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Review Article

Cymbopogon schoenanthus (L.) Spreng: A Comprehensive review on phytochemical and pharmacological biodiversity

Iman A.M. Abdel-Rahman[1], Ali E. Raslan[2], Abdallah Dawy[1], Ayda Wail[1], Fatma Ahmed[1], Klara Hany[1], Mostafa M. Al-Monair[1], Omnia Ahmed[1], Mohammed I. Rushdi[1], And Ahmed E. Allam[2]*

[1]Department of Pharmacognosy, Faculty of Pharmacy, South Valley University, 83523, Qena, Egypt
[2]Department of Pharmacognosy, Faculty of Pharmacy, Al-Azhar University, Assiut 71524, Egypt

ABSTRACT

There are a broad variety of classes of bioactive compounds that have already been isolated from *Cymbopogon schoenanthus* (L.) Spreng. (Poaceae). The phytochemical composition of *C. schoenanthus* has recently received considerable interest and a vast array of components including terpenes, diterpenes and sesquiterpenes as well as phenolic acids have been characterized. The contribution of these valued metabolites to the biological potential, includes inhibiting kidney stone formation, antimicrobial, antioxidant, anti-proliferative, anti-inflammatory, anticonvulsant, and nephroprotective activities has also been explored. The structural diversity, selectivity for *C. schoenanthus*, and biological effects of the reported isolated constituents have generated a huge interest in the field of drug discovery research. Therefore, phytochemical, pharmacological, and biopharmaceutical characteristics of components identified from *C. schoenanthus* since 1975 are the topic of this comprehensive review.

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1. Introduction

The World Health Organization's (WHO) strategy, 2014–2023 aims to strengthen the role of traditional medicine, placing a strong emphasis on the importance of promoting and incorporating the use of medicinal plants in the health systems of its member countries (Sánchez et al, 2020).

In developed countries, there is growing interest in the use of medicinal plants, which are also the primary therapeutic approach in 80% of developing countries. The majority of the global population (87.5%) uses traditional herbal medicine to treat health difficulties (Parveen et al, 2015). Furthermore, the rise in systematic reviews and prevalence studies about herbal medicines over the past 15 years is indicative of the increased interest in the use of medicinal plants (McLay et al., 2016). Over the few years, a huge number of scientific investigations have been performed on a wide range of herbal plants which were reported to play a critical role in the life of human beings and have an eliciting part in their lifestyles. These attempts have led to the isolation of a large number of valuable natural compounds in different plant species. In reality, medicinal plants are used in different scientific disciplines, from food industries to the fragrance and cosmetics domain, to different medicinal and pharmaceutical approaches (Mohammadhosseini et al, 2021a; Olaoluwa et al., 2022). Approximately, 74% of the 121 therapeutically active phytochemicals derived from plants that are being used around the world were identified after additional study was conducted to substantiate their use as ethnomedicine. However, medical systems are still not well-documented (Olaoluwa et al., 2022). The World Health Organization (WHO) recently classified traditional medicine, which includes herbal remedies, as therapeutic strategies used for hundreds of years before the invention and popularity of modern medicine. The Food and Drug Administration (FDA) and the European

✉ Corresponding author: Ahmed E. Allam
Tel:+2 0882080711; Fax: +2 0882080711
E-mail address: ahmedallam@azhar.edu.eg, **doi: 10.30495/tpr.2022.1966529.1276**

Medicines Agency (EMA) have recently showed a strong interest in the development of botanical medications and investigated the regulatory frameworks that control their use (Thagriki and Ray, 2022). Medicinal plants have been used for the treatment of viral infections in humans and animals (Betancur-Galvis et al., 1999; Kudi and Myint, 1999; WHO, 2008). They have been reported to inhibit viruses from replicating their DNA and RNA (Mahmoudi et al., 2014). Bhuiyan and his team reported 219 plants from 83 families that have powerful antiviral activity during the COVID-19 epidemic. For use against covid-19, 149 plants from 71 families were selected from the list and evaluated for major secondary metabolites (Bhuiyan et al., 2020).

Many biologically active compounds were isolated from plants that were traditionally used in folk medicine (Mohammadhosseini et al; 2021b; Rushdi et al., 2022). Referring to the biodiversity in the Egyptian environment leads to the diversity of the sources of medicinal plants that are both economically significant and beneficial to human health (Rushdi et al., 2020).

The genus *Cymbopogon* Spreng. is widely distributed in the tropical and subtropical regions of Africa, Asia and America (Ullah et al., 2020). The *Cymbopogon* genus consists of about 180 plants, including different species, subspecies, varieties, and subvarieties (Zahra et al., 2020). *Cymbopogon* species are mostly recognized for their highly content of essential oil that has been exploited in perfumes, cosmetics, food flavors, and pharmaceuticals (Khanuja et al. 2005). This genus is famous for its high content of essential oils which have found widespread use in the cosmetic, medicinal, and perfumery applications (Avoseh et al., 2015; Ullah et al., 2020; Nahar et al., 2021; Mohammadhosseini et al; 2022), Additionally, the oils possess numerous biological activities against several illnesses, such as infections, cancer, and digestive disorders (Khadri et al., 2008; Malti et al., 2020). The essential oil contains varying volatile constituents among the different Cymbopogon chemotypes, e.g., neral, geranial, citronellol, geraniol, and piperitone (Avoseh et al., 2015). Moreover, phytochemical investigation of different species revealed the presence of terpenoids, alkaloids, phenolic acids, tannins, and carotenoids, and the genus *Cymbopogon* was reported to be a rich source of C-glycosyl flavonoids (Rizk et al., 1995; Cheel et al., 2005; Asaolu et al., 2009). The high essential oil and phenolic content in *Cymbopogon* emphasizes its strong antioxidant activity. Most phytochemical studies on *Cymbopogon* have focused on *C. citratus*, with less emphasis on other species within that genus (Otify et al., 2022). Most reports have been also related to the essential oil composition (Cerceau et al., 2020; Otify et al., 2022) with limited research on other secondary bioactive constituents likely to mediate for the genus biological effects. *Cymbopogon schoenanthus* (L.) Spreng., locally known as Halfabar traditionally named as camel grass, is a desert species that grows in deserts, semi-arid bushlands, dry steppes, savanna and woodland. It can also be found in open stony areas, stone gullies and disturbed areas along roads and drainage lines (Sabry et al., 2014; Hashim et al., 2017; Prota 2019).

The species *Cymbopogon schoenanthus* (L.) Spreng. is constituted of two sub-species, *C. schoenanthus* ssp. Schoenanthus [synonyms = ssp. *laniger* (DESF.) Maire & Weiller; *Andropogon schoenanthus* Linnaeus] and ssp. *Proximus* (Hochst. ex A.Rich.) Maire& Weiller (Malti et al., 2020). The plant is an effective renal antispasmodic and diuretic agent and it was shown to possess sedative, digestive and anti-parasitic properties (El-Askary et al., 2003; Sabry et al., 2014). It was used for the prevention and treatment of acute inflammatory skin conditions as an antifungal and anti-inflammatory agent (Norbert et al., 2014). It has also been used as an anti-abortive, anti-convulsive or laxative agent, aroma and anti-rheumatic, asthmatic, and antipyretic agent (Ketoh et al., 2006). *C. schoenanthus* is native to the Sahara and Sahel region, from North and West Africa to the Arabian Peninsula (Clayton et al., 2016). The current review was designed to discuss the industrial, phytocosmotic applications, bioactive constituents and pharmacological activities of *C. schoenanthus* which includes inhibiting kidney stone formation, antimicrobial, antioxidant, anti-proliferative, anti-inflammatory, anticonvulsant, antidepressant, antiulcer, antihypertensive, and nephroprotective activities. The phytochemical analysis of *C. schoenanthus* showed the presence of alcohols, aldehydes, terpenes, diterpenes, sesquiterpenes, amino acids, as well as phenolic acids (Fig. 1 and Fig. 2).

2. Results and Discussion

2.1. Chemotaxonomic approach of *Cymbopogon schoenanthus* (L.) Spreng.

Heiba and Rizk (1986) studied the essential oils of *Cymbopogon schoenanthus* (L.) Sprengel from Tunisia and their components. They reported the presence of citronellol, farnesol, geraniol and sesquiterpene alcohols.

The major constituents of *C. schoenanthus* (L.) Spreng. fresh leaves oil from Jaisalmer of Indian Thar desert just after the monsoon season (July to September 1990) were found to be characterized by the presence of a series of methyl ketones like 2-nonanone (2.6%), 2-undecanone (14.7%) and 2-tridecanone (3.8%). Other major constituents of the oil were limonene (19.5%), camphene (8.0%), and a group of oxygenated sesquiterpenes of which elemol (4.5%), α-cadinol (3.4%), τ-cadinol (2.7%) and τ-muurolol (2.2%) were the most abundant (Shahi et al., 1993).

During the study of essential oil extraction process of *C. schoenanthus* Spreg leaves obtained from Algeria, where they were dried in the shade with pressured CO_2, and to compare the results with a conventional process of extraction with solvent (ethanol).The main components of the oil of *C. schoenantus* were *cis-p*-ment-2en-1-ol, *trans-p*-ment-2-en-1-ol and elemol for the extract using CO_2 as solvent and *cis*-piperitol, *trans*-piperitol and elemol for the extract using ethanol as solvent. The process showed viability for the extraction of the oil, which was clear and limpid.The extraction yield and the solubility of the oil were satisfactory, showing no significant changes in relation to the technique and origin.

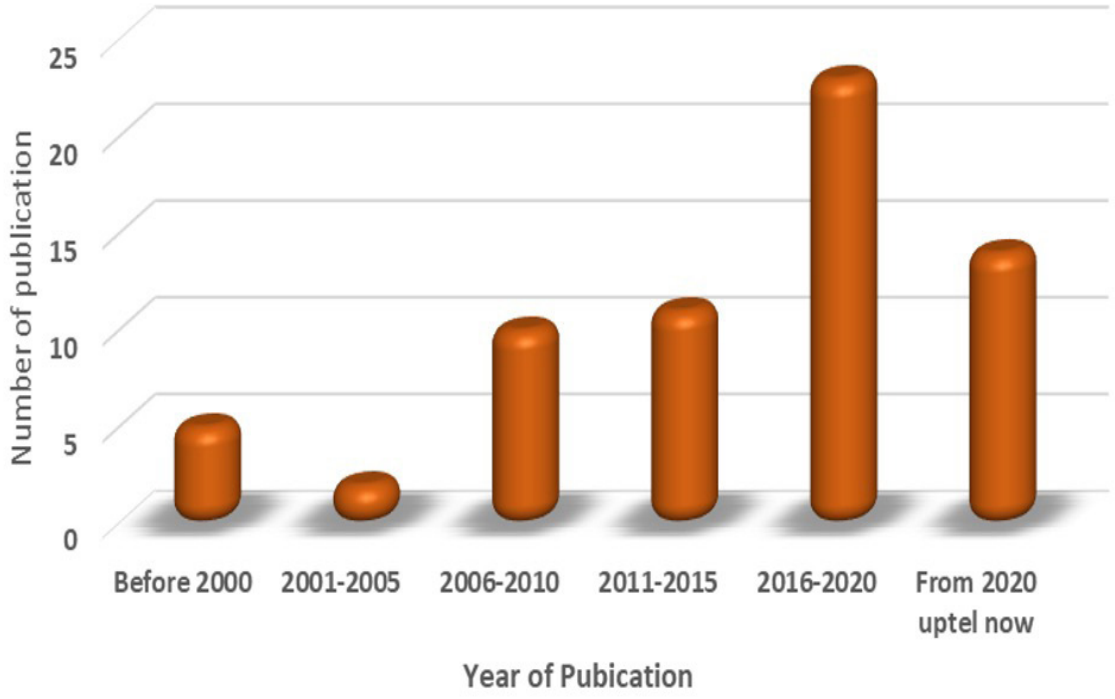

Fig. 1. The publication rate of the *Cymbopogon schoenanthus* (L.) Spreng.

