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REVIEW ARTICLE

Historical and contemporary development of novel chemotype varieties with high essential oil of lemongrass in India: A review

KUMAR A • LAL RK* • GUPTA AK • CHANOTIYA CS

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ABSTRACT

Lemongrasses found in India encompass Cymbopogon flexuosus, C. citratus, C. khasianus, and C. pendulus. This fragrant perennial grass belongs to the Poaceae family and is indigenous to India as well as other tropical and subtropical regions in Southeast Asia and Africa. Pinpointing its precise place of origin is challenging due to its extensive history of cultivation and utilization across various cultures. It is believed to have originated in the maritime Southeast Asian region, encompassing countries like India, Sri Lanka, Indonesia, and Malaysia. Lemongrass thrives in these regions and has played a significant role in their culinary and medicinal traditions for many generations. Among these, Cymbopogon citratus, a tropical lemongrass variety, is native to multiple Asian regions, particularly Southeast Asia and South Asia. It is widely cultivated and employed in a range of global cuisines and traditional healing practices. Lemongrass finds extensive applications in the herbal, medicinal, cosmetic, pharmaceutical, and fragrance industries. Lemongrass oil is known for its diverse biological properties, which encompass antibacterial, immunomodulatory, and antioxidant effects. Not too long ago, India ranked as one of the world's leading exporters of lemongrass essential oil. Several prominent lemongrass cultivars have emerged, including GRL-1 (geraniol-rich), Krishna, Cauveri, Pragati, Praman, T-1, CIM Shikhar, Chirharit, CKP-25, SD-68, CIMAP Suwarna, and Krishnapriya. Among these, CIMAP Suwarna, Krishna, and CIM Shikhar stand out as the most widely favoured varieties across India developed at the CSIR-CIMAP in Lucknow, India. Indian universities and research institutions have also played a pivotal role in the development of novel lemongrass cultivars. Examples include Jor Lab L-2, OD-19, SD-68 (C. flexuosus), RRL-16 (C. pendulus), and CKP-25. Notably, there's Jor Lab L-9, a distinctive strain of C. khasianus known for its high methyl eugenol content. Furthermore, the germplasm for Malabar lemongrass (C. khasianus) is notable for its abundant herbage and elevated elemicin content, reaching up to 70%. The CSIR-NEIST in Jorhat and the CSIR-CIMAP, Lucknow have contributed to the development of new high geraniol-rich lemongrass cultivars, such as "Jor Lab L-15" (C. khasianus), GRL-1, and CIM Atal (C. flexuosus), respectively. b: citral, elemicin, geraniol, methyl eugenol content, vitamin A, Cymbopogon, flexuosus, Cymbopogon pendulus, Cymbopogon khasianus, Cymbopogon citratus, Lemongrass varieties

*Corresponding author; Email : rajkishorilal@gmail.com; CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow-226015
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INTRODUCTION

Lemongrass (*Cymbopogon flexuosus* (Steud.) Wats. is a fragrant grass (family Poaceae) of the genus *Cymbopogon* contains around 80 species. Lemongrass may be grown well in India, conducive to vegetative development and oil biosynthesis. Lemongrass may be grown in locations with an average daytime temperature above 15 °C and enough sunlight and rainfall. High temperatures and plenty of sun promote crop growth, development, and essential oil biosynthesis. Its cultivation is best suited to sandy loam to loam soil with good drainage and medium fertile soil. Every year, India produces approximately 1000 tonnes of lemongrass oil, which is exported to the United States, England, Germany, Australia, and Japan (Dutta *et al*., 2016; Bahl *et al*., 2018).

