Environment and Ecology 42 (2A) : 708—715, April—June 2024
Article DOI: https://doi.org/10.60151/envec/MLAF6939
ISSN 0970-0420

Antifungal Potential of *Ocimum sanctum* Linn. Essential Oil against Fungal Pathogens Causing Economic Losses in *Cymbopogon flexuosus* Nees Ex Steud. (Lemongrass)

Himanshu Yadav, Ankita Maurya, Richa Sharma, Amritesh Chandra Shukla, Ramesh Kumar Srivastava, Manish Arya

Received 17 February 2024, Accepted 14 March 2024, Published on 6 May 2024

ABSTRACT

Cymbopogon flexuosus Nees Ex Steud. (Commonly known as lemongrass, family Poaceae) is one of the commercially important aromatic plants having medicinal properties. India is one of the largest producers and exporters of lemongrass essential oil in the world; in the year 2021-22, India exported about 610 tons of lemongrass oil, contributing more than 4 lakh US $ million in Gross Domestic Productivity (GDP). However, despite a good national and international market, this crop suffers quantitative and qualitative losses due to the leaf spot and leaf blight diseases caused by the fungi *Curvularia trifolii* and *Rhizoctonia solani,* respectively; therefore, an attempt has been made to manage these fungal pathogens. The essential oil of basil (*Ocimum sanctum* Linn.) was extracted by hydro-distillation method using *Clevenger apparatus.* The oil thus extracted was used for *in vitro* antifungal efficacy against both the test fungi *Curvularia trifolii* and *Rhizoctonia solani,* using the poison food technique. The results show that the minimum inhibitory concentration (MIC) of the basil oil against *C. trifolii* 2000 ppm and *R. solani* was 1600 and however, it was cidal in nature at 3200 and 2400 ppm against both fungi, respectively. The current study's findings show that *O. sanctum* oil could be an alternative to synthetic fungicides after detailed investigations.

Keywords Essential oil*, Cymbopogon flexuosus, Ocimum sanctum, Curvularia trifolii, Rhizoctonia solani,* Antifungal activity.

Himanshu Yadav[1], Ankita Maurya[2], Richa Sharma[3], Amritesh Chandra Shukla[4]*, Ramesh Kumar Srivastava[5], Manish Arya[6]

[1,2,6]PhD Research Scholar, [3]Research Assistant, [4]Professor, [5]Principal Scientist and Head

[1,2,3,4]Department of Botany, University of Lucknow, Lucknow 226007, India

[6]Department of Chemistry, University of Lucknow, Lucknow 226007, India

[1,5]Technology Dissemination and Computational Biology, CSIR-Central Institute of Medicinal and Aromatic Plant, Lucknow 226015, India

Email: amriteshcshukla@gmail.com
* Corresponding author

INTRODUCTION

Cymbopogon flexuosus Nees ex Steud. popularly known as lemongrass, Cochin or Malabar grass, is an important aromatic and medicinal herb commonly known for its lemony odour due to citral (a cyclic monoterpene), usually grown and distributed in temperate and tropical/subtropical parts of the world for its essential oil. Citral is used as a basic raw material for synthesis of β-ionone, which is used for synthe-

sis of a number of useful aromatic compounds and Vitamin A. *C. flexuosus* is an erect herb with a stem that grows up to 1.0-1.5 m long, leaves are linear and lanceolate, and flowers freely. The inflorescence is very large spikes bearing spikelets in pairs (sessile and pedicellate). The