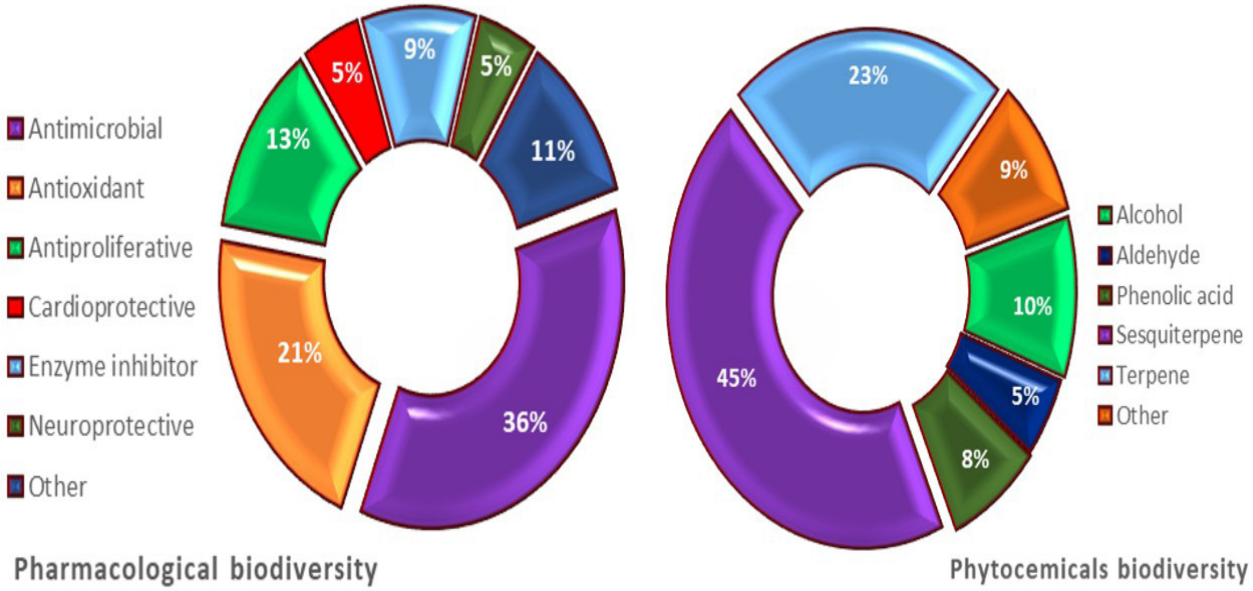

Fig. 2. Pharmacological and phytochemicals biodiversity of *Cymbopogon schoenanthus* (L.) Spreng.

The main components of the oil of *C. schoenantus* were *cis*-for-ment-2en-1-ol, *trans*-for-ment-2en-1-ol and elemol (Sousa et al., 2005).

Cymbopogon schoenanthus (L.) Spreng. (a sub-spontaneous grass that grows in the Savannah zone in northern Togo and collected around Djamde in the Kozah region and dried at 30 °C for 72 h before extraction) oil was obtained by steam distillation and the yield was 3% (w/w based on dry weight). The major components obtained by GC and GC/MS analysis were piperitone (69%), 2-carene (17%) and elemol (5.8%). This oil was characterized by a high percentage of oxygenated monoterpenes (72%) (Ketoh et al., 2005). The vegetable material (leaves) of *C. schoenanthus* (L.)

Spreng. was collected during the rainy season, in July in Saaba, located at the periphery of Ouagadougou, Burkina Faso. The chemical analysis results showed that the 16 made up ones identified accounting for 65.2% of the essential oil composition. These compounds belong to the two classes monoterpenes and sesquiterpenes. The proportion of monoterpenes (53.2%) is higher than that of sesquiterpenes (12%). Among the identified compounds two monoterpenes (the piperitone and δ-2-carene) remain the principal components in the essential oil. The rate of piperitone is about 42% and that of δ-2-carene, 8.2%. (Yentema et al., 2007).

The essential oils from fresh leaves, dried leaves and roots *Cymbopogon schoenanthus* (L.) Spreng. ssp. *laniger* (Hook) Maire et Weill was collected during the flowering phase (June-July 2006) from three locations in southern Tunisia: Echareb-mountains region (3404.723N, 00904.177E); Dhibat-desert region (3210.309N, 01059.497E) and Gourdhab-experimental plot (3308. 564N, 01049.531E) and a voucher specimen was deposited at the herbarium of the I.R.A. The essential oil yield obtained by the conventional hydrodistillation from fresh leaves, dried leaves and dried roots of the *C. schoenanthus*, collected during flowering phase in three different locations in southern Tunisia, desert, mountain and an experimental plot, ranged from 1.1% to 2.6% (w/w). More than 30 constituents were identified representing 95.6%, 95.0%, 91.0%, 95.3%, 93.0%, 93.3%, 96.8% and 92.3% of the total oils of the fresh leaves form Dhibat (FLD), fresh leaves form Gourdhab (FLG) and fresh leaves from Echareb (FLE), dried leaves from Dhibat (DLD), dried leaves from Gourdhab (DLG), dried leaves from Echareb (DLE), dried roots from Dhibat (DRD) and dried roots from Echareb (DRE). The essential oils from *C. schoenanthus* were characterized by high percentages of monoterpene hydrocarbons (25.7-66.3%), for which the four major constituents were limonene (10.5-27.3%), β-phellandrene (8.2-16.3%), δ-terpinene (4.3-21.2%) and α-terpineol (6.8-11.7%). The sesquiterpene fraction, ranging from 12.8% to 30.8%, consisted mostly of sesquiterpene hydrocarbons. Oxygenated sesquiterpenes were also found but in moderate amounts (6.3-27.3%). Other components, *i.e.*, fatty acids methyl esters, were also detected at trace levels (Khadri et al., 2008).

For instance, analysis of commercial C. schoenanthus oil sample that purchased from WNF Ind. e Com. Ltda (R. Dr. Mario Pinto Serva, 64 - Sao Paulo, SP, Brazil) with lot no. 10608, d = 0.911 revealed that Terpenes are a chemical class of chemicals found in essential oils, had approximately 20 constituents, being rich geraniol (62.5%), geranial (12.5%), neral (8.2%). Other components like citronelol (3.6%), (*E*)-β-caryophyllene (3.4%), geranyl acetate (2.0%), linalool (1.3%), δ-cadinene (0.9%), caryophyllene oxide (0.6%), citronelal (0.5%), 6-methyl-5-heptenone (0.5%), α-humulene (0.4%), elemol (% 0.4%), α-cadinol (0.4%) (Katiki et al., 2011).

During analysis the sample isolated from leafy stems of Cymbopogon schoenanthus (L.) Spreng. (collected in Nalohou 2 (N09°45.626′ E01°36.153′), Benin and a specimen was deposited at the National Herbarium of Benin), 23 components were detected via solid phase microextraction, and simultaneous distillation extraction and the main compounds detected were piperitone (56.6%, 53.1%), β-elemene (5.1%, 1.3%), (*E*)-caryophyllene (6.5%, 2.3%) and elemol (2.2%, 9.3%) for a total of 70.4% and 66%, respectively, via SPME and SDE. In addition, -2-carene (1.3%, 4.4%), (*Z*)-*p*-menth-2-en-1-ol (1.6%, 1.1%), citronellal (1.0%, 1.6%), α-terpineol (1.5%, 1.4%), γ-cadinene (1.1%, 0.8%) and hinesol (0.2%, 2.7%). Methyl salicylate (2.8%), isoascaridole (1.0%), cuparene (1.0%) and β-selinene (3.0%) have been detected only *via* solid phase microextraction, whereas valencene (1.5%) was identified only *via* simultaneous distillation extraction (Bossou et al., 2015). The essential oil extracted by hydrodistillation from this plant species exhibited the presence of two major constituents namely δ-2-carene (15.5%) and piperitone (58.9%) (Bossou et al., 2013).

Essential oil of *C. schoenanthus* (L.) Spreng. dried leafy stems (collected from West Kordofan on January 2015. Botanical identification and authentication were performed and voucher specimens No.13/CS have been deposited in Botany Department Herbarium, Faculty of Science, University of Khartoum, Sudan) yielded 2.1% (w/w) light yellowish oil. 49 components were identified representing 93.0% of the total oil composition. The proportion of sesquiterpene sesquiterpenes (71.6%) was higher than that of monoterpenes (21.4%). The oil revealed the presence of monoterpenes (1.6%), oxygenated monoterpenes (19.8%), sesquiterpenes (11.0%), oxygenated and sesquiterpenes (60.6%) and other components as ester and diterpene, were also detected at trace levels. The major components were the monoterpene piperitone (18.4%) followed by the sesquiterpenes elemol (18.3%), eudesm-11-en-1-ol (17.0%), α-eudesmol (10. 7%), bulnesol (7.0 %) and γ-eudesmol (5.8%), respectively (Yagi et al., 2016).

An oil sample from *C. schoenanthus* (L.) Spreng. (Al-Ethkher) was collected from Asfan area, north-east of Jeddah, Saudi Arabia contained eight major components that identified were: piperitone (14.6%), cyclohexanemethanol (11.6%), β-elemene (11.6%), α-eudesmol (11.5%), elemol (10.8%), β-eudesmol (8.5%), 2-naphthalenemethanol (7.1%) and γ-eudesmol (4.2%) (Hashim et al., 2017).

Aerial parts of *C. schoenanthus* (L.) Spreng. collected from Raiwala near Haridwar Uttarakhand, North Himalaya region in the month of July 2013 and planted in university demonstration site and a voucher specimen has been kept in the herbarium of Doon University dually by Botanical Survey of India, Dehradun, Dr. DK Shrivatava for further reference showed that the essential oil content in cultivated sample was found to be higher (2.1%) than that in wild sample (1.8%). A total of 10 components were identified in both the samples where proportion of monoterpenes was higher than that of sesquiterpenes. Results of chemical identification advocates three monoterpenes as principal components whereas highest concentration was shared by *cis*-sabinene followed by *trans* isomer and *cis*-piperitol. The concentration of major component that is, *cis*-sabinene hydrate was found to be 30.1 and 31.6% while second major component was *trans*-sabinene which was found to be 17.1% in wild sample and 14.5% in cultivated sample. *cis*-Piperitol was detected as the third major

component in cultivated sample (18.5%), but its concentration was found to be just half in wild sample. Other components were α-terpinolene, piperitone and limonene. (Andola and Maithani, 2018).

The oil sample of aerial parts *C. schoenanthus* (L.) Spreng. which purchased from a local herbal market in Luristan Province, Iran, in February 2018 and a voucher specimen No. 1602-Aupf by N. Kazemivash, Department of Pharmacognosy, Faculty of Pharmacy and Pharmaceutical Sciences, Tehran Medical Sciences, Islamic Azad University, Tehran, Iran composed of a mixture of monoterpenes as piperitone (62%), α-terpinene (7.1%), *p*-cymene (2.9%), and limonene (2.3%) as its main compounds (Golestaneh Talaei and Jahandideh, 2019).

Whole plant, rhizomes, aerial parts (stems and leaves) from 30 individual plants *C. schoenanthus* (L.) Spreng. were collected in two locations of Algeria, sixteen plants were sampled at Béchar province (July 2017: B17 AP E1-E6; B17 R E1-E6, B17 WP E7-E10 and in April 2019: B19 WP E1-E6) and fourteen plants were sampled at Ghardaïa province (seven in April 2016: G16 WP E1-E7 and seven in January 2017: G17 WP E1-E7) were Identified and a voucher specimen has been deposited with the Laboratory of Natural Products (Department of Biology, University of Tlemcen) under the accession No. P.111. The compositions of the three oil samples isolated from the whole plant, were dominated by various alcohols bearing the *p*-menthane skeleton: *cis*-*p*-menth-2-en-1-ol (22.6-28.5%), *trans*-*p*-menth-2-en-1-ol (15.4-16.3%), *cis*- and *trans*-piperitols (5.4-8.5% and 8.8-8.9%, resp.). Monoterpene hydrocarbons were represented by *δ*-2-carene (8.6-17.0%) and limonene (2.4-5.9%). β-elemol (5.6-7.4%) was the main oxygenated sesquiterpene accompanied by β-eudesmol, α-eudesmol, intermedeol and juniper camphor (up to 3.5% each). The twelve oil samples of aerial parts and rhizomes composition of were dominated by *cis*-*p*-menth-2-en-1-ol (24.0% ± 8.6 and 28.1% ± 3.3, respectively) and *trans*-*p*-menth-2-en-1-ol (15.5% ± 4.8 and 18.5% ± 1.8, resp.). Other components present at appreciable content were *cis*- and *trans*-piperitols, β-elemol, selina-6-en-4α-ol, and juniper camphor. Although slight differences have been observed, they were only quantitative, and it could be concluded that aerial parts and rhizomes produced similar essential oils (Malti et al., 2020).

