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Review article

Ecological analysis of *Cymbopogon* species: A comprehensive review

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Abstract

Cymbopogon species are known for their characteristic aroma and grow in different regions of the world. In India, 45 species are being grown for producing lemongrass essential oil (EO). Globally, grasslands are among the most widely distributed terrestrial biomes, including all herbaceous vegetation, and *Cymbopogon* types (low hills) are one of them. This review addresses the different physiological trait variations for adaptations influenced by climatic factors and the rate of biomass accumulation and carbon sequestration, EO yield, quality, and chemical compositions. EO extracted from different *Cymbopogon* species used in managing stored grain pests and pathogens to decrease the harmful effects and risk of synthetic insecticides on human beings and their surroundings is also reviewed. Previous studies on *Cymbopogon* species had primarily focused on pharmaceutical applications, cosmetics, aromatherapy, food preservation, and agriculture. Thus, the comprehensive review is done to understand the different environmental interactions, productivity, and carbon sequestration in aromatic grass biomass that can potentially contribute to the socio-economic. Enhancement of our nation and mitigate the present scenario of global warming, as well as aromatic grass as potent biopesticides to overcome the post-harvest lost in the world.

Keywords: Biomass, Carbon sequestration, *Cymbopogon* stability analysis, Environmental factors, EOs, Pathogens, Pests.

Introduction

In different agricultural sectors, essential oil (EO) bearing plant cultivation has rapidly expanded to meet the ever-growing demand for EO since 1950. Essential oils are extracted from different plant parts such as leaves, flowers, twigs, fruits, bark, buds, roots, seeds, and wood. Lemongrass is among the most important medicinal and aromatic plants (MAPs) growing in different ecosystems, as habit-wise classification of MAPs showed 33% trees, 32% herbs, 20% shrubs, 12% creepers, and 3% others (Kumar & Jnanesha, 2016). The plant belongs to the Poaceae family, which has more than 635 genera and 9000 species, and is widely distributed worldwide. More than 180 species of this aromatic grass are cultivated (Figure 1), of which 52 species are grown in Africa, 45 in India, 6 in Australia, 6 in South America, 4 in Europe (only in Montenegro), 2 in North America, and the others in South Asia as well (Devi et al., 2019; Ewa et al., 2019; Hassan, 2016; Khanuja et al., 2005). In India, more than 60000 hectares of area are under cultivation, which is distributed in different states like Madhya Pradesh, Gujarat, Karnataka, Assam, Kerala, Maharashtra, Uttar Pradesh, and Andhra Pradesh (Padalia et al., 2011). The plant is native to Asia and Africa and cultivated in Guatemala (Srivastava et al., 2009). Among 17,500 native higher plant species in our country, 1300 species contain odiferous principles (Lawrence, 2004; Bruneton, 1999). The commercially important *Cymbopogon* species, namely, *C. flexuosus* Nees ex Steud. Wats (Poales: Poaceae), lemongrass, *C. winterianus* Jowitt ex Bor (Poales: Poaceae), citronella, *C. martini* Roxb. Wats (Poales: Poaceae), palmarosa, and *C. pendulus* (North Indian Lemongrass) are cultivated in tropical and subtropical regions of India (Devi et al., 2020).

Studies on grassland communities in Northeast India are limited in various aspects (Lehmkuhl, 1994). Kanjilal and Bor (1940) listed 152 genera, including 631 species of grasses from Assam. In Meghalaya, 11 genera (32 species as sympodial and 3 as monopodial types) and 35 bamboo species were enumerated, of which four species were endemic to North-East India (Kharlyngdoh, 2008). Barbhuiya et al. (2013) highlighted 98 grass species of 49 genera, which account for 32% of the grass community