In India, several Lemongrass species are grown, however identifying them can be difficult. *C. flexuosus* (Steud.) Wats.; *C. pendulus* (Steud.) Wats.; *C. khasianus* (Hack) Stapf. ex Bor.; *C. nardus* (L.) Rendle; *C. commulatus* (Steud.) Stapf. Empirical evidence suggests that the genus *Cymbopogon* has citral-rich species such as *C. citrates*; *C. flexuosus*; *C. pendulus*, *C. khasianus*, and *C. pendulus* (Sarkar, 2021; Padalia *et al*., 2021; Kumar *et al*., 2022a, b, c). Geraniol- and elemicin-rich oil from *C. nardus*; *C. commulatus*; and certain *C. khasianus* is widely utilized in the scent industry to make mosquito repellent products, soaps, vitamin A synthase, etc. These three-geraniol forms of lemongrass have a variety of biological actions, including antibacterial, immunomodulatory, and antioxidant effects. Only a few years ago, India was one of the world's leading importers of lemongrass essential oil (Kumar *et al*., 2022a). Now India has become one of the world's biggest exporters as a result of the "CSIR-Aroma Mission" project run by CSIR-CIMAP. Every year, around 1,000 tons of essential oil are produced. It is transported in batches of 300 to 400 tonnes (Kumar and Jnanesha, 2019; Kumar *et al*., 2022a, b, c). During the COVID-19 outbreak, disinfection consumption skyrocketed, driving up global demand for lemongrass essential oil. Lemongrass essential oil had a global market value of USD 38.02 million in 2022, and it was expected to grow to USD 81.23 million by 2030, up from USD 41.98 million in 2023 (Kumar *et al*., 2023a). Lemongrass oil is in high demand and is widely exported around the world.

Lemongrass is grown extensively in Indian states such as Kerala, Karnataka, Andhra Pradesh, Uttar Pradesh, and Assam. Citral gives lemongrass essential oils an enticing citrus fragrance. Citral possesses antibacterial, anti-inflammatory, anti-parasitic, allelopathic, and mosquito-repelling effects. As seen by the expanding number of articles on the bioactivities of its essential oil, essential oils' therapeutic and pharmacological usefulness is fast developing. Consequently, this paper aims to compile all useful research information in one place.

Botanical Description

Cymbopogon flexuosus is also known as lemongrass, Cochin grass, or Malabar grass in India. It is an aromatic grass with several tillers growing from a short, rhizomatous base. The leaf blade is linear, tapering at both ends and can grow 50 cm long and 1.5 cm wide; the tubular leaf sheath functions as a pseudo stem. At the mature stage of growth, this plant produces flowers. The clump sends out new tillers, which grow vertically as new plants/clumps.

Propagation

Clumps are divided to create new plants, or the plant can be reproduced vegetatively by creating genetic clones. A healthy sandy-loam soil with constant moisture (pH 2-12) is ideal for the plant's growth (Padalia *et al*., 2021; Sarkar, 2021).

Traditional/Economic Importance

Bioactive compounds discovered in the leaf are responsible for the plant's anti-inflammatory, antiseptic, anti-dyspeptic, and anti-fever effects, as well as its analgesic, antipyretic, tranquillizer, anti-hermetic, and diuretic characteristics (Sarkar, 2021). Several products, such as perfume, regional soaps, candles, and insect repellents, contain deodorants (Sarkar, 2021). It has been used as a snake and reptile repellant in several Asian and African nations. Citral, geraniol, oxo bisabolene, and myrcene are essential oils extracted from lemongrass (Padalia *et al*., 2021).

Phytochemistry

The presence of phytochemicals or secondary metabolites in such substances may be related to the medical potential of herbal remedies. The medicinal plants have an equal distribution of these chemicals. Some important substances that have been isolated include phytosterols, anthocyanins, amino acids, organic acids, phenolic compounds, volatile

components, fatty acids, fumesol, flavonoids, isovaleranic aldehyde, methylheptenone, valeric esters, L-linanool, furfurol, isopulegol, and p-coumaric acid (Padalia *et al*., 2021).