High-performance liquid chromatography with time-of-flight mass spectrometry (HPLC-TOF/MS) analysis suggested the presence of phenols and flavonoids in the EtOAc and *n*-BuOH extracts of air-dried herb of *C. schoenanthus* (L.) Spreng. (common name lemongrass) that harvested in the Southwest of Algeria, in the region of Bechar, in April 2011and the plants species were indexed under the numbers CS/124/17/04/12 in the herbarium of the research unit Varenbiomol, University des Frères Mentouri Constantine 1 (Djemam et al., 2020). Diosmin was the major compound found in the *n*-BuOH extract of *C. schoenanthus*. The EtOAc extract of *C. schoenanthus* was quite rich in catechin but also in rutin, gallic and sinapic acids. Several other phenols and flavonoids were found (Djemam et al., 2020). Hydroxybenzaldehyde, taxifolin, apigetrin, resveratrol and silibinin were found in trace amounts in the EtOAc and *n*-BuOH extracts (Djemam et al., 2020).

2.2. Phytochemical biodiversity of *Cymbopogon schoenanthus* (L.) Spreng.

Several bioactive extracts along with bioactive compounds were reported with diverse chemical structures, from sesquiterpenes, terpenes, alcohols, hydrocarbons, fatty acid derivatives, esters, and phenolic acids (Table 1 and Table 2; Fig 3 and Fig. 4). NMR-based metabolomic profiling for essential (volatile) oils composition has been investigated and demonstrated a strong variability. Proximadiol **(1)**, 5α-hydroxy-β-eudesmol **(2)**, 5α-hydroperoxy-β-eudesmol **(3)**, 1β-hydroxy-β-eudesmol **(4)**, 1β-hydroxy-α-eudesmol **(5)**, and 7α,11-dihydroxycadin-10(14)-ene **(6),** sesquiterpenes were detected in the unsaponifiable fraction of the petroleum ether extract of *C. schoenanthus* subsp. *proximus* from Harraz Herbal Drugstore in Cairo, Egypt (El-Askary etal., 2003).

Essential oils **(7-53)** were detected in whole plants of *C. schoenanthus* (L.) Spreng. collected from Algeria, while **(9, 11-14, 18, 19, 21-23, 25, 27, 40, 43, 44, 50, 51)** were isolated from the aerial parts and rhizomes of the same individual plants. The volatile oils **(9, 11-13, 18, 19, 21-23, 25, 27, 40, 43, 44, 45, 50, 51)** were the main components of essential oil extracted from *C. schoenanthus* subsp. *proximus* (Malti et al., 2020). The oils **(26, 27, 35, 37, 46, 54-69)** were detected in the Brazilian *C. schoenanthus* (Katiki et al., 2011). The major components limonene **(10),** β-phellandrene **(13)**, α-terpineol **(19)**, and δ-terpinene **(70)** were detected in the essential oil of southern Tunisian *C. schoenanthus* (Khadri et al., 2008). The eight major components of the essential oil were piperitone **(25)**, β-elemene **(27)**, α-eudesmol **(43)**, β-eudesmol **(44)**, γ-eudesmol **(45)**, elemol **(65)**, cyclohexane methanol **(77)**, and 2-naphthalenemethanol (**78**) were detected in water extract of Saudi *C. schoenanthus* (L.) Spreng. (Al-Ethkher) essential oil (Hashim et al., 2017).

Two important secondary metabolites, proximadiol **(1)** and trigonelline **(79)** have been identified and quantified using GC-MS and NMR spectroscopy in the polar extracts of the wild plant. *C. schoenanthus* seeds and aerial parts collected from Aswan, Egypt (Abdelsalam et al., 2017).

Seven phenolic compounds were successfully identified in the leaves of *C. schoenanthus* (L.) Spreng (locally known as "El bekherai") (growing wild in the southern part of Tunisia) ethanolic extracts based on the retention time and spectral characteristics of their peaks against those of the standards using RP-HPLC coupled with UV-Vis multiwave length detector. The chromatogram of plant extract was compared to authentic standards of phenolic acid and flavonoid profiles, which allowed us to identify 5 phenolic compounds at 330 nm: Caffeic acid (3.1%) **(71)**, 2,5 dihydroxybenzoic acid (2%) **(72)**, *trans*-cinnamic acid (9.7%) **(74)**, and quercetin-3-rhamnoside (32.6%) **(76)** and resorcinol (5%) and 2 other phenolic compounds at 280 nm: ferulic acid (9.8%) **(73)** and gallic acid (8.8%) **(75)** (Ben Othman et al., 2013).

Identified 32 phenols such as fumaric acid, gentisic acid, chlorogenic acid, protocatechuic acid, vanillic

Table 1
Therapeutic biodiversity of *Cymbopogon schoenanthus* (L.) Spreng. compounds.

No.	Name	Class	Activity	References
1	Proximadiol	Sesquiterpenes	Anti-inflamatory, antioxidants, antimicrobial	(El-Askary et al., 2003)
2	5α-Hydroxy-β-eudesmol	Sesquiterpenes	-	(El-Askary et al., 2003)
3	5α-Hydroperoxy-β-eudesmol	Sesquiterpenes	-	(El-Askary et al., 2003)
4	1β-Hydroxy-β-eudesmol	Sesquiterpenes	-	(El-Askary et al., 2003)
5	1β-Hydroxy-α-eudesmol	Sesquiterpenes	-	(El-Askary et al., 2003)
6	7α,11-Dihydroxycadin-10(14)-ene	Sesquiterpenes	-	(El-Askary et al., 2003)
7	α-Pinene	Terpene	Anti-inflamatory, antioxidants antimicrobial, acetylcholenstrase inhibitors	(Malti et al., 2020; Russo, 2011)
8	Camphene	Terpene	Antioxidants, antimicrobial, antinociceptive	(Malti et al., 2020)
9	δ-2-Carene	Terpene	Antioxidants antimicrobial	(Malti et al., 2020)
10	α-Terpinene	Terpene	Antioxidants antimicrobial	(Khadri et al., 2008; Malti et al., 2020)
11	*p*-Cymene	Aromatic derivatives	Antinociceptive, anti-inflamatory	(Malti et al., 2020)
12	Limonene	Terpene	Anti-inflamatory, antioxidants, antifungal	(Malti et al., 2020)
13	β-Phellandrene	Terpene	Antioxidant, antimicrobial, pesticides	(Khadri et al., 2008; Malti et al., 2020)
14	(*Z*)-β-Ocimene	Hydrocarbon	Anticonvulsant, antiproliferative, antimicrobial	(Malti et al., 2020)
15	(*E*)-β-Ocimene	Hydrocarbon	-	(Malti et al., 2020)
16	Terpinolene	Terpene	Antioxidant, antimicrobial	(Malti et al., 2020)
17	Fenchol	Terpene	Antioxidant, antimicrobial	(Malti et al., 2020)
18	*cis-p*-Menth-2-en-1-ol	Terpene	Antimicrobial	(Malti et al., 2020)
19	*cis-p*-Mentha-2,8-diene-1-ol	Terpene	-	(Khadri et al., 2008; Malti et al., 2020)
20	*trans-p*-Menth-2-en-1-ol	Terpene	Antioxidant, antimicrobial	(Malti et al., 2020)
21	α-Terpineol	Terpene	Anticonvulsant, antiproliferative, antiulcer, antihypertensive	(Malti et al., 2020)
22	*cis*-Piperitol	Terpene	Antimicrobial	(Malti et al., 2020)
23	*trans*-Piperitol	Terpene	Antimicrobial	(Malti et al., 2020)
24	Nerol	Alcohol	-	(Malti et al., 2020)
25	Piperitone	Terpene	Antimicrobial, pesticide	(Ketoh et al., 2006; Hashim et al., 2017; Malti et al., 2020)
26	Geraniol	Alcohol	Anti-inflammatory, antimicrobial, antioxidant	(Katiki et al., 2011; Malti et al., 2020)
27	β-elemene	Terpene	Antiproliferative	(Katiki et al., 2011; Hashim et al., 2017; Malti et al., 2020)
28	γ-Muurolene	Sesquiterpene	-	(Malti et al., 2020)
29	Selina-4,11-diene	Sesquiterpene	-	(Malti et al., 2020)
30	Germacrene D	Sesquiterpene	Antimicrobial	(Malti et al., 2020)
31	Germacrene B	Sesquiterpene	Antimicrobial	(Malti et al., 2020)
32	β-Selinene	Sesquiterpene	Antioxidant	(Malti et al., 2020)
33	α-Selinene	Sesquiterpene	Antimicrobial	(Malti et al., 2020)

Table 1 Continued

No.	Name	Class	Activity	References
34	δ-Selinene	Sesquiterpene	-	(Malti et al., 2020)
35	4-*epi*-Cubebol	Sesquiterpene	-	(Katiki et al., 2011; Malti et al., 2020)
36	γ-Cadinene	Sesquiterpene	Antimicrobial	(Malti et al., 2020)
37	δ-Cadinene	Sesquiterpene	Antimicrobial	(Katiki et al., 2011; Malti et al., 2020)
38	β-Elemol	Terpene	Antimicrobial	(Malti et al., 2020)
39	Spathulenol	Sesquiterpene	Anti-nociceptive, antimicrobial	(Malti et al., 2020)
40	Selina-6-en-4α-ol	Sesquiterpene	-	(Malti et al., 2020)
41	Alismol	Sesquiterpene	Antimicrobial	(Malti et al., 2020)
42	Eremoligenol	Sesquiterpene	Antiproliferative	(Malti et al., 2020)
43	α-Eudesmol	Sesquiterpene	Antimicrobial, antiproliferative	(Hashim et al., 2017; Malti et al., 2020)
44	β-Eudesmol	Sesquiterpene	Antiproliferative	(Hashim et al., 2017; Malti et al., 2020)
45	γ-Eudesmol	Sesquiterpene	Antioxidant	(Hashim et al., 2017; Malti et al., 2020)
46	α-Cadinol	Sesquiterpene	Antimicrobial	(Katiki et al., 2011; Malti et al., 2020)
47	τ-Cadinol	Sesquiterpene	Antioxidant	(Malti et al., 2020)
48	Valerianol	Sesquiterpene	-	(Malti et al., 2020)
49	τ-Muurolol	Sesquiterpene	Antimicrobial	(Malti et al., 2020)
50	Intermedeol	Sesquiterpene	Antimicrobial	(Malti et al., 2020)
51	Juniper camphor	Sesquiterpene	Antimicrobial	(Malti et al., 2020)
52	Geranyl linalool	Alcohol	Antimicrobial	(Malti et al., 2020)
53	5-*epi*,7-*epi*-α-Eudesmol	Sesquiterpene	Antimicrobial	(Malti et al., 2020)
54	Geranial	Aldehyde	Anti-Inflammatory, neuroprotective antidepressant	(Katiki et al., 2011)
55	Neral	Aldehyde	Anti-inflammatory	(Katiki et al., 2011)
56	Citronelol	Alcohol	Antimicrobial, antidepressant, antispasmodic, anti-Inflammatory	(Katiki et al., 2011)
57	(E)-β-caryophyllene	Sesquiterpene	Anti-Inflammatory, antioxidant, antiproliferative	(Katiki et al., 2011)
58	Geranyl acetate	Ester	Anti-inflammatory, antimicrobial	(Katiki et al., 2011)
59	Linalool	Alcohol	Anti-inflammatory, antioxidant, antimicrobial	(Katiki et al., 2011)
60	Caryophyllene oxide	Sesquiterpene	Anti-Inflammatory, antimicrobial, antiproliferative	(Katiki et al., 2011)
61	Citronelal	Aldehyde	Antimicrobial	(Katiki et al., 2011)
62	6-Methyl-5-heptenone	Ketone	-	(Katiki et al., 2011)
63	α-humulene	Sesquiterpene	-	(Katiki et al., 2011)
64	Elemol	Alcohol	-	(Katiki et al., 2011)
65	Decanal	Aldehyde	-	(Hashim et al., 2017)
66	Geranyl formiate	Ester	-	(Katiki et al., 2011)
67	Eugenol	Phenolic acid	Antioxidant	(Katiki et al., 2011)
68	γ-Humulene	Sesquiterpene	-	(Katiki et al., 2011)
69	α-Muurolene	Sesquiterpenes	-	(Katiki et al., 2011)
70	δ-Terpinene	Terpene	-	(Khadri et al., 2008)