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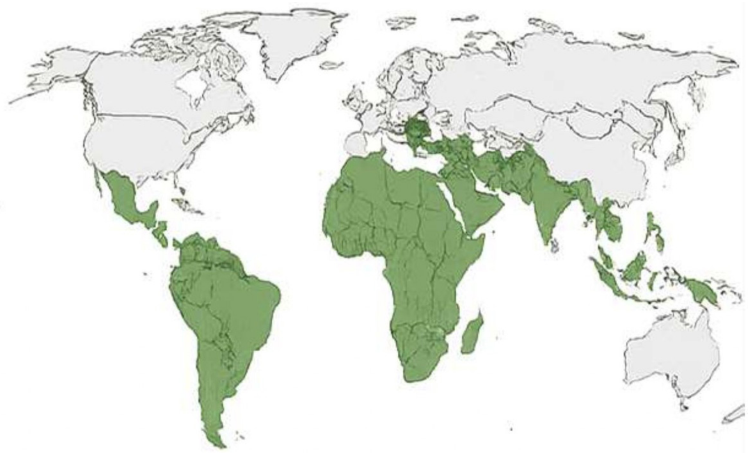

Figure 1: Commonly growing *Cymbopogon* species in different parts of the world

in Assam, where sub-family Panicoideae (52 species), Bambusoideae (25 species), Chloridoideae (13 species), Ehrhartoideae (4 species), Centothecoideae (3 species) and Arundinoideae (1 species), respectively. In Manipur, *C. citratus*, *C. khasianus* and *C. nardus* are growing in different locations as wild varieties, where *C. khasianus* and *C. nardus* are added to the list of wild aromatic grasses in the state for the first time (Devi et al., 2023). The taxonomic characteristic of aromatic grasses was studied by various workers (Kassahun et al., 2011; Lal et al., 2018, 2019, 2020; Shamsheer et al., 2020; Yogendra et al., 2022), but any has never undertaken comprehensive taxonomic studies because of the highly diverse area. Ethnopharmacology and phytochemical analysis have been extensively studied by Avoseh et al. (2015), showing the potentiality for pest control, cosmetics and as anti-inflammation agents. Tibenda (2022) broadened different aspects of the analysis of the *Cymbopogon* genus, but still ignored ecological traits.

The grassland ecosystem plays a vital role in various ecological services (MEA, 2005) and also provides numerous food supplies to domestic animals, humanity and a source of medicine for the welfare of human beings (Devi et al., 2021; Mukarram et al., 2021). They also provide essential non-physical services like recreation and tourism, national culture and heritage, climate regulation, and erosion control for the welfare of human beings and biodiversity (Zhao et al., 2020), but impacts of climate change and human activities affect grassland ecosystem services (Zhang et al., 2020). Thus, the present review integrates ecological performance data, biomass, carbon sequestration, and EO-based pest management, thereby filling the gap in studies on *Cymbopogon* species as shown in Figure 1.

Morphological stability analysis of aromatic grasses

In lemongrass, the stability and variation of oil and citral biosynthesis are influenced by the environment. Morphological characteristics of 15 species of lemongrass have been studied for height per plant, length of culm, color of leaf, leaf sheath, and nature of the flowering by Kuriakose, 1995. All the types of lemongrass showed significant differences between them for all the characters studied. From the 15 collections, 3 red and 4 white types and the remaining light red lemongrass varieties have been found. Singh and Singh (1999) analyzed the morphological characteristics of 12 genotypes of lemongrass. The study showed significant variability for all the characters studied, except plant height, among the selected genotypes of lemongrass. Fresh weight of the herb showed maximum range of variability, followed by essential oil yield and plant height, and minimum variability was shown for oil content. Sharma et al. (2002) analyzed morphological characteristics of lemongrass, such as plant height, number of leaves per plant, number of tillers per plant, biomass production, and oil yield per plant during different growth phases. The study revealed that various morphological characteristics were optimal at the flowering stage. Essential oil yields were correlated with the morphological characters of plant height, number of leaves per plant, and number of tillers per plant. The genotype showed significant differences in all the different environmental factors for all the traits measured. The stability behaviour of six varieties of lemongrass, viz., *C. flexuosus, C. khasianus*, and *C. pendulus*, and their hybrids for four years in oil yield was studied by Bhan et al. (2005).