Phytochemical Constituents

The phytochemical screening of *C. flexuosus*, both qualitative and quantitative, identifies several essential bioactive chemical elements that might be connected to the plant's therapeutic potency (Padalia *et al*., 2021; Sarkar *et al*., 2021). Researchers have identified and studied ketones, alcohols, phenols, terpenes, flavonoids, saponins, steroid hormones, tannins, alkaloids, geranial, terpenoids, polyphenols, esters, and fatty acids (Kumar *et al*., 2023c). The most substantial medical and pharmacological effects of *C. citratus* are attributed to its flavonoids and essential oil, considered the plant's most significant compounds (Lal, 2012). Numerous types of bioactive chemicals have already been identified from *Cymbopogon schoenanthus* (L.) Spreng, according to Abdel-Rahman *et al*., (2022). (Poaceae). Recently, there has been a lot of interest in the phytochemical composition of *C. schoenanthus*, and a wide variety of components, including terpenes, diterpenes, and sesquiterpenes, as well as phenolic acids, have been defined. The biological potential of these highly valued metabolites, which include nephroprotective, antibacterial, antioxidant, anti-proliferative, anti-inflammatory, and anticonvulsant actions, has also been investigated. The reported separated components' purported structural variety, selectivity for *C. schoenanthus*, and biological activities have sparked intense interest in the field of drug development research.

Essential Oil

The main reason behind growing lemongrass is its essential oil, which is predominantly biosynthesized in the plant's leaves. Its essential oil has considerable commercial value as it is used in various products, including fragrances, flavours, perfumes, cosmetics, detergents, domestic cleaning products and pharmaceuticals (Lal *et al*., 2010; Sarkar, 2021).

Extraction of Essential Oil

Solvent extraction, steam/ or hydro-distillation (HD), microwave-assisted hydro-distillation (MAHD), and supercritical fluid extraction (SFE) with carbon dioxide are all methods for obtaining lemongrass essential oil. According to several research studies, the quality of essential oils is largely controlled by their contents, which are altered by extraction techniques (Padalia *et al*., 2021). Moreover, the thermal degradation or hydrolysis of fragile components may result from heating processes. Many variables impact the yield, including the size and weight of the raw material, the type of herb, and the quantity of water utilized. Guenther stated in 1950 that a typical HD is carried out for three hours in a machine similar to the Clevenger (Clevenger, 1928). According to reports, the yields of oil recovered via HD range from 0.43% to 1.80%. (Sharma *et al*., 1987a,b). Using neutral and weakly acidic and basic media, Sarkar (2021) asserts that essential oil extraction from lemongrass leaves by HD had a substantial effect on the essential oil composition. MAH had a yield of 0.64% compared to HD's overall yield of 0.73%. The most prevalent ingredient in the oil was citral, which comprised 72.6% of the HD, 44.7% of the MAHD, 30.07% of the acid distillation, and 76.61% of the base distillation. Significant adjustments were also made to the composition of essential components (geranial, neral, and myrcene).

Citral concentrations in oils distilled under acidic conditions were low due to chemical changes that citral may undergo in an acidic solution (Lal *et al*., 2006; Lal, 2018; Sarkar, 2021). Essential oil is extracted from water molecules distilled together after condensation. The method does not require significant initial investment and is easy to apply. Due to extended heat exposure and the slow nature of the process, some compounds may deteriorate during hydrolysis or polymerization reactions of sensitive constituents.

Composition of Essential Oil

The leaves, which comprise 1% and 2% of the plant's dry matter, are the primary source of lemongrass essential oil. (Lal, 2012). Lemongrass oil stands out for its powerful flavour, sherry colour, and lemon-like aroma (Lal, 2018; Padalia *et al*., 2021).

Oil extracted from *C. flexuosus* leaves was analyzed for chemical composition using GC and GC/MS techniques. In addition to the geographical origin, geobotanical environmental elements, agricultural practices, age of the plant, photoperiod, harvest period, and genetic variation, it changes based on the plant's age, photoperiod, harvest

period, and extraction process. Regardless of these variances, hydrocarbon terpenes, alcohols, ketones, esters, and substantial aldehydes have all been found. Citral, composed of two geometric isomers, is the main chemical in lemongrass essential oil. Whereas the Z-isomer is neral or citral B, the E-isomer is geranial or citral A. The amount of citral in lemongrass essential oil determines its quality. According to the research, a high-quality lemongrass oil should have at least 75% citral (Sharma *et al*., 1987a,b). Since the composition and content of oils are directly correlated to the developmental stage of the entire plant, plant organs, and plant cells, the quality, and quantity of lemongrass oil are highly dependent on the time of plant harvest (Kumar *et al*., 2023a,b,c).