Table 1 Continued

No.	Name	Class	Activity	References
71	Caffeic acid	Phenolic acid	Antioxidant	(Ben Othman et al., 2013; Djemam et al., 2020)
72	2,3- Dihydroxybenzoic acid	Phenolic acid	Antioxidant	(Ben Othman et al., 2013; Djemam et al., 2020)
73	Ferulic acid	Phenolic acid	Antioxidant	(Ben Othman et al., 2013)
74	*trans*-Cinnamic acid	Phenolic acid	Antioxidant	(Ben Othman et al., 2013)
75	Gallic acid	Phenolic acid	Antioxidant	(Ben Othman et al., 2013; Djemam et al., 2020)
76	Quercetin-3-rhamnoside	Flavnoied glycoside	Antioxidant	(Ben Othman et al., 2013)
77	Cyclohexanemethanol	Alcohol	-	(Hashim et al., 2017)
78	2-Naphthalenemethanol	Alcohol	-	(Hashim et al., 2017)
79	Trigonelline	Alkaloid	-	(Abdelsalam et al., 2017)

Table 2
Therapeutic biodiversity of *Cymbopogon schoenanthus* (L.) Spreng. extracts and essential oils.

No.	Name	Activity	References
1	Proanthocyanidin rich, organic, aqueous extracts and essential oil	Anti-acetylcholinesterase, antimicrobial, antioxidant	(Khadri et al., 2008; Khadri et al., 2010)
2	Essential oil	Antiproliferative	(Yagi et al., 2020)
3	Essential oil	Antimicrobial	(Hashim et al., 2017)
4	Methanol extract	Antimicrobial	(Aly et al., 2017)
5	Essential oil	Antifungal, antiaflatoxin	(Sawadogo et al., 2022)
6	Essential oil	Antimicrobial, antiproliferative	(Kpadonou et al., 2022)
7	Essential oil	Antimicrobial, antibiofilm	(Piasecki et al., 2021)
8	Essential oil	Anthelmintic	(Katiki et al., 2011; Katiki et al., 2012)
9	Essential oil	Anti-inflammatory, anti-nociceptive, analgesic	(Golestaneh Talaei and Jahandideh, 2019)
10	Ethanol extract	Antiproliferative	(Villareal et al., 2017)
11	Hydroalcoholic extract	Immunomodulatory, hepatoprotective	(Saggu et al., 2019)
12	Essential oil	Anti-acetylcholinesterase, spasmolytic	(Pavlović et al., 2017)
13	Aqueous, *n*-Hexane fraction, chlorofom fraction, ethyl acetate fraction extracts	Spasmolytic	(El-Askary et al., 2008)
14	Ethyl acetate, *n*-BuOH extracts	Spasmolytic	(Djemam et al., 2020)

Table 2 Continued

No.	Name	Activity	References
15	Essential oil	Cardioprotective	(Althurwi et al., 2020)
16	Methanol and *n*-hexane fraction extracts	Antihypertensive	(El-Nezhawy et al., 2014)
17	Aqueous extract	Inhibits kidney stone formation, nephroprotective antioxidant	(Al-Ghamdi et al., 2007; Ibrahim and El-Khateeb, 2013; Ahmed-Farid et al., 2018)
18	Aqueous extract and essential oil	Anti-inflammatory, nephroprotective, antioxidant	(Abu-Serie et al., 2019)
19	Alcohol extract	Nephroprotective	(Younis et al., 2021)
20	Ethyl acetate and methanol extracts	Anti-acetylcholinesterase	(Khadri et al., 2010)
21	Essential oil	Anti-acetylcholinesterase, anti-butyrylcholinesterase, antioxidant, anti-α-amylase, antiproliferative anti-tyrosinase	(Khadri et al., 2008; Yagi et al., 2020)
22	Ethanol extract	Antistress	(Ben Othman et al., 2013)
23	Ethanol extract	Antioxidant, antiproliferative	(Sief et al., 2020)
24	Essential oil	Pesticide	(Ketoh et al., 2006; Norbert et al., 2014)
25	Methanol, aqueous and petroleum ether extracts	Pesticide	(Hasaballah, 2018)

acid, syringic acid, sinapic acid, ferulic acid, rosmarinic acid, salicylic acid, cinnamic acid, caffeic acid **(71),** 4-hydroxybenzoic acid **(72)**, gallic acid **(75)**, and flavonoids such as catechin, neohesperidin, kaempferol, morin, diosmin, and diosmetin were detected in ethyl acetate (EtOAc) and *n*-butanol extracts of Algerian *C. schoenanthus* (L.) Spreng. (common name lemongrass) by HPLC-TOF/MS. (Djemam et al., 2020).

2.3. Pharmacological effects of *Cymbopogon schoenanthus* (L.) Spreng.

2.3.1. Antioxidant effect

The aqueous extract, proanthocyanidin-rich extract, and organic extract of *C. schoenanthus* ssp. *laniger* (Hook) Maire et Weill shoots collected during the flowering phase (June-July 2006) from three different locations in South Tunisia were screened for their antioxidant, acetylcholinesterase, and antimicrobial activities. Antioxidant activity measured by 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay showed that the proanthocyanidin extract exhibited higher antioxidant activity than the aqueous extract. Extract concentration providing 50% inhibition (IC_{50}) ranged from 16.4 ± 6.8 µg/mL to 26.4 ± 6.8 µg/mL. The antioxidant activity was also determined using the β-carotene/linoleic acid bleaching test. The best results (IC_{50} = 0.11 ± 0.10 mg/mL) were obtained with the proanthocyanidin extract of the plants collected from the desert region (Dhibat). The greatest acetylcholinesterase inhibitory activity was exhibited by the ethyl acetate and methanol extracts of the plants collected from the mountainous region with IC_{50} values of 0.23 ± 0.04 and 0.23 ± 0.03 mg/mL, respectively. It seems that extracts obtained with more polar solvents gave better results (Khadri et al., 2010).

2.3.2. Antiproliferative effect

Essential oils from the inflorescence of *C. schoenanthus* (L.) Spreng. growing in Northern Sudan (longitude: 33° 26′ E; latitude 16° 41′ N) that taxonomically identified and voucher specimen No. 2014/1CS has been deposited in the Botany Department Herbarium, Faculty of Science, University of Khartoum, Sudan were not toxic to normal vero cell line (IC_{50} > 100 µg/mL). Although the oils showed different chemical profiles, they exhibited high and comparable antiproliferative activity against three tested cancer cell lines. They showed high antiproliferative activity against human breast carcinoma (MCF7, IC_{50} = 5.8 ± 0.8 µg/mL), human colon adenocarcinoma (HT29, IC_{50} = 4.4 ± 0.5 µg/mL and HCT116, IC_{50} = 4.3 ± 0.5 µg/mL), antioxidant activity (phosphomolybdenum, antiradical, reducing power, and ferrous chelating), and enzyme inhibition activity against acetylcholinesterase butyrylcholinesterase, tyrosinase, α-glucosidase, and α-amylase. Piperitone **(25)** (59.1%) and isomers of *p*-menthadienols **(19)** (35.3%) were the main compounds in *C. schoenanthus* (Yagi et al., 2020). and *C. nervatus* oils,

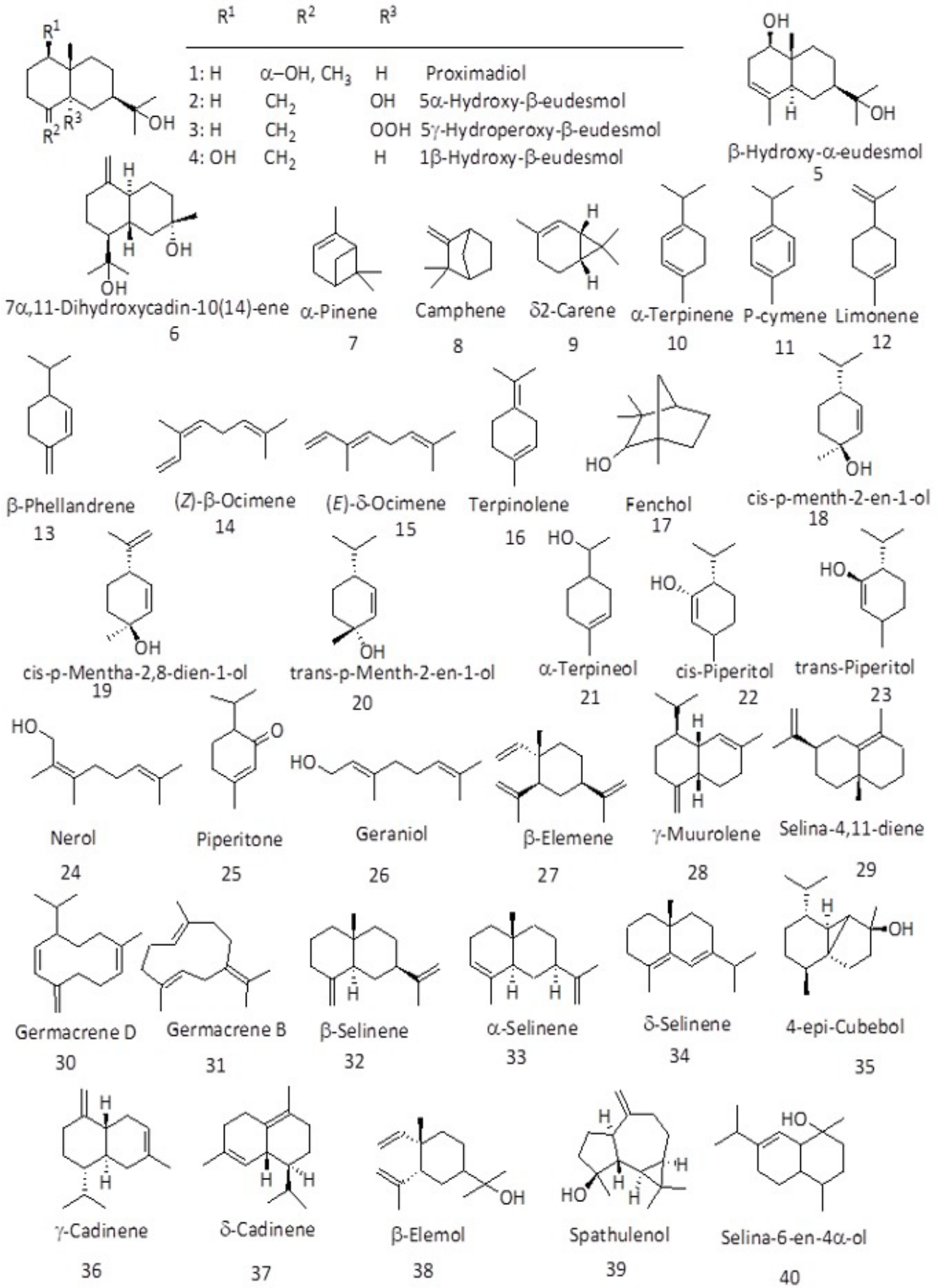

Fig. 3. Chemical structure of compounds **1-40**. (**1-6**, **28-37**, **39-40**) Sesquiterpenes, (**7-10**, **12-13**, **16-24**, **27**, **38**) terpenes, (**11**) aromatic derivatives, (**14-15**) and hydrocarbons (**26**) alcohol isolated from *Cymbopogon schoenanthus* (L.) Spreng.