The difference in the number of tillers (NT) observed in *Cymbopogon* species might be due to dissimilarity in the inherited characters of the genotypes as well as different environmental variations (Ibrahim & Khalidh, 2013). Lal et al. (2018) reported that *C. khasianus* reached 98 cm in vegetative plant height (VPH) and 201 cm in the flowering stage, having 93 and 870 NT and number of leaves (NL). The plant height of Jor Lab L-15 was 109 cm, and the check variety, i.e., IIMJ (CK) – 10, reached an average height of 79 cm of *C. khasianus* (Lal et al., 2019).

Different morphological studies had also been done by Shamsheer et al. (2020) in 50 accessions of *C. citrates* collected from various regions, showing a range of 67 to 168 cm plant height, having 2 to 56 NT, and the highest NT produced was from the accession of Khairpur, having 21 and 56 tillers in the first and second year of growth. Among the cultivars of *C. flexuosus*, CIM-Shikar showed a significantly higher plant height of 136.75 cm, which was followed by CIM-Suwarna (131 cm) and the presence of higher NT per clump was noticed in CIM-Shikar (47.60), followed by Krishna (47.53) and CKP-25 (42.13), where the *C. flexuosus* cultivar, Nima, obtained a lesser number of tillers per clump of 38.13, respectively (Yogendra et al., 2022). Table 1 represents some of the major morphological characteristics of *Cymbopogon* species growing for commercial cultivation.

Biomass and carbon sequestration

Grassland is vital in biomass accumulation and carbon assimilation in the ecosystem. The study of biodiversity is much needed to understand the relationship of various ecosystem structures and functions. Biomass is the amount of organic matter present in the organism per unit area of the community, and at a particular time, the estimation of weight results in a standing crop of biomass. It was reported that average herbage yield of 27.6 to 30 ton ha^{-1} year-^{1} for Jor Lab L-10, whereas 21.45 to 22.33 in the check variety for first and second year of analysis, 30.32, 36.5, 29.57 ton ha^{-1} year^{-1} for Jor Lab L-8, Jor Lab C-5 of Java Citronella and Jor Lab L-14 (Lal et al., 2019; Lal et al., 2018; Lal et al., 2016a; 2016b). Yogendra et al. (2022) and Kumar et al. (2023) also reported that the herbage yield of CIM-Shikar (24.25 tons ha^{-1} year^{-1}), followed by Krishna (22.50 tons ha^{-1} year^{-1}) and CKP-25 (20.72 tons ha^{-1} year^{-1}) and 373.61 to 434.36 quintal/ha/year of *C. spreng* (Table 2). In grassland communities, a larger proportion of their biomass is below ground as compared to the ground ecosystem, resulting in large ratios of shoot components. Slow decomposition and weathering rates lead to significant accumulations of soil organic matter and often highly fertile soils due to more significant biomass accumulation in root-to-shoot systems (Blair et al., 2014). Astapati & Das (2011) found that rhizome biomass varied between 357.33 to 1073.33 g m^{-2} in the burnt plot and 229.95 to 710.22 g m^{-2} in the unburnt plot during the first year of study and 546.66 ± 98.88 to 750.67 ± 153.12 gm^{-2} in burnt and unburnt plots in the second year of analysis in Barak Valley, Assam, North East India. The composition, structure, and functioning of the grassland. Ecosystems are greatly influenced by climate, fire, grazing, and the independent effects of each driver alone. Productive grassland communities tend to store the most organic matter and nutrients in the soil, correlated with water availability. Grassland species are mainly characterized by fine roots that are highly branched, fibrous in nature, and concentrated in the upper soil profile from the top 20 to 50 cm. Still, they quietly differ in the co-existing woody and herbaceous ecosystem, species (fibrous, taproots, etc.), root depth distribution, and root-to-shoot biomass allocation, respectively. The species richness in the grassland ecosystem increases plant biomass (Singh & Misra, 1969; Naugraiya & Pathak, 1986). Differences in the rooting system and coexistence of various types of grass with many forbs and woody plants lead to differential use of soil resources, water, and nutrient uptake, and hence, abundance of grasses and other plant life forms under changing environmental conditions. Even in the same ecosystem, the amount of root biomass differs among grass species in different grasslands and within