Myrcene is a molecule found in lemongrass essential oil. From 0.8% in Egyptian essential oil to 25% in Brazilian and Nigerian oils, it has a wide range of age concentrations (Sarkar, 2021). Different amounts of myrcene depend on where an essential oil is produced. Geraniol, citronellal, and limonene are commonly detected in amounts greater than 1% in some samples, in addition to citral and myrcene. A high amount of limonene (7.90%) was present in the essential oil isolated using HD from Nigerian plants. In contrast, none was present in the oil recovered using the same method from Kenyan lemongrass. From 0.12% to 12.77%, citronellal content in essential oils varies substantially. Regarding alcohols identified in *C. citratus* oils, geraniol was by far the most prevalent (1.34% to 21.86%). Significant quantities of the ester geranyl acetate were discovered (0.24% to 3.42). The ingredients in *C. citratus* essential oil are created using diverse extraction techniques worldwide. The origin of *C. citratus* oil significantly impacts its chemical composition. The essential oil from Ethiopian lemongrass included the principal constituent geraniol (40%), citral (13%), and oxo-bisabolene (12%). In contrast, the oil from *C. citratus* of African provenance contained a high amount of myrcene (Sarkar *et al*., 2021). Geranial (20.90 to 40.72%), neral (16.20 to 34.98%), geraniol (8.30%), and linalool (5.60%) were the main components of Egyptian oil.

As distinguishing components, limonene, citronellal, myrcene, and geraniol are found in lemongrass essential oil, geranium, and neral (Kumar *et al*., 2023c). Specific compounds are chemical components found in a medicinal herb that could be utilized to confirm its identity or effectiveness. Geranial or neral is not present in any of the oils produced from the various chemotypes of *C. citratus* (Kumar *et al*., 2023c). According to studies by Sarkar *et al*., (2021), the drying method significantly impacts *C. citratus* oil concentration. These researchers found that the oil from dried lemongrass leaves had the highest essential oil level (2.45%). Lemongrass leaves dried in the sun, and the shade produced identical amounts of oil, 2.10% and 2.12%, respectively. The primary ingredients of essential oils extracted from lemongrass leaves dried by the sun, in an oven, or in the shade were geranial (31.53%, 37.24%, and 39.86%), neral (30.08%, 31.28%, and 34.52%), and myrcene (16.61%, 15.42%, and 14.49%). According to Kumar *et al*., (2023a,c), drying methods have no appreciable impact on the composition of the principal components of essential oils (neral and geranial) in lemongrass leaves. Depending on the harvesting stage, the content of lemongrass essential oil changes significantly (Kumar *et al*., 2023c). When lemongrass was harvested 5.5 months after it was planted, 44 elements were found, accounting for 98.64% of the essential oil. 6.5 months after planting, the essential oil extracted from lemongrass included just 15 chemical components, which made up 98.62% of the essential oil. Nevertheless, 7.5 months after planting, 50 chemical elements that comprised 97.2% of the essential oil were evaluated. Just 13 chemicals were consistently present at each maturity stage, and only 7 had amounts greater than 1%. (geranyl acetate, geranyl neral, geranyl geranial, myrcene, 3-undecyne, nerol, and geranyl acetate) When lemongrass was collected between 5.5 (37.58%) and 6.5 (45.95%) months after planting, the geranial concentration in the oil increased. When the plants were harvested 7.5 months after sowing, their content slightly decreased to 42.95 per cent.