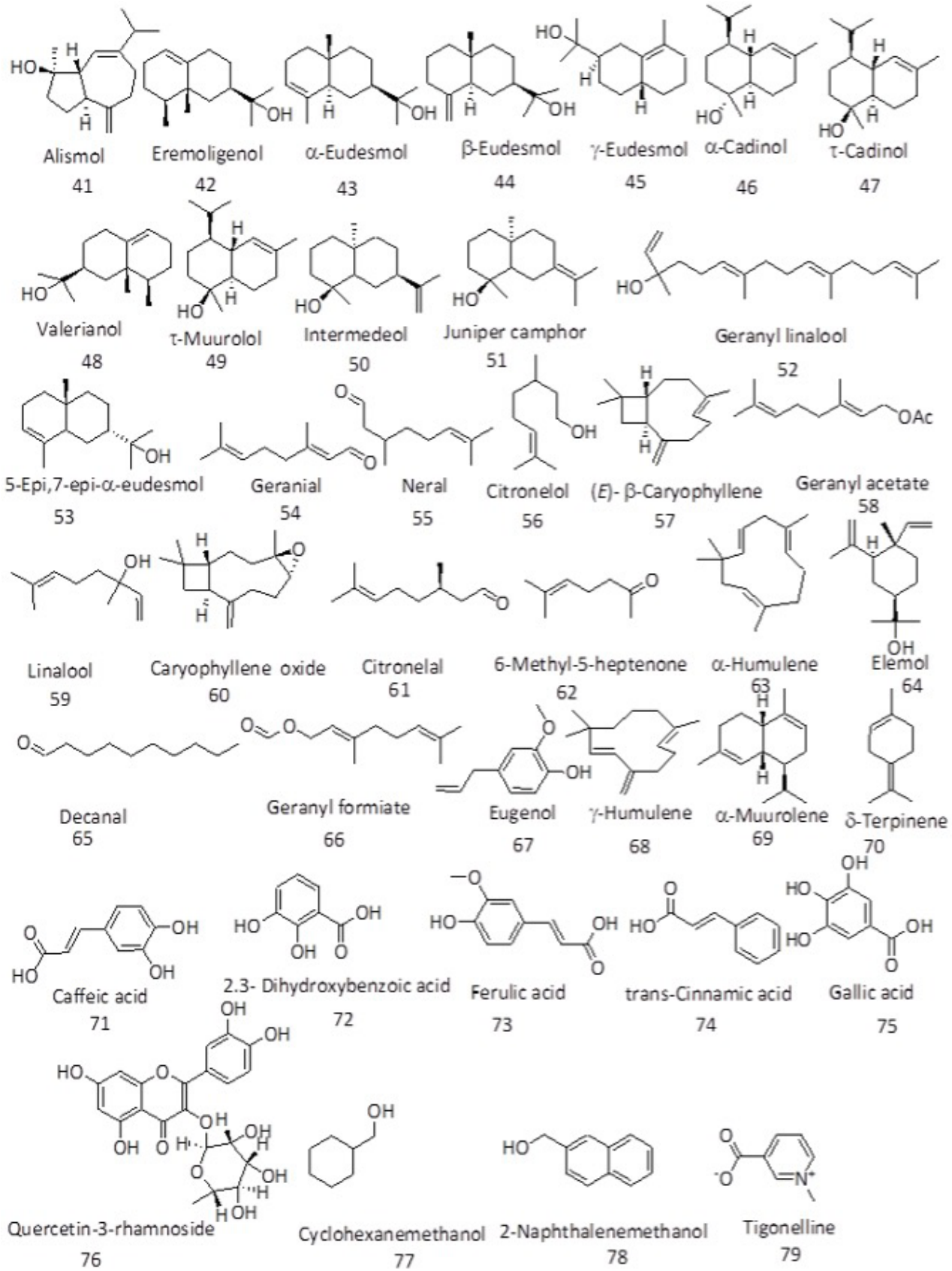

Fig. 4. Chemical structure of compounds **41-79**. (**41-52**, **53**, **57**, **60**, **63**, **68-69**) Sesquiterpenes, (**70**) terpenes, (**67**, **71-75**) phenolic acid, (**54-55**, **61**, **65**) aldehydes, (**58**) ester, (**52**, **56**, **59**, **64**, **66**, **77-78**) alcohols, (**76**) flavonoid glycoside and (**79**) alkaloids isolated from *Cymbopogon schoenanthus* (L.) Spreng.

respectively. A possible mechanism of oil may be explained on the basis of its metal chelating ability. In silico study showed that *trans-p*-mentha-2,8-dien-1-ol and piperitone (both isomers) revealed the best docking scores for α-amylase and tyrosinase, respectively (Yagi et al., 2020).

2.3.3. Antimicrobial effect

The proanthocyanidin-rich extract of *C. schoenanthus* ssp. *laniger* (Hook) Maire et Weill shoots collected during the flowering phase (June-July 2006) from three different locations in South Tunisia (a mountainous region; Dhibat: a desert region, and Gourdhab: an experimental plot) showed good antimicrobial activity against *Streptococcus sobrinus* (strain 4010 CECT) at low concentrations (MIC = 4 ± 0.5 mg/mL for mountainous region, 4 ± 0.2 mg/mL for desert region and 8 ± 0.2 mg/mL for cultivated plant) compared to aqueous extracts (MIC = 32 ± 5 mg/mL for mountainous region, 32 ± 3 mg/mL for desert region and 32 ± 1 mg/mL for cultivated plant). The higher content of phenols and flavonoids in proanthocyanidin extracts, as compared to aqueous extracts, is probably responsible for this effect (Khadri et al., 2010). The extracts could be used to prevent carious lesions by inhibiting *S. sobrinus* growth as the human oral flora is quite diverse and complex, two species of streptococci, *S. mutans* and *S. sobrinus*, have been implicated as the primary etiologic agents of dental caries (Loesche, 1986). The *C. schoenanthus* (L.) Spreng. (Al-Ethkher) plant essential oil extract collected from the Asfan area, north-east of Jeddah, Saudi Arabia, was effective against *E. coli* ATCC 11229, *S. aureus* ATCC 6538, methicillin-susceptible *S. aureus* (MSSA) ATCC 6538, methicillin-resistant *S. aureus* (MRSA) ATCC 33591, and *K. pneumoniae* ATCC 4352, at concentration >150 µg/mL. The minimum inhibitory concentrations (MICs) values were as follows: 9.37 µg/mL for *E. coli* 4.69 µg/mL for *S. aureus* (MRSA), 2.34 mg/mL for MSSA, and 2.34 µg/mL for *K. pneumoniae*. The time-kill assay indicated that there was a sharp time-dependent decline in *K. pneumoniae* counts in the presence of the oil. This is in contrast to a gradual decline in the case of *S. aureus* under the same conditions. The authors concluded that the mechanism of action of volatile oils is mediated by the inhibition of DNA, RNA, proteins and polysaccharides synthesis in both fungal and bacterial cells (Kalemba and Kunicka, 2003) Future investigation is needed to investigate the efficacy of the individual component separately in order to better understand the underlying mechanism (Hashim et al., 2017). The antibacterial activity and biological properties of the aerial part of *C. schoenanthus* were collected from the Southeast of Tunisian (Boughrara), in flowering stage (April 2015) were detected. The plant extracts were obtained by using different combination of extraction methods [ultrasound-assisted extraction (UAE) using an ultrasonic sonotrode (UP400S, Dr. Hielscher, Teltow, Germany) and distilled water (100%, v/v) and a hydroethanolic solution (50:50, v/v, ethanol/water) *vs.* conventional extraction (CE) carried out under the same experimental conditions but replacing the ultrasonic probe by a mechanical stirrer (RZR 1, Heidolph, Germany) provided with an axial flow impeller working at 540 rpm. The impact of the extracts on specific beneficial bacteria as well as their action against potential pathogenic/foodborne bacteria was determined. The strains used as probiotics were *Lactobacillus casei* BL23, and *Bifidobacterium lactis* NCC2818 and the reference foodborne bacteria were *Listeria innocua* CECT 910, *Salmonella enterica* CECT 4138 and *Staphylococcus aureus* CECT 86. The aqueous extracts from *C. schoenanthus* obtained by conventional extraction (CE) significantly increased the growth rate and the maximal optical density of *L. casei* and decreased the growth rate of *S. aureus* and *L. innocua*. Aqueous extracts of *C. schoenanthus* has also a slight influence on the growth of Bifidobacterium. Overall, the extract had a selective activity concerning pathogens and probiotic bacteria and may provide an advantage both in terms of antimicrobial and prebiotic activity (Rocchetti et al., 2020). The antibacterial effect could be explained by the phenolic composition of *Cymbopogon* (de Oliveira et al., 2010). In fact, monoterpenes are the main phenolic compound of oil extracted from *C. schoenanthus*, thus allowing *via* its toxic effects the modification in the structure and function of the bacterial cell membrane. In fact, phenolic compounds act as antiradical agents that can modulate the oxidative stress in the medium due to metabolic activities and consequently generate a better environment for the growth of beneficial bacteria (Rocchetti et al., 2020). The essential oils (EOs) from the leaves of *C. citratus* (DC) Stapf, *C. nardus* (L.) Rendle and *C. schoenanthus* (L.) Spreng. collected, early morning, from the botanical garden of the Research Institute in Applied Sciences and Technologies (IRSAT) (latitude 12°250′ N, longitude 1°290′ W), Ouagadougou (Burkina Faso) and voucher specimens were deposited at the herbarium of the Center of diversity (University Joseph KI-ZERBO, Ouagadougou) under numbers 17,940, 17,950, and 17,952 for *C. citratus*, *C. nardus*, and *C. schoenanthus*, respectively exerted good antifungal and anti-aflatoxinogenic effects against both *Aspergillus flavus* (GenBank accession number OL907105) and *Aspergillus parasiticus* (GenBank accession number OL907106) from the culture collection of the University of Western Brittany (Brest, France) and these effects were enhanced when combined. The effects were dose-dependent on fungal growth and aflatoxin production. The study also showed that the combination of essential oils from *C. citratus*, *C. nardus*, and *C. schoenanthus* produced synergistic and additive effects (Sawadogo et al., 2022). The combination of *C. citratus* and *C. nardus* and that of *C. nardus* and *C. schoenanthus* exhibited a synergistic effect against *Aspergillus flavus*. Both *C. citratus* and *C. schoenanthus* EOs totally inhibited the synthesis of aflatoxin B1 at 1 µL/mL. *C. citratus* blocked the production of aflatoxins B2 and G2 at 0.5 µL/mL. Both *C. citratus* and *C. schoenanthus* totally hampered the production of the aflatoxin G1 at 0.75 µL/mL. The combination of *C. citratus* and *C. schoenanthus* completely inhibited the production of the four aflatoxins. The study shows that the combinations can be used to improve their antifungal and anti-aflatoxinogenic activities

(Sawadogo et al., 2022). The antifungal activities of the essential oil components have been attributed to several mechanisms, including the leakage of intracellular biological macromolecules, the inhibition of ATPase activity, the intracellular generation of reactive oxygen species (ROS), the destruction of the cytoplasmic membrane, and the damage of mitochondria and DNA (Hu et al., 2021; Zhan et al., 2021; Sawadogo et al., 2022).