Table 1: Major morphological characteristics of commonly growing *Cymbopogon* species

Species	*Plant height (cm)*	*Leaf shape & texture*	*Tiller number*	*Leaf width (cm)*	*Special traits*	*References*
C. flexuosus	100–150	Linear, glabrous, light green	20–40	1.0–1.5	High citral content; dense clumps	Lal et al. (2020); Kumar et al. (2023)
C. citratus	90–120	Long, arching, green	15–30	1.2–1.8	Strong lemon aroma; robust stem	Kassahun et al. (2011); Devi et al. (2023)
C. martinii	80–100	Narrow, soft, slightly hairy	25–35	0.8–1.2	Geraniol-rich; aroma persists after drying	Chauhan et al. (2017)
C. khasianus	150–180	Broad, light green	30–45	1.5–2.2	High biomass, oil-rich cultivar	Kumar et al. (2023); Lal et al. (2019)
C. winterianus	120–140	Dark green, shiny, narrow	20–30	0.8–1.3	Citronellal-rich; used for mosquito repellents	Devi et al. (2020); Isman (2006)
C. pendulus	90–110	Narrow, rough leaf surface	20–25	0.7–1.0	Contains elemicin; hardy in poor soils	Sharma et al. (2002)
C. nardus	110–130	Thick, coarse, dull green	20–35	1.0–1.5	Citronellal dominant; excellent for cuticle oils	Ibrahim & Khalid (2013); Devi et al. (2021)

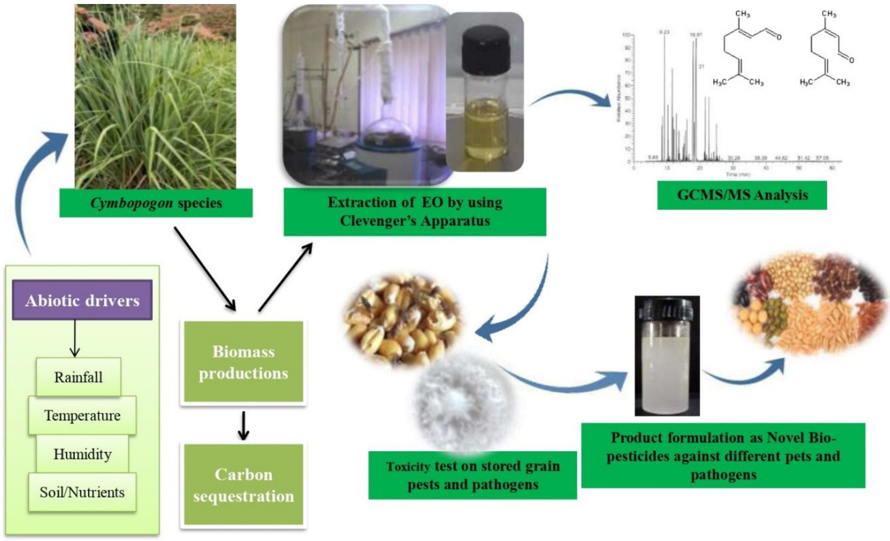

Figure 2: Schematic diagram of different environmental factors on biomass, carbon sequestration, EO yield, EO toxicity against pest, pathogens and its potential applications as bio-pesticides

a single site due to interannual variability in climate, topography, soil type, site management, and soil depth (Blair et al., 2014).