Seasonal Variations in Essential Oil Content and Plant Characteristics

Aerial segments of Arabian lilac were removed in the middle of each month to track the variation in secondary metabolites over a year. Using a gas chromatography-flame ionized detector (GC-FID) and gas chromatography-mass spectrometer, the amount of oils in fresh and dried plant materials were counted (GC-MS). The phytochemical makeup and the associated methanol extracts capacity to scavenge free radicals were independently

evaluated. The more essential oil was produced by the fresh and dried spring and fall samples than by the other samples. The oils comprised 41 chemicals, with β-caryophyllene, sabinene, and caryophyllene oxide being the most prevalent ones. The highest total phenolic concentration was found in the extracts from the winter and summer samples. Winter yielded the highest levels of overall flavonoid and flavanol content, whereas summer yielded the highest anthocyanin content. The antiradical activity of the extracts was also higher in spring and autumn samples than in those from other times of the year. The results of this study can be utilized to estimate the ideal time to harvest Arabian lilac to get the necessary chemicals for use in the food and phytopharmaceutical industries. To determine how the seasons affect these molecules, authors (Kumar *et al*., 2023c) compared the components of *Vitex trifolia* essential oils and phenolic compounds. Because endogenous and exogenous (environmental) factors impact secondary metabolites in plants, their amount and chemical variety change throughout the plant's life cycle. For instance, seasonal variations are a significant factor that could affect the quantity and quality of these compounds.

The chemical makeup of lemongrass oils from various medicinal plants and seasonal fluctuations are strongly correlated. For instance, the amount and quality of essential oils extracted from various *Ocimum* and *Thymus* species, including *Origanum syriacum*, *Mentha pulegium*, *Thymbra spicata*, *Satureja thymbra*, *Saliva trilobal*, *Lanata camara*, have changed significantly throughout the months and seasons (Kumar *et al*., 2023a,c; Lal *et al*., 2022a,b; Lal *et al*., 2023a,b). There has been evidence linking seasonal variations in the quality and quantity of secondary metabolites produced by the *Vitex* genus to changes in the antioxidant capacity of the *Thmus* genus, *Vaccinium myrtillus*, total phenolics, and flavonoid concentrations. As a result, the study concentrated, for the first time, on the variability of the chemical profile of Arabian lilac in various months. According to Kumar *et al*., (2023a,c), samples collected in the spring and fall had higher essential oil content (due to defence and protection roles), which could be related to the plant's stress due to a quick shift in the environment. The essential oil content recovered from fresh and dried aerial portions of Arabian Lilac also varied significantly between collection times (when the temperature began to cool). On the other hand, a decrease in essential oil content throughout the summer and winter may be related to a change in the secondary metabolite biosynthetic pathway that favours the formation of metabolites with more defensive potential, like phenolic compounds. According to studies on *Ocimum basilicum*, *Mentha spicata*, and *Mentha pulegium* (Kumar *et al*., 2023c; Lal *et al*., 2022a,b; Lal *et al*., 2023a,b), environmental factors can dramatically influence the essential oil content of medicinal plants (Gupta *et al*., 2023).

According to Kumar *et al*., (2023a), significant variations in the essential oil's composition were found depending on the time of collection. *M. longifolia* essential oils have potent antibacterial properties. On the other hand, the volume of these biological activities varies according to the harvest season. Winter crops had exceptional antibacterial and AchE inhibitory qualities, corresponding to the flowering time (Gupta *et al*., 2023). These findings help decide when to collect plant-active substances with tremendous therapeutic potential.

Crop Improvement Approaches for Commercial Cultivation

Some improved cultivars recommended for cultivation are Cauvery, CIM-Atal, Krishna, CIM-Krishnapriya, Nima, Pragati, Praman, CIMAP-Suwarna, and CIM-Sikhar, etc., developed at the CSIR-CIMAP, Lucknow, India. Lemongrass varieties developed by CSIR-CIMAP are in cultivation in India on around 3000 hectares, producing around 320 tonnes of essential oil. Currently, Krishna, CIM Shikhar, and CIMAP Suwarna are the most famous varieties among Indian farmers (Kumar *et al*., 2022a; Kumar *et al*., 2023a). The oil from lemongrass is called "East Indian lemongrass oil." The first variety of lemongrass selected was OD-19 from Kerala, India, followed by OD-408 and OD-440. After that, several vital cultivars were developed while studying genetic diversity and chemo-genetic improvement in citral-producing lemongrass as cultivar OD-19. Some important lemongrass cultivars are GRL-1 (geraniol-rich lemongrass), Krishna, CIM Shikhar, CIMAP Suwarna, Cauveri, Pragati, Praman, Nima, Chirharit, CKP-25, and SD-68. Among these, Krishna, CIM Shikhar, and CIMAP Suwarna are most prevalent throughout India and were developed at the CSIR-CIMAP Bangalore center (Lal *et al*., 2010; Kumar and Jnanesha, 2017a; Kumar and Jnanesha, 2017b). Krishna produces much biomass (25–28 mt/hectare) and much oil (230–250 kg/ha) because of the high percentage of oil in the biomass.