2.3.4. Insecticidal effect

The insecticidal activity of crude essential oil extracted from the Leafy stems of *Cymbopogon schoenanthus* (L.) Spreng. collected from Nalohou 2 (N09°45.626′ E01°36.153′), Benin and of its main constituent, piperitone, was assessed on different developmental stages of *Callosobruchus maculatus* F. (Coleoptera: Bruchidae). Adults of *C. maculatus* were obtained from infested seeds of cowpea in southern Togo. The plant was collected around Djamde in the Kozah region and dried at 30 °C for 72 h before extraction. A voucher specimen is conserved in the Herbarium of the University of Lome, Togo. Piperitone was more toxic by fumigation to adults with a IC_{50} value of 1.6 µL/L *vs.* 2.7 µL/L. Piperitone inhibited the development of newly laid eggs and of neonate larvae but was less toxic than the crude extract to individuals developing inside the seeds (Ketoh et al., 2006). The evaluation of the essential oil isolated from the leafy stems of *Cymbopogon schoenanthus* (L.) Spreng. that were collected in Nalohou 2 (N09°45.626′ E01°36.153′), Benin and a specimen was deposited at the National Herbarium of Benin against *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae), the red flour beetle demonstrated the susceptibility of this beetle to the essential oil tested by fumigation with LC_{50} value of 2.1 mL/L air. Concerning the isolated compounds, the LC_{50} values were 0.5 mL/L air for piperitone. Furthermore, mortalities of 100%, 82%, 75%, 72%, 68% and 42%, respectively, were found for piperitone at 2.4 mL/L air and the essential oil at 4 mL/L air. Piperitone, the major compound of *C. schoenanthus* was more than three times more efficient than the crude oil. The insecticidal tests against *T. castaneum* revealed the essential oils of *C. schoenanthus* as well as their main identified compound piperitone as promising bio-insecticides against this pest (Bossou et al., 2015).

2.3.5. Anthelmintic effect

The oils of *C. schoenanthus* (L.) Spreng. that purchased from WNF Ind. e Com. Ltda (R. Dr. Mario Pinto Serva, 64 - Sao Paulo, SP, Brazil) with lot no. 10608, d = 0.911 were evaluated against developmental stages of trichostrongylids obtained from sheep naturally infected and kept at Embrapa Pecuária Sudeste (fecal culture indicated 95% *Haemonchus contortus* and 5% *Trichostrogylus* spp.) (Katiki et al., 2011). *C. schoenanthus* essential oil had LC_{50} value of 0.045 mg/mL in egg hatch assay (EHA), 0.063 mg/mL in larval development assay (LDA), 0.009 mg/mL in larval feeding inhibition assay (LFIA), and 24.66 mg/mL in larval exsheathment assay (LEA). Terpenoid compounds are known to be active against a range of organisms and the synergy of several terpenoids can be effective on several targets because they are a complex mixture of compounds that can interact with multiple molecular targets on various developmental stages of *Haemonchus contortus* parasite (Marie-Magdeleine et al., 2009). For *Trichostrongylids*, the L_3 exsheathment is a key process in the life cycle because it is the transition step between the free living and the parasitic stages (Hertzberg et al., 2002). Studies on the kinetics of larvae exsheathment have emphasized that any disturbing factors or toxic compounds might reduce the parasite establishment in the host. Because geraniol was the main component in *C. schoenanthus*, which had better anthelmintic effects we can hypothesize that geraniol might be of potential interest for *in vivo* tests (Dakkak et al.,1981). The anthelmintic activity of essential oils followed the same pattern in all *in vitro* tests, suggesting *C. schoenanthus* essential oil could be an interesting candidate for nematode control (Katiki et al., 2011).

2.3.6. Anti-inflammatory and analgesic effects

The essential oil of aerial parts of the *C. schoenanthus* (L.) Spreng. that purchased from a local herbal market in Luristan Province, Iran, in February 2018. It was identified under the voucher specimen No. 1602-Aupf by N. Kazemivash, Department of Pharmacognosy, Faculty of Pharmacy and Pharmaceutical Sciences, Tehran Medical Sciences, Islamic Azad University, Tehran, Iran exhibited an analgesic effect, especially in the chronic phase of formalin test. In the carrageenan test, all administrated doses of *C. schoenanthus* essential oil significantly reduced the paw edema, compared to the control. The anti-inflammatory activity of the essential oil at doses 50, 100, and 200 mg/kg were tested against mefenamic acid (30 mg/kg) (Golestaneh Talaei and Jahandideh 2019). The phytochemical results indicated that the anti-inflammatory effects of *C. schoenanthus* essential oil may be due to its piperitone content (Sun et al., 2014). Since some studies have shown that carrageenan injection into the rat paw releases bradykinin which later induces the inflammation of prostaglandin and other autacoids, responsible for the formation of the inflammatory exudates (Ueno et al., 2000), it is possible that the existing piperitone in *C. schoenanthus* essential oil inhibits the biosynthesis of prostaglandins. Also, in the formalin test. Several studies have reported the anti-inflammatory activities of plants enriched with piperitone. The essential oil caused a graded inhibition of the second phase of the formalin induced pain. Therefore, *C. schoenanthus* essential oil could be a potential candidate as an anti-inflammatory drug (Golestaneh Talaei and Jahandideh 2019). Several studies have so far reported the immunomodulatory and anti-inflammatory properties of other compounds such as α-terpinene, *p*-cymene, and limonene found in *C. schoenanthus* essential oil and/or other plants rich in these compounds (de Cássia da Silveira e Sá et al., 2013; Silva et al., 2015). These studies have concluded that the existing compounds in *C. schoenanthus* essential oil may have either direct or indirect anti-inflammatory activities (Golestaneh Talaei and Jahandideh, 2019).

2.3.7. Dermal effect

Melanin biosynthesis is enhanced by treatment with a phenolic compounds rich fraction of ethanolic extract of *C. schoenanthus* (L.) Spreng. sp. leaves collected from Tunisia and identified at the Ecology Laboratory, Institute des Regions Arides (IRA), Tunisia, while voucher specimens of the leaf samples (UT-ARENA-00709) were deposited in the Alliance for Research on North Africa, University of Tsukuba, Japan in B16 murine melanoma cells and human epidermal melanocytes (HEM). The extract at 1/100 v/v appeared to have lower melanin content but this was due to the slight cytotoxicity of the extract at this concentration. The viability of the cells used in the quantification of intracellular melanin was not affected by 1/10,000 v/v and 1/1,000 v/v extract. For the succeeding experiments, the extract at 1/1,000 v/v was used. 1/10,000 v/v had higher melanin content compared to the control (by 6%) while 1/1000 v/v increased the melanin content by 30%, 48 h after treatment. The extract upregulated microphthalmia-associated transcription factor (Mitf) and possibly activates tyrosinase enzyme, providing evidence for its possible use to promote melanogenesis and as a therapeutic agent against hypopigmentation disorders. A possible mechanism of action is that *C. schoenanthus* increases the melanin content of the cells by upregulating the expression of the tyrosinase-related protein, tyrosinase, and dopachrome tautomerase at the protein and mRNA levels, comparable to the effect of the α-melanocyte-stimulating hormone, in both B16 cells and HEM, providing evidence for its possible use to promote melanogenesis and as a therapeutic agent against hypopigmentation disorders (Villareal et al., 2017).

2.3.8. Hepatoprotective effect

During the investigation of the possible role of hydro-alcoholic extract of dried leaves of *Cymbopogon schoenanthus* (L.) Spreng. (called Ethkher in Saudi folk medicine) that purchased from the local market on heavy metal cadmium (Cd) induced oxidative stress in mice. The partial characterization of the Ethkher extract was done in relation to the total phenolic contents and its total antioxidant capacity (IC_{50}). The extract contains 75 mg/g of the gallic acid equivalent of total phenols which may be responsible for its observed antioxidant activity. Ethkher extract showed the dose-dependent activity and the IC_{50} value of the extract were found to be 110 µg/mL. It was also found to contain high flavonoid contents [(10.42 mg/g of rutin equivalents (RE)]. The *C. schoenanthus* extract had a significant immunomodulatory activity and had a preventive effect on the hematological alterations in Cd intoxicated mice through prevention of Cd-induced elevations of blood parameters as bilirubin, aspartate aminotransferase (AST), alanine transaminase (ALT), alkaline phosphatase (ALP) and gamma-glutamyl transpeptidase (GGTP) compared to the control group. A low effective dose of 100 mg/kg of the extract was chosen and no signs of mortality and toxicity were observed up to 3000 mg/kg (Saggu et al., 2019). *C. schoenanthus* extract is considered a possible source of natural antioxidants, phenolics, alkaloids that contain potent immunomodulatory action. Phenolics are non-enzymatic antioxidants and the antioxidant property owes to the redox properties, which permit their action as reducing agents, hydrogen donors and singlet oxygen quenchers (Thirugnanasampandan and Jayakumar, 2011). A possible mechanism of action is that the extracts may protect the liver through free radical scavenging activity and this may be due to the antioxidants and flavonoids in the extract, where pretreatment with the extract (100 mg/kg) prevented Cd-induced elevations compared to the control group (Saggu et al., 2019).

2.3.9. Spasmolytic effect

The aerial parts of *C. schoenanthus* (L.) Spreng. were collected from the experimental field of the Medicinal & Aromatic Plants Research Institute (MAPRI), Khartoum, Sudan, in November 2013 and in February 2015. The voucher specimens are deposited at MAPRI, Khartoum, Sudan. The oil exhibited strong dose-dependent spasmolytic activity. The oil (10-130 µg/mL) dose-dependently inhibited spontaneous contractions of isolated rat ileum. The effect was strong and in the dose of 130 µg/mL comparable (105.23 ± 29.5%) to the maximal relaxant effect of atropine obtained in a dose of 6.4 µM in a previous series of experiments. Essential oil exhibited a dose-dependent effect in the second series of experiments where the effect on doses induced by acetylcholine (Ach) was investigated. The spasmolytic effect of the oil was assessed for four doses (30, 60, 90, and 120 µg/mL). In a dose of 30 µg/mL, the oil exhibited a weak effect. At 60 µg/mL, the oil exhibited a strong and significant spasmolytic effect on doses induced with lower doses of ACh (0.01-0.44 µg/mL). In the concentration of 90 µg/mL, the oil exhibited similar activity at lower concentrations of ACh (0.01-0.44 µg/mL). Atropine, used as a reference drug in this model, exhibited stronger activity and in a concentration of 0.14 μM completely inhibited the spasmogenic effect of ACh. Piperitone, the main metabolite of the investigated essential oil (58.7%), was previously shown to exhibit spasmolytic activity. Tested in a range of 1-100 µg/mL, piperitone concentration-dependently inhibited contractions of isolated rat uterus contracted with KCl (60 mM) with a calculated EC_{50} = 10.73 ± 1.27 µg/mL (Ponce-Monter et al., 2008). It was previously shown that limonene, a minor component of this oil, exhibits spasmolytic activity as well (Cardoso Lima et al., 2012). Relaxant activity was previously demonstrated for β-eudesmol, another minor metabolite of *C. schoenanthus* essential oil (1.3%). This sesquiterpene inhibited histamine- and barium chloride-induced contractions of guinea-pig ileum (Morita et al., 1996). A high essential oil content and stable composition makes *C. schoenanthus* from Sudan a valuable source of the commercially important monoterpene, piperitone. Significant spasmolytic activity of inflorescence essential oil was observed, emphasizing its beneficial properties, especially for gastrointestinal complaints. (Pavlović et al., 2017). The antispasmodic effect of the total aqueous extract of the air-dried herb of *C. schoenanthus* (L.) Spreng.

