharmacological potential of this species. The application of the Neighbor-Joining method allowed the identification of three distinct genetic groups, each exhibiting unique morphological and genetic characteristics. These differences likely reflect varied evolutionary dynamics within the studied population [26]. Group 1 displays higher genetic diversity, indicating significant genetic variability among its accessions. This variability could be the result of strong natural selection pressures and environmental factors favouring specific adaptations. Such genetic diversity is commonly observed in populations subjected to intense selection pressures, which promote powerful adaptive mechanisms [27]. Accessions of Group 1, characterized by larger and more branched sizes, are likely better adapted to favourable environments, which could explain their more complex genetic structure. Group 2, on the other hand, shows intermediate genetic diversity, which may result from more restricted gene flow or less intense selection pressure. This could suggest an adaptation to specific ecological conditions that are less demanding, where genetic diversity is sufficient to maintain genetic stability while favouring local adaptation. Studies have shown that such groups can evolve in particular ecological niches without experiencing strong selection pressures [28]. Group 3 exhibits a more homogeneous genetic structure, indicating stronger genetic isolation. This group includes smaller and less branched accessions, which may be linked to more severe environmental conditions or a more restricted mode of reproduction. Geographic or ecological isolation may be responsible for this genetic fixation, as has been observed in other studies on genetically isolated populations [27]. Chemical analyses also allowed for the examination of variation in bioactive compounds within this species, although differences between groups in parameters such as moisture, dry matter, acidity, pH and water activity were not significant. These results suggest that intrinsic factors such as genetics and the environment are the main influences on the chemical composition of *C. sesamoides*. On the other hand, the lack of significant variations in these parameters might indicate some robustness in the samples, which is favourable for their conservation and use in pharmacological applications [29]. The absence of significant differences in moisture and dry matter content suggests a general stability of the samples, which could have implications for the extraction and stability of bioactive compounds. Chemical stability observed in the samples is often a crucial criterion for pharmaceutical applications, where consistency in bioactive properties is essential [30]. Alkaloids, known for their antitumor, analgesic and antimicrobial effects, are particularly concentrated in Group 1, making it promising for pharmacological applications. This high concentration of alkaloids in Group 1 supports the idea that specific genetic or environmental factors favour the production of these compounds [31]. Previous studies have also shown that higher alkaloid concentrations in certain plant populations can be linked to specific growth conditions. Flavonoids, being antioxidants, anti-inflammatory and antimicrobial, are also present in high concentrations in Group 1. This observation further highlights the potential of this group for therapeutic applications related to oxidative stress management and inflammatory diseases. Flavonoids are well-studied bioactive compounds and their concentration can be influenced by environmental factors such as UV irradiation and growth conditions [30]. Group 3 also shows elevated concentrations of polyphenols and tannins, but to a more moderate extent. These compounds, which have antioxidant and antimicrobial properties, could also be utilized in the development of pharmacological treatments and medicinal formulations aimed at combating infections and inflammation [32]. The analysis of mineral elements shows that Group 1 contains significantly higher concentrations of copper and iron, essential minerals for various biological functions such as energy production and enzyme synthesis. Therefore, this group could have important pharmacological potential, particularly for treating nutritional deficiencies [33]. Minerals are crucial for human health and their variation within *C. sesamoides* could have implications for their use in medical treatments, as indicated by various studies on mineral-rich plants. *C. sesamoides* exhibits significant genetic and chemical variability that could be exploited for various pharmacological applications. The differences between the genetic and chemical groups of this species suggest that populations with specific characteristics may offer distinct therapeutic benefits. Future research should explore the relationship between genetics, environment and the production of bioactive metabolites to optimize the utilization of this plant for healthcare purposes. The negative correlations observed between tannins, saponins, flavonoids and mineral contents are noteworthy and may reflect underlying biological trade-offs. One possible explanation is a biosynthetic trade-off, where the plant allocates limited metabolic resources preferentially toward the synthesis of secondary metabolites such as tannins and flavonoids, potentially at the expense of mineral accumulation [34,35]. Furthermore, interactions with soil nutrients could influence these patterns, as variations in mineral availability may modulate the biosynthesis of bioactive compounds [36,37].

Conclusion

This study highlights the genetic, physico-chemical and biochemical diversity of *Ceratotheca sesamoides*, employing an integrated and comparative approach to the identified genetic groups. Genetic group 1 stands out for its high genetic parameters, marked agromorphological diversity and significant richness in bioactive compounds such as alkaloids, flavonoids, polyphenols and tannins. It also exhibits significantly higher concentrations of iron, copper and sodium, further strengthening its potential as a reservoir of pharmacologically interesting compounds. Correlation analyses reveal strong positive associations between certain minerals, remarkably copper, magnesium, sodium and bioactive compounds such as alkaloids and polyphenols, while saponins, flavonoids and tannins

are negatively correlated with these same minerals. Hierarchical analysis uncovers two distinct biochemical profiles, emphasizing a clear structuring of the groups. Finally, the evaluation of combined medicinal and mineral potential scores places Group 1 as the most promising for both therapeutic and industrial applications, followed by Group 3, which could be suitable for targeted uses focusing on bioactive compounds. Although Group 1 appears to be the most promising overall, Group 3, which has the highest polyphenol content, may also hold specific potential for applications in the nutraceutical or antioxidant industries. These findings open up prospects for the phytopharmaceutical valorization of this locally exploited species, contributing to a modern pharmacopeia based on biodiversity. To better contextualize the pharmacological potential of *C. sesamoides*, it is useful to compare its bioactive compound profile and mineral composition with those of other Pedaliaceae species as well as medicinal plants commonly used in West Africa. Such a comparison includes alkaloids, flavonoids, polyphenols, saponins, tannins and terpenoids, together with key minerals such as copper, magnesium, sodium, iron and calcium. Reference species include *Sesamum indicum* and *Ceratotheca triloba*, while widely recognized regional medicinal plants include *Hibiscus sabdariffa*, *Moringa oleifera* and *Ocimum gratissimum*. This comparative approach highlights the specific chemical and mineral richness of *C. sesamoides*, situates it within a broader pharmacological and nutritional framework and provides a solid basis for its pharmaceutical or nutraceutical valorization.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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