CKP-25 is another successful variety that performs well even in areas with less rainfall. CKP-25 was developed by the CSIR-IIIM, Jammu (Regional Research Laboratory (RRL), Jammu). Chirharit is very popular in the Tarai region of Uttarakhand as it remains green throughout the year, producing high biomass. However, the oil recovery percentage is lower due to such areas' cold climates. Because it contains fewer grassy components, such as methyl heptenone, the Nima variety has a distinct citrusy clean odour. This variety can also be grown on west-facing land with a high salt content. Except for GRL-1, and CIM Atal, which produce geraniol-rich essential oils, all of the above lemongrass cultivars that produced essential oils were high in citral. The high concentration of geraniol (89.39%) separated it from other cultivars. Lemongrass has been utilized in Indian medicine for over 2000 years (Kumar *et al*., 2019; Kumar *et al*., 2022, a, b, c). However, its use for distillation dates back roughly a century, with the earliest distillation in India beginning around 1890 during the British rule from a wild grass in Kerala. Previously, the yearly global production of East Indian lemongrass oil was 1500 tonnes (Lal, 2012; Lal *et al*., 2022; Kumar *et al*., 2023a,b,c; Lal *et al*., 2023a,b,c,d). Lemongrass cultivars typically used by farmers include:

1. **Pragati:** CSIR-CIMAP created a high citral-rich variant appropriate for the Indian plains. This variety can generate up to 350 q/ha/year of herb production, resulting in 200 kg of oil/ ha with an 85% citral content. This innovative variety was created using half-sib seed and the clonal selection breeding process (Sharma *et al*., 1987a). Praman: This variety was released by CIMAP, Lucknow suitable for cultivating marginal or drought-prone land. This novel variety was developed by the clonal selection breeding method. This variety can yield 370 q/ ha/year herb yield, thus yielding 225 kg oil/ha containing 75-80% citral (Sharma *et al*., 1987b; Sharma *et al*., 1989).
2. **Chirharit:** This new variety results from clonal selection for the frost-resistant variety in OPSPs. This variety can yield up to 370 q/ha/ year of herb yield, resulting in 220 kg of oil per ha with a 75-80% citral content.
3. **T-1:** The half-sib breeding method was used to develop this variety, followed by the clonal selection breeding method. This variety can produce 364 herb yields q/ha/year and 181 kg/ha/year of essential oil with 45–50% citral.
4. **Nima:** Nima has a unique, essential oil production (250–260 kg/ha), herb yield q/ha (289.00), and a high citral content (85–90%). The salt-tolerant cultivar thrives in sodic soils in U.P. and other Indian states. The Nima cultivar is recognized for its characteristic lemony, clean odour because it includes fewer grassy components such as methyl heptenone (Lal *et al*., 2006).
5. **GRL-1:** This variety develops by clonal selection breeding. The variety is suitable for drought-prone areas and marginal land. This variety can produce 285q/ha herb yield and 185 kg of oil per hectare per year, with a geranial content of 60-65% (Nair *et al*., 1984a, b).
6. **CIMAP-Suwarna:** This variety is suitable for drought-prone areas and marginal land. This variety can yield up to 500 kg/ha of herb yield per year and 200 kg of oil per ha with an 80% citral content (Lal *et al*., 2010; Kumar *et al*., 2023b) (Figure 4).
7. **Krishna:** The CSIR-CIMAP has created a high oil-yielding variety, Krishna. Variety Krishna is quite popular with the farmers. This variety can yield up to 300 q/ha of herb output with an oil content of 0.8-0.9%, yielding 230-250 kg oil/ha and an 80-82% citral concentration (Kulkarni *et al*., 2020).
8. **CIM-Sikhar:** This new cultivar can yield 20–25% more essential oil with an 80% citral content in irrigated conditions. This variety has an oil yield of more than 280 kg/ha and an average oil content of 1.6% in herbage.
9. **CIM-Atal:** Compared to other types, this cultivar grows quite vigorously, with light green leaves, light brown stems, semi-erect leaves, and an erect growth tendency. Geraniol content is 89.6%, with an oil content of 2.1%. This variety with geraniol can produce more excellent oil and herb production than palmarosa. The new variety produces 250–300 q/ha/y of herb and 300–325 kq/ha/y of oil.
10. **Krishnapriya:** A new variety of lemongrass (*Cymbopogan flexuosus*) was released by CIMAP under the CSIR-Aroma Mission. This new variety gives an herb yield of 300–320 q/ha/