(common name lemongrass) that harvested in the Southwest of Algeria, in the region of Bechar, in April 2011 and the plant was indexed under the numbers CS/124/17/04/12 in the herbarium of the research unit Varenbiomol, University des Frères Mentouri Constantine 1 was elucidated and compare their effect on the reactivity of the rat distal colon. *n*-BuOH and EtOAc caused marked relaxation of the isolated rat distal colon, either when applied directly on the basal tone or when tested over KCl- and Ach-induced precontraction, which is probably related to the composition of each extract. Moreover, the *n*-BuOH extract of *C. schoenanthus* decreased the basal tone more markedly than the EtOAc extract. These results start to unravel scientific support for the use of *C. schoenanthus* as a relevant plant to alleviate gastrointestinal conditions, as abdominal pain or diarrhea. A possible mechanism of action of both EtOAc and the *n*-BuOH extracts of *C. schoenanthus* may be *via* decreasing the basal tone of the rat distal colon levels. We have no explanation for this now. However, since colonic basal tone is generally dependent on cholinergic transmission and Ca^{2+} currents, it is possible that components of *C. schoenanthus* block the tonic regulation of colonic smooth muscle tone, thus causing relaxation of the basal tone (Djemam et al., 2020). The results of the *in vitro* antispasmodic testing of air-dried powdered herb of *C. schoenanthus* subsp. *proximus* Stapf. that obtained from Halayeb and Wadi Alaba, Aswan, Egypt in March 2003 and a voucher specimen has been deposited in the Herbarium of the Pharmacognosy Department, Faculty of Pharmacy, Cairo University using the rabbit jejunum revealed that all of the tested concentrations of the different fractions failed to provoke any inhibitory effect on the pendular movement of rabbit intestine. However, all fractions exhibited a reversible inhibitory effect on ACh-induced contractions. The concentration of the *n*-hexane fraction that produced 50% inhibition to ACh evoked contractions was 10 µg/mL *vs*. 20 µg/mL for both chloroform and ethyl acetate fractions and 16 µg/mL for the total aqueous extract. In addition, the potency of the various fractions was tested in comparison to the standard antispasmodic drug, atropine; *n*-hexane and chloroform fractions were twice as potent as atropine in producing 50% inhibition to the same submaximal dose of ACh.However, the total aqueous extract and the ethyl acetate fraction were less potent than atropinee (El-Askary et al., 2008). The activity of the *n*-hexane and chloroform fractions could thus be attributed to the presence of proximadiol and β-sitosterol as in accordance with previous data (El-Deeb, 1981). Recent reports indicated that phenolic acids possess an antispasmodic activity; caffeic and protocatechic acids exerted a non-specific antispasmodic action on rat smooth muscle (Ortiz Urbina et al., 2006). Therefore, we can conclude that the ethyl acetate fraction obtained *via* successive fractionation of the total aqueous extract of the air-dried herb of *C. schoenanthus* subsp. *proximus* Stapf. exerted a moderate *in vitro* antispasmodic activity on the isolated rabbit intestine, an effect that may be attributed to its phenolic acid components *viz*. *p*-coumaric and caffeic acids (44.4% and 8.7%, respectively) (El-Askary et al., 2008).

2.3.10. Cardioprotective effect

Male albino rats were administered *Cymbopogon schoenanthus* subsp. *proximus* (Hochst. ex A. Rich.) Maire & Weiller (the plant material was purchased from a local market in Alexandria, Egypt) essential oil intraperitoneally daily with vehicle, (800 µL/kg/d), in the presence or absence of hypertrophic agonist isoproterenol. Cardiac hypertrophy and fibrosis were assessed using real-time polymerase chain reaction (PCR) and histological examination. Pre-treatment of rats with *C. schoenanthus* subsp. *proximus* decreased the ratio of heart weight to body weight and gene expression of hypertrophy markers atrial natriuretic peptide (ANP), brain natriuretic peptide (BNP), and β-myosin heavy chain (β-MHC), which were induced by isoproterenol. Pretreatment with *C. schoenanthus* subsp. *proximus* oil significantly decreased the isoproterenol-mediated induction of ANP, BNP and β-MHC by 73% ($p = 0.004$), 59% ($p = 0.007$), and 91% ($p = 0.024$), respectively. The pretreatment with *C. schoenanthus* subsp. *proximus* oil significantly reduced the elevated collagen volume fraction (CVF) levels induced by isoproterenol by 66% ($p = 0.006$). Isoproterenol treatment resulted in significant induction of Pro I and Pro III expression with 17.8-fold ($p < 0.001$) and 17.9-fold increases ($p = 0.004$), respectively. However, these increases of Pro I and Pro III mRNA levels were significantly reduced by 80% ($p < 0.001$) and 77% ($p = 0.004$), respectively, when the rats were pretreated with *Cymbopogon schoenanthus* subsp. *proximus* oil. The pre-treatment with *C. schoenanthus* subsp. *proximus* essential oil conferred cardio protection against isoproterenol-induced cardiac hypertrophy and fibrosis (Althurwi et al., 2020). Hence, a possible mechanism of action may be through preventing the increase in gene expression of fibrosis markers procollagen I and procollagen III and alleviated the collagen volume fraction caused by isoproterenol. The pre-treatment with *C. proximus* essential oil conferred cardio-protection against isoproterenol-induced cardiac hypertrophy and fibrosis (Althurwi et al., 2020).

2.3.11. Nephroprotective effect

Proximadiol **(1)** is a dicyclic sesquiterpenediol separated from the unsaponifiable matter fraction of the petroleum ether extract of *C. schoenanthus* subsp. *proximus* Stapf. from Asfan area, north-east of Jeddah, Saudi Arabia. T (Abdel-Moneim et al., 1969; El-Deeb, 1981). It proved to have unique antispasmodic characteristics and could be used for the propulsion of renal and ureteric calculi. The success of this principle in the propulsion of renal and ureteric calculi could be attributed to this pharmacological characteristic where ureteric dilation occurs without paralysis and preserving the propulsive waves (Radwan, 1975).

The effects of *C. schoenanthus* (L.) Spreng. herb (called El-Ethkher in Saudi folk medicine) on experimentally induced kidney stones in male Wistar albino rats were detected. Oxalate nephrotoxicity was experimentally induced by a 200 mg single dose of glycolic acid given orally. Rats were divided into three groups, glycolic acid, glycolic acid plus *C. schoenanthus*, and control

(D. water). Urine analysis of blood urea nitrogen (BUN), creatinine, and calcium revealed significant differences compared to the control. In addition, significant pathological changes were found in the kidney revealed by histopathological studies. Daily oral treatment with *C. schoenanthus* (1 mL of the extract) significantly corrected the incidence of nephrotoxicity, BUN (2274 ± 22.5 mg/dL), creatinine (60 ± 3.6 mg/dL), and calcium (4.7 ± 0.2 mg/dL) level differences compared to the control (2875 ± 4.4 mg/dL, 75 ± 4.4 mg/dL and 18.2 ± 0.2 mg/dL, respectively). The prophylactic effects of *C. schoenanthus* may possibly be attributed to its diuretic activity to maintain the oxalate concentration having less common effect and below supersaturation to precipitate as calcium oxalate and/or inhibit the formation of oxalate presence. *C. schoenanthus* contains many chemicals in different concentrations. Piperitone forms approximately 61% of the total *C. schoenanthus* constituents, whereas Carene-2 forms approximately 32%. The diuretic activity of *C. schoenanthus* could be attributed to one or both of these compounds. The mechanism of *Cymbopogon schoenanthus* attenuated calcium oxalate nephrotoxicity could be attributed to inhibition of glycolic acid metabolism and therefore inhibits calcium oxalate formation. The other possibly could be due to increasing the urine output (diuresis), and therefore prevent calcium oxalate crystals formation. Though it can rightly be concluded that *C. schoenanthus* extract has prophylactic effect in oxalate stone formation. Its diuretic effects in rats and on human volunteers emphasize its solubility properties on calcium oxalates. (Al-Ghamdi et al., 2007).

Investigation the protective role of branched-chain amino acids (BCAAs) and the 70% ethanolic extract of leaves of *C. schoenanthus* collected from Egypt against the potassium dichromate (PDC)-induced oxido-nitrosative nephrotoxic insult in the experimental rat model. The PDC-induced nephrotoxic effect caused a depletion of renal oxidative scavengers glutathione, superoxide dismutase with consequent lipo-oxidative cellular membrane deterioration manifested by a rise in malonaldehyde, oxidized glutathione, myeloperoxidase, and the concomitant increase in inflammatory response elements tumor necrosis factor-α (TNFα), nitric oxide, and interleukin-1β (IL-1β). Moreover, the comet assay and increased 8-hydroxy-2-deoxyguanosine proved an accelerated apoptotic DNA fragmentation. These local renal changes were met with global altered blood biochemistry. The BCAAs and *C. schoenanthus* extract or their compiled administration showed an ameliorative effect against PDC-induced nephrotoxic in a synergistic pattern. Hence, Both BCAAs and *C. schoenanthus* extract or their combined administration affords potential competitors against renal insult induced by polyvalent anion pollutants in experimentally studied animals' model. As a route for novel drug discovery, further investigation should be attempted to optimize their augmenting reno-protecting potential (Ahmed-Farid et al., 2018).

New herbal beverages from Egyptian *C. schoenanthus* subsp. *proximus* (kindly gifts from the Central laboratory, National Research Center, Giza, Egypt.) used for inhibiting or preventing calcium oxalate crystals formation. *C. schoenanthus* subsp. *proximus* contained average values of 13.25 GAE/g for total polyphenols and the concentration of total flavonoids was 3.5 mg QE/g for *C. schoenanthus* subsp. *proximus*. (0.0, 0.5, 1.0, 1.5 and 2) grams of *C. schoenanthus* subsp. *proximus* were prepared as beverages alone and mixtures put on a package similar with tea package, and 100 mL of boiling distilled water was added in cups with 5 g of sugar at room temperature forming beverages A, B, C, D, and E. Furthermore, the efficiency of formulated beverages of investigated plants has been studied to elucidate their activities on oxalate-induced renal calculi formation and the associated renal injury in rats. Formulated beverages D and E in ratio 0.0:2.0% from *C. schoenanthus* subsp. *proximus* were the most effective treatments to inhibit kidney stone formation which afford 0.4 mg/24 h for oxalate concentration while calcium content was 1.2 mg/24 h for beverages D and E, respectively. Also, urinary marker enzymes such as γ-GT, ACP, and ALP were (1.7 and 1.5), (0.73 and 0.71), and (0.92 and 0.86) measured as (U/min/mg protein) for beverages D and E, respectively. In addition, serum creatinine and blood urea were (13.1 and 14.6) and (0.77 and 0.59) mg/dl for beverages D and E, respectively. Malondialdehyde (MDA) levels were estimated as the index of lipid peroxidation of kidney tissues. Finally, light microscopic observations of urinary crystals and histological sections of urolithic kidneys remained like normal rats for treated rats with beverages C, D, and E. The results indicate that the inhibition efficiency of formulated beverages from *C. schoenanthus* subsp. *proximus* on calcium oxalate renal stone formation in rats increased gradually through rising the ratio of *C. schoenanthus* subsp. *proximus*. Therefore, it is recommended that intake 2 or 3 cups of beverages D or E will adjust the levels of urinary risk factors, marker enzymes, and kidney functions when divided into two or three times a day (Ibrahim and El-Khateeb, 2013).

Comparing both alcohol extract of seeds of *Ammi visnaga* and Halfa-bar (*C. schoenanthus* subsp. *proximus* (Hochst. ex A.Rich.) Maire & Weiller) for their anti-urolithic activity using a mature female rabbit weighing 1-1.5 kg were detected. Forty-two rabbits randomly divided into four groups. Group A negative control, group B positive control (chemically induced urolithiasis), group C like group B but treated with *Ammi visnaga* extract 5 mL orally twice daily for 2 weeks and group D like group B but treated with Halfa Bar extract, 5 mL twice daily for 2 weeks also. Group of induced urinary lithiasis for 14 days and 21 days showed clear body weight loss, higher consumption of drinking water and increased morning urine excretion. In addition to significant increase of blood urea, uric acid, serum creatinine and calcium levels. After 14 days of treatment with *Ammi visnaga* extract and proximol we noticed reversed body weight loss and overcome low blood urea, serum uric acid, creatinine, and calcium. Furthermore, urinary lithiasis groups showed clear crystallization compared to the control urine samples, but after 14 days treatment with *Ammi visnaga* and Halfa Bar extracts, there was nearly clearance of the urine and disappearance of the crystals from the urine (Younis et al., 2021).