Several abiotic and biotic factors and differences in the root structure, i.e., fine roots, are very important in soil organic matter and carbon sequestration. The relationship between fine root biomass and soil pH, moisture, temperature, and variability of fine root biomass in the different seasons has shown differences in the rate of biomass accumulation and carbon sequestration (Singh et al., 1999). Fu et al. (2016) highlighted the contribution of the story layer in fine root biomass in the mid-subtropical monsoon climate. Carbon sequestration occurs in an ecosystem when carbon assimilation is more significant than environmental carbon loss. However, the rate of absorption of CO_2 through photosynthesis and storage on land or at sea is declining. Various anthropogenic activities lead to global climate change atmospheric increase in CO_2 concentration of approximately 40% from the pre-industrial levels, so a study on the changes in the global pattern of carbon sequestration which will alter. The performance of plants and the control they exert on the global carbon cycle is, therefore, a scientific priority. Gebhart et al. (1994) reported that 1.1 and 1.7 Mg of carbon can be stored in ha^{-1} year^{-1} of soil annually. Conservation of different grassland ecosystems is a necessary step as their transformation would lead to less carbon sequestration and loss of soil organic carbon (SOC) from the environment (Deng et al., 2016; Laganiere et al., 2010; Li et al., 2020; Wei et al., 2014; Zhou et al., 2019). Therefore, conservation and management practices should ensure the safety of bio-diverse carbon pools in the respective ecosystems (Sanjita et al., 2022). A comprehensive study of biomass production and carbon sequestration has been conducted in different ecosystems (Madgwick, 1976; Houghton et al., 2007; Han et al., 2022), but minimal information on aromatic grass analysis related to various ecological parameters. Thus, the study of biomass production and carbon sequestration in aromatic grass biomass can potentially contribute to the socio-economic enhancement of our nation and mitigate the present scenario of global warming in every aspect of the world.

Essential oil

Lemongrass can be used for EO and lignocellulosic material for ethanol production (Zheljazkov et al., 2011). It has been reported that the fresh EO content of 0.34 to 0.53% and EO yield/ha of 42.29 to 108.16 kg was obtained for the first year, whereas, 0.45 to 0.55% with 155.09 to 342.69 kg of EO content and EO yield/ha for the second year of analysis (Kassahun et al., 2011). The overall mean performance of lemongrass in terms of citral content over the tested locations varied from 70.81 to 82.68% (Kassahun et al., 2011). Hanaa et al. (2012) reported that the highest EO percentage (2.45%) was shown by oven drying compared to shade-drying (2.12%) and sun-drying methods (2.10%) of *C. citrates* by analyzing eighteen essential oil components identified from fresh and dried leaves, geranial (citral-a), neral (citral-b) and myrcene found as main components. The EOs were more decadent in citral (83.0%), geranial (48.9%), lemon (42.3%), neral (34.8%), eudesm-3-en-7-ol (29.5%), geraniol (12.1%), α-bisabolene oxide A (9.1%) eudesm-11-en-4α-ol (9.6%) geranyl acetate (8.3%) isopulegol (1.9%), epi-α-eudesmol (6.1%) etc., in different parts of the plant. It has been revealed that leaf sheaths (76.2%) and inflorescence stems (80.5%) yielded citral-rich oils (Rao et al., 2015).

C. flexuosus produced 1% EO content, and Jor Lab C-5 of Java Citronella (*C. winterianus*) had a 1.20% EO yield (Lal et al., 2016a & 2016b). Chauhan et al. (2017) reported that the EO of the palmarosa (*C. martini*) crop yields comparatively less oil recovery of about (0.56%) with an average oil yield of 139.7 kg ha^{-1}. Kumar et al. (2023) stated that *C. spreng* produced annual EO yield ranging from 0.51 to 0.86% and EO yield of 210.03 to 375.13 kg/ha/year. Yogendra et al. (2022) reported that the EO content was in the range of 0.70 to 1.35% (v/w), and EO yield ranged from 133.56 to 302.40 kg ha^{-1} $year^{-1}$ in different cultivars of lemongrass. In Manipur, the indigenous (*C. khasianus*) and exotic lemongrass (*C. flexuosus*) produced EO yield of 0.09% (pale yellow) with herbage yield of 31.0 ± 1.55 tons/ha/year and 1.87% (light yellow) of herbage yield 32.0 ± 1.60 tons/ha/year containing methyl isoeugenol (51.44%), α-Pinene (19.28%), Dlimonene (7.64%), Cubebol (4.20%), Tricyclo [3.2.1.0(2,4)] octane, 8-methylene-(2.11%) as the major constituent in indigenous lemongrass whereas citral (32.52%), neral (40.96%), geraniol (7.94%), carophyllene (3.14%), camphene (1.71%), as major constituents of *C. flexuosus* (Table 2), respectively.