year and an essential oil yield of 200–250 kg/ha/year.

11. **Sugandhi (OD-19):** This variety develops in AMPRS, Odakkali, KAU, and Kerala. The variety can yield 0.3-0.4% oil, 125 kg/ha oil yield and 35-40 t/ha/year herb yield with 84-86% citral content.
12. **CKP-25:** This variety was developed by the Regional Research Laboratory (RRL), Jammu (Now CSIR-IIIM, Jammu India). The variety is a hybrid between *C. khasianum* × *C. pendulus*. This variety gives 60 t/ha of herbage, and the oil contains 82.85% citral.
13. **RRL-16** is a *C. pendulus* evolution approved for cultivation by the RRL, Jammu, now CSIR-IIIM, Jammu, India. The herb's typical output is 15 to 20 t ha annually, yielding 100 to 110 kg of oil. The oil content ranges from 0.6 to 0.8%, with a citral content of 80%.
14. **SD-68:** Developed by mutation breeding yields 375 kg of oil/ha with a citral content of 90-92 % (Nair, 1984a).
15. **RRL-39:** Developed by RRL, Jammu, now CSIR-IIIM, Jammu. This variety can yield 150 kg oil/ha, and herb yield 250 q/ha.
16. **CKP-F2-38-Kalam:** A hybrid lemongrass between *Cymbopogon khasianus* × *Cymbopogon pendulus*. Regional Research Laboratory, Jammu, now CSIR-IIIM, Jammu, developed this variety. This variety can yield 250-300 q/ha herb yield and 160 kg essential oil/ha.

Several novel varieties/cultivars developed by universities and institutes are Jor Lab L-2, OD-19, SD-68 (*C. flexuosus*), RRL-16 (*C. pendulus*), and CKP-25. Lal *et al*., (2020), identified a new strain of *C. khasianus* rich in methyl eugenol, which was identified and named Jor Lab L-9. Lal, M., 2019 identified a Malabar lemon grass (*C. khasianus*) germplasm with high elemicin content (70%) and high herbage yield (24.26 tonnes/ha/year and named it Jor Lab L-10. Lal *et al*., (2019) also identified a new high geraniol-rich variety, "Jor Lab L-15" of lemongrass [*C. khasianus* (Hack) Stapf (ex Bor)] at CSIR-NEIST, Jorhat (Assam), India.

CONCLUSION

Lemongrass is grown commercially in India's states. Citral imparts a vibrant citrus scent to lemongrass essential oils. Citral possesses antibacterial, anti-inflammatory, anti-parasitic, allelopathic, and mosquito-repelling effects. Citral is the most profitable monoterpene in flavorings, scents, cosmetics, and pharmaceuticals. Various notable cultivars were generated following genetic diversity and chemo-genetic improvement research in citral-producing lemongrass cultivars (OD-19). Lemongrass cultivars with high yields include CIM Atal, GRL-1 (geraniol-rich lemongrass), Krishna, Nima, Cauveri, Pragati, Praman, Chirharit, CKP-25, SD-68, CIMAP Suwarna, Krishnapryia, and CIM Shikhar, which were developed and released for commercial cultivation in India. The unique cultivars of lemongrass Jor Lab L-2, OD-19, SD-68 (*C. flexuosus*), RRL-16 (*C. pendulus*), and CKP-25 were created by universities and research facilities in India. A unique strain of *C. khasianus* with a lot of methyl eugenol as Jor Lab L-9. The novel elemicin-

Figure 1: A. variety Pragati, B. Variety Praman of lemongrass.