2.3.12. Enzymatic effect

Enzyme inhibitory activity of essential oils from inflorescence of *C. schoenanthus* (L.) spreng. growing in Northern Sudan (longitude: 33° 26′ E; latitude 16° 41′ N). that taxonomically identified and voucher specimen No. 2014/1CS has been deposited in the Botany Department Herbarium, Faculty of Science, University of Khartoum, Sudan against Acetylcholinesterase (1.24 ± 0.09 mg galantamine equivalents GALAEs/g), Butyrylcholinesterase (1.21 ± 0.03 mg GALAEs/g), Tyrosinase (68.80 ± 3.15 mg kojic acid equivalents KAE/g) and α-amylase (55.22 ± 1.16 mg acarbose equivalents ACAEs/g). The oil did not exert any α-glucosidase inhibition (Yagi et al., 2020). AChE is a key hydrolytic enzyme that is responsible for the reduction of acetylcholine (ACh) levels in the hippocampus and cortex of the brain and inhibition of this enzyme is considered as an appropriate strategy to treat Alzheimer disease (Zengin et al., 2015). Tyrosinase is a vital enzyme in many skin conditions like hyperpigmentation and also in dopamine toxicity in Parkinson's disease and inhibition of this enzyme could be beneficial for the treatment of such diseases (Erdogan Orhan and Tareq Hassan Khan, 2014). The inhibition of α-amylase and α-glucosidase, key enzymes in hydrolysis of starch and oligosaccharide, control the blood glucose level and thus counted as an important strategy in the management of diabetes mellitus (Mnafgui et al., 2015).

2.3.13. Antistress effect

Through the investigation of the effect of ethanolic extract of leaves of *C. schoenanthus* (L.) Spreng. (locally known as "El bekherai") collected from the south of Tunisia in February 2011 on H_2O_2-induced cytotoxicity and stress in human neuroblastoma SH-SY5Y cells. The extract treatments significantly reversed heat shock protein expression in heat-stressed HSP47-transformed cells (42°C, for 90 min) and mRNA expression of HSP27 and HSP90 in H_2O_2-treated SH-SY5Y. Daily oral administration of 100 mg/kg and 200 mg/kg CSEE was conducted to ICR mice for 2 weeks. It resulted in a significant decrease of immobility time in forced swimming and tail suspension tests. The effect of the extract on animal behavior was concordant with a significant regulation of blood serum corticosterone and cerebral cortex levels of catecholamine (dopamine, adrenaline, and noradrenaline). The results demonstrated that the extract was effective in producing significant antistress effects at *in vitro* and *in vivo* levels. The molecular mechanism by which *C. schoenanthus* extract exhorted its beneficial effects seems to be partially modulated by chaperone activation, monoaminergic system, and hypothalamic-pituitary-adrenal (HPA) axis regulation. Furthermore, the *in vivo* results of CSEE oral administration showed a comparable effect to the established commercial antidepressant drug (imipramine). The decrease of immobility time was dose dependent in two models. These results indicated that ethanolic extract had a dose dependent antistress effect that was comparable to established commercial antidepressant drugs. The HPLC analysis of the extract identified several compounds with known neuroprotective activities like caffeic acid, ferulic acid, and quercetin. However, future studies should be addressed in exploring their mixture and the molecular mechanism that may regulate their activities. (Ben Othman et al., 2013).

2.4. Histopathological and biochemical toxicity of *Cymbopogon schoenanthus* (L.) Spreng.

A study demonstrated that the essential oil of *C. schoenanthus* (L.) Spreng. was practically nontoxic with an LD_{50} greater than 2000 mg/kg. However, the repeated administration of *C. schoenanthus* at a relatively lower dose over a 28-day period induced hypoglycemia, hyperuremia, hypernatremia, and liver organ damage in mice. At the dose of 10 mg/kg, there were no significant changes in biochemical parameters and histological analyses. No mortality was observed in the acute administration; the oral median lethal dose (LD_{50}) was greater than 2000 mg/kg. In the chronic administration, the animals showed no adverse effect on the behavioral responses, no toxic symptoms and mortality with variation on blood sugar, serum glutamate pyruvate transaminase SGPT (alanine transferase, ALT), serum glutamic oxaloacetic transaminase SGOT (aspartate transaminase, AST), creatinine, urea, Ca^{2+}, K^+ and Na^+ levels (Table 3). Moreover, the terminal necropsies revealed low toxic effects on the liver (Fathifar, Rastegar, and Asgarpanah 2021). No eye irritant reaction was shown in the rabbits exposed to *C. schoenanthus* essential oil. No adverse reactions such as edema and erythema were observed throughout rabbits dermally exposed to *C. schoenanthus* essential oil for 4 hr. Further clinical relevance of the results and complete toxicological profile elucidation, toxicity studies must be extended to long term toxicity test as carcinogenicity, nephrotoxicity, mutagenicity, and teratogenicity investigations (Sylvain et al., 2019). Thus, it would be cautious to use *C. schoenanthus* at lower doses to limit its adverse effects.

2.5. Industrial applications of *Cymbopogon schoenanthus* (L.) Spreng.

2.5.1. Bioenergy applications

The thermal degradation of *C. schoenanthus* (L.) Spreng. (camel grass) grass under an inert environment at three heating rates, including 10, 30, and 50 °C/min to evaluate its bioenergy potential. *C. schoenanthus* has shown considerable bioenergy potential with low-cost biomass. Thermal data were used to analyze kinetic parameters through isoconversional models of Kissenger-Akahira-Sunose (KSA) and Flynn-Wall-Ozawa (FWO) methods. The pre-exponential factors values have shown the reaction to follow first order kinetics. Activation energy values were shown to be 84-193 and 96-192 KJ/mol calculated by KSA and FWO methods, respectively. Differences between activation energy and enthalpy of reaction values (~5 to 6 kJ/mol) showed product formation is favorable. The Gibb's free energy (173-177 kJ/mol) and High

Table 3
Effects of *Cymbopogon schoenanthus* (L.) Spreng. essential oil on biochemical parameters in the sub-chronic toxicity in female mice.

Serum Biochemical Parameters/Groups	Control	10 mg/kg	100 mg/kg	200 mg/kg
Blood sugar	245.0 ± 13.6	220.0 ± 13.2	175.7 ± 22.5*	170.7 ± 2.9*
SGPT (ALT)	90.0 ± 30.5	61.3 ± 9.1#	59.0 ± 0.6#	59.7 ± 12.4
SGOT (AST)	199.3 ± 49.5	199.7 ± 17.2	211.0 ± 10.4	295.7 ± 15.3
Creatinine	0.52 ± 0.00	0.50 ± 0.01	0.52 ± 0.00	0.52 ± 0.00
Urea	64.3 ± 5.8	47.7 ± 1.8*	48.7 ± 0.9*	42.3 ± 0.3**
Ca^{2+}	11.03 ± 0.3	11.07 ± 0.2	10.83 ± 0.2	10.50 ± 0.2
K^{+}	11.80 ± 1.3	10.20 ± 0.6	11.3 ± 0.1	8.5 ± 0.3*
Na^{+}	145.3 ± 0.3	147.7 ± 1.3	150.3 ± 0.3**	151.0 ± 0.5**

Cymbopogon schoenanthus (L.) Spreng. essential oil was administrated at sub-chronic oral doses (10, 100, and 200 mg/kg/day over 28 days). The serum biochemical parameters were measured at the end of the experimental period. Data are expressed as mean ± SEM; n=3; *p < 0.05, **p < 0.01 compared to the control group and # p < 0.05 compared to the test group 200 mg/kg.

Heating Value (15.00 MJ/kg) have detectable bioenergy potential of this low-cost biomass. Pyrolysis of Camel grass comprised of three stages; stage-I, up to 180 °C, showed release of retained water, stage-II depicted major biomass loss due to degradation of celluloses from 270 to 319 °C, and stage-III occurred from 340 to 470 indicating lignin degradation and charring. The temperature range of 270-470 °C may be employed for its gasification. Pyrolysis yielded 30.4% of biochar at 550 °C. The volatile matter (82.6%), high heating value (15.00 MJ/kg), lower activation energy (84-193 kJ/mol) and Gibb's free energy (173-177 KJ/mol) have shown that *C. schoenanthus* biomass can be directly converted into energy, gaseous fuels and chemicals in a cost and energy-efficient manner (Mehmood et al., 2017).

2.6. Corrosion applications of *Cymbopogon schoenanthus* (L.) Spreng.

C. schoenanthus (L.) Spreng. aerial ethanol extract, (CSAEE) could reduce the corrosion of aluminum brass in acid cleaning solutions in the distillation plant. At 250 ppm, the efficiency of CSAEE was excellent (97%). Polarization assessments confirmed that the organic compounds in CSAEE were effective mixed-type corrosion inhibitors. HPLC and FTIR analysis were used to explore the key chemical components of CSAEE. CSAEE caused the corrosion process to have a higher energy barrier. Observations of SEM and FT-IR spectra confirmed that CSAEE prevents corrosion attacks at the aluminum brass's surface (Deyab and Al-Qhatani 2022).

2.7. Cosmetic industries

Cymbopogon genus essential oils are widely used in the fragrance, cosmetic, food, and flavor industries. Cosmetic products containing. *C. schoenanthus* (L.) Spreng. (Ethkher and camel grass) is a citral containing species (Tibenda et al., 2022). Geraniol and citral are two major constituents of the essential oil that, due to their specific rose and lemon-like aromas, are the preferred raw material for the commercial production of flavors, cosmetics, and fragrances in soaps and detergents (Tibenda et al., 2022). *C. Schoenanthus* volatile oil were detected in global markets such as LUSH Amazon primer oil bar®, Origins flower fusion violet nourishing sheet mask®, Truly Cooka oil pubic hair oil serum®, Dermalogica precleanse cleansing oil® and the creme shop Rise and Shine ampoule serum® (Tibenda et al., 2022).

2.8. Ethnopharmacology and uses of *Cymbopogon schoenanthus* (L.) Spreng. in folk medicines

Traditional applications of *Cymbopogon* genus in different countries show high applicability as a common tea, medicinal supplement, insect repellant, insecticide, in flu control, and as anti-inflammatory and analgesic (Opeyemi et al., 2015).
Cymbopogon schoenanthus (L.) Spreng. ssp. *laniger* (Hook) Maire et Weill is an aromatic herb consumed in salads and used to prepare traditional meat recipes in Tunisia (Khadri et al., 2008). Due to its pleasant aroma and taste it is used to prepare an aromatic ''tea" that is much appreciated and largely consumed in the north of Africa (Ressources, 2005). Besides its use in culinary, *C. schoenanthus* is also used in folk medicine. Its medicinal properties are known from the antiquity, being already described by ''Pliny the Eldey" in his book Naturalis Historia (L'ANCIEN, 1848-1850).
Le Floc'h (1983) reports its use for the treatment of rheumatism and fever. This author also describes its use as a diuretic, insecticide and a poultice to cure dromedary wounds. In the South of Tunisia, this plant is also used for the treatment of rheumatism, and to diminish fever.

The plant is particularly appreciated for its medicinal action in North Africa and it is also used for anorexia. In the Djanet area (Alger), it is well known for bringing back the appetite. The infusions are taken as a diuretic, it cures intestinal troubles and, in the form of decoction, it acts against food poisoning and helps also in the digestion (Khadri et al., 2008).

3. Concluding remarks

This review proved that plants of the genus *Cymbopogon* either in the extract form or essential oil form have a lot of pharmacologically biodiversities especially *C. schoenanthus* (L.) Spreng. which was studied mostly as a drug source. Its isolated compounds and/or extracts displayed diverse biological activities such as antioxidant, antimicrobial, anti-inflammatory, antiproliferative, antidepressant, antispasmodic, nephroprotective, inhibit kidney stone formation, cardioprotective, antihypertensive, and enzyme inhibitor activities, also displayed an antiproliferative activities *vs*. different cancer cell lines. These compounds isolated from different *Cymbopogon* species can be either a new drug or a base for the new drug. *C. schoenanthus* (L.) Spreng. could be new natural agents with functional properties for food, cosmetics, and pharmaceutical industries. All these findings should evoke researchers for development of new drugs from natural ingredients.

Conflict of interest

The authors declare that there is no conflict of interest.

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Author Contribution Statement

A.D., A.W., F.A., K.H., M.M.A., O.A., and M.I.R. collected a complete survey of all compounds and their biological activities isolated from *Cymbopogon schoenanthus* (L.) Spreng. M.I.R. and I.A.M.A. wrote the manuscript. A.E.R., I.A.M.A., and A.E.A. revised the surveyed literature data. A.E.R., I.A.M.A., and A.E.A. discussed the results scientifically and contributed to the design and editing of the review. All authors reviewed the final manuscript References.

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