Toxicity of *Cymbopogon* EO on pest and pathogens

Chemical pesticides are used for the control of infestation caused by pests, but prolonged use of many conventional fumigants leads insects to develop resistance against these synthetic pesticides, which affect health and the environment (Isman, 2006; Pimentel et al., 2007). Several reports (Table 3) have shown that essential oils of genus *Cymbopogon* were toxic to stored-product beetles, and their individual constituents work against stored grain insect pests and act as potential fumigants (Shaaya & Kostyukovsky, 2011; Caballero-Gallardo et al., 2012; Rajashekar et al., 2012 & 2013; Rajendran & Sriranjini, 2008). Essential oils possess insecticidal activity with low mammalian toxicity and biodegradation (Isman,

Table 2: Chemical constituents, EO yield, biomass, and applications of most commonly grown *Cymbopogon* species

Species	*Major constituents (% Range)*	*EO yield (% w/w)*	*Biomass yield (t/ha)*	*Applications*	*References*
C. flexuosus	Citral (70–85%), Geraniol (3–8%)	0.6–1.3	20–25	Flavoring, perfumery, antimicrobial; Food preservative	Lal et al. (2020); Devi et al. (2023); Padalia et al. (2011)
C. citratus	Citral (65–85%), Geranyl acetate (3–6%)	0.5–0.9	15–20	Anti-inflammatory, fragrance	Kassahun et al. (2011); Ewa et al. (2019); Devi et al. (2021)
C. martinii	Geraniol (75–90%), Linalool (2–5%)	0.5–1.0	18–22	Cosmetics, insect repellent, antifungal	Chauhan et al. (2017); Devi et al. (2019); Padalia et al. (2011)
C. winterianus	Citronellal (32–45%), Geraniol (10–15%)	0.8–1.4	25–30	Mosquito repellent, perfumery, antiseptic	Devi et al. (2021); Isman (2000); Devi et al. (2020)
C. khasianus	Citral (70–80%), Elemicin (5–7%)	1.0–1.6	20–28	Fragrance, high EO-yielding cultivar	Kumar et al. (2023); Lal et al. (2019); Khanuja et al. (2005)
C. pendulus	Elemicin (10–54%), Limonene (3–5%)	0.4–0.7	12–18	Perfumery, medicinal, industrial solvents	Shahi et al. (1997); Sharma et al. (2002); Padalia et al. (2011)
C. nardus	Citronellal (35–40%), Citronellol (15–20%)	0.8–1.2	18–25	Aromatherapy, antiseptic, repellent	Ibrahim & Khalid (2013); Devi et al. (2021)

Table 3: Insecticidal activities of common *Cymbopogon* essential oils against different pests

Species	*Target pest*	*Bioactivity type*	*Effectiveness*	*References*
C. flexuosus	*S. oryzae*, *T. castaneum*	Insecticidal, fumigant	High mortality and repellency	Devi et al. (2020); Devi et al. (2019)
C. citratus	*T. castaneum*	Repellent, contact toxicity	High repellency at 5–10 μL concentrations	Caballero-Gallardo et al. (2012); Ewa et al. (2019)
C. martinii	*C. maculatus*	Contact toxicity	Effective at low concentrations	Devi et al. (2021)
C. winterianus	*T. castaneum*, *L. serricorne*	Fumigant and repellent	Strong fumigant activity; knockdown observed	Isman (2006); Kim et al. (2003)
C. khasianus	*T. castaneum*, *S. oryzae*	Insecticidal	Promising in lab assays for pest management	Kumar et al. (2023); Devi et al. (2019)
C. nardus	*A. aegypti*,	Repellent	Effective mosquito repellency	Arpiwi et al. 2020

2006). Various essential oils (EOs) and volatile compounds have been used as potential fumigants, repellent and contact toxicity against stored grain insect pests like *Callosobruchus maculatus*, *Sitophilus oryzae* and *Tribolium castaneum* (Keita et al., 2000; Kim et al., 2003; Garcia et al., 2005; Zapata & Smagghe, 2010; Caballero-Gallardo et al., 2012; Rajashekar et al., 2013; Kim & Lee, 2014; Nenaah et al., 2015; Hu et al., 2019; Devi et al., 2019; Devi et al., 2020). These EOs contained secondary metabolites, and their toxicity worked against many stored grain insects as their activity enormously differs from that of the secondary plant product. *T. castaneum* causes heavy loss during post-harvest storage of milled products in quality and quantity, constituting 10–40% of grain loss (Rajashekar et al., 2012 & 2016). The toxicity of essential oil has also been shown in *Myzuspersiae* (Chen et al., 2017), and their toxicity to stored-product insects may act as stomach poison after being ingested (Padin et al., 2013; Isman, 2006). Soltani et al. (2022) analyzed the contact toxicity of ethanolic and methanolic extracts from *Urginea maritima* bulbs and *Asphodelus microcarpus* tubers against *T. castaneum* collected from three locations of North West of Tunisia. The toxicity test showed that both the plant extracts had an effective control against *T. castaneum* at a concentration of 7.5 μL/L air, with a high mortality percentage of the methanol extract, which depends on the soil components and geographical distribution of the plants. The important chemical constituents of these EOs are geraniol, citral, citronellal, and piperine, respectively. Azeem et al. (2022) analyzed the toxicity of essential oils from *C. sumatrensis* and *E. canadensis* against *T. castaneum*, showing toxicity against adults with LD_{50} of 3.7 and 5.6 mg per 10 g grains, whereas in a fumigation bioassay, it showed LD_{50} of 6.6 and 10.6 mg/L, whereas the EOs of *C. ambrosioides* and *E. canadensis* exhibited antifungal activity against *A. flavus*. Devi et al. (2020) also analyzed plant essentials of *C. flexuosus*, *C. winterianus*, *C. martini*, and *P. cablin*, show toxicities effects on *S. oryzae* (L.). The EOs of four aromatic plants contained citral, neral, geranyl acetate, geraniol, citronellal, geraniol, citronellol, photocontrol B, azulene, and α-guanine, respectively. At LC_{50}, 44.5 and 26.1 μL/L air after 24 and 48 hours exposure of *C. flexuosus* was found to be the most potent fumigant compared to *C. winterianus*, followed by *C. martini* and *P. cabin*. Whereas in contact toxicity, *C. martini* oil was the most effective against adults of *S. oryzae* at LC_{50} 2.6 and 1.8 $\mu L/cm^2$ after 24 and 48 hours exposure, and the EOs of *C. winterianus* and *P. cablin* showed moderate toxicity to *S. oryzae*, respectively. The results suggested that the extracted EOs can have potent insecticidal efficacy in managing *S. oryzae* as an eco-friendly initiative. The antifungal activity of essential oils extracted from *C. flexuosus*, *C. winterianus*, *C. martini* was analyzed by trapping the volatile organic compounds using SPME-GCMS against plant fungal pathogens like *F. oxysporum* and *S. oryza* (Devi et al., 2021).

Thus, the present review examined the various aspects of ecological studies of *Cymbopogon* species growing in different parts of the world. From the literature review survey, several workers worldwide have studied grassland ecosystems. Still, there is minimal data on grasses like *Cymbopogon* species, one of the world's grassland ecosystems. In India, deforestation, agricultural practices, and succession at various levels by grazing, burning, and harvesting result in grasslands originating from forest ecosystems. Several works have been studied on grassland communities in India. Still, no information is available on aromatic grasses about different environmental factors for identifying the overall higher biomass, productivity, rate of carbon sequestration, and toxicity of *Cymbopogon* EOs against various pests and pathogens.

Conflict of Interest

The authors declare no conflict of interest.

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