Figure 2: Variety Nima and Chirharit of lemongrass.

Figure 3: Variety E. CIMAP Suwerna, F. CIM Shikhar, G. GRL-1, H. Krishna, I. Cauvery, J. T-1 of lemongrass.

rich (70%) genotype from the Malabar lemon grass (*C. khasianus*) is also identified at CSIR-NEIST. The high geraniol-rich cultivar of lemongrass "Jor Lab L-15" (*C. khasianus*), GRL-1, and CIM Atal (*C. flexuosus*) have also been produced by the CSIR-NEIST in Jorhat and the CSIR-CIMAP in Lucknow.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Raj Kishori Lal: http://orcid.org/0000-0002-9713-8908.

Credit Authors Statements

AK was involved in planning and actual experimentation, RKL in statistical analyses and manuscript preparation, AKG in Gene Bank, data collection, CSC & Chemical fingerprinting.

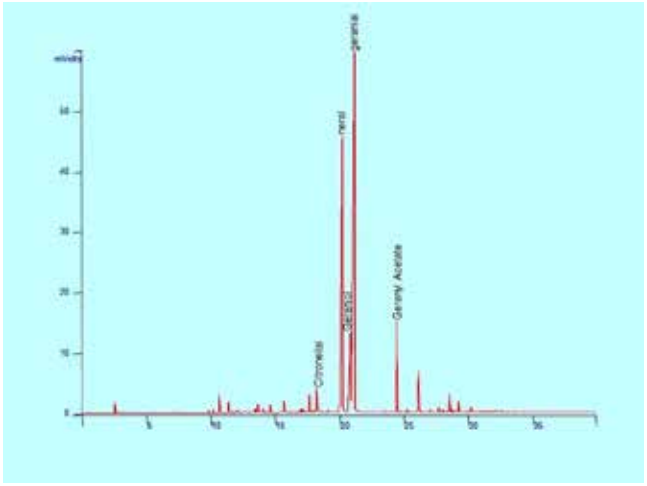

Figure 4: Chromatogram of essential oil of lemongrass variety CIMAP-Suwarna

Table 1: High essential oil yielding varieties of lemon grass developed by CSIR-CIMAP (India)

S. No.	Varieties	Botanical name	Herb yield (q/ha)	Essential oil yield (Kg/ha)	Citral content (%)	Remarks
1.	Pragati	*Cymbopogan flexuosus*	350	200	85	Suitable for North Indian plains
2.	Nima	*C. flexuosus*	289	250-260	85-90	Suitable for drought / marginal, high pH, alkaline soils
3.	Krishna	*C. flexuosus*	300	230-250	80-82	For Suitable for North Indian plains and South India deccan
4.	CIM-Sikhar	*C. flexuosus*	350	280	80	For Suitable for North Indian plains and South India deccan
5.	CIM-Krishnapriya	*C. flexuosus*	300-320	200-250	80	For Suitable for North Indian plains and South India deccan
6.	Chirharit	*C. flexuosus*	370	220	75-80	Suitable for terai belt
7.	GRL-1	*C. flexuosus*	364	181	60-65 (geraniol)	For geraniol
8.	CIM Atal	*C. flexuosus*	250-300	300-325	89 (geraniol)	For geraniol
	Cauvery	*C. flexuosus*	243.00	103.00	84	Suitable for South India deccan
9.	Praman	*C. pendulus*	370	280	75-80	For drought/marginal land
10.	T-1	*C. citratus*	364	181	45-50	Suitable for tea lemon aroma
11.	CIMAP-Suwarna	*C. khasianus*	500	200	80	Suitable for drought / marginal, high pH, alkaline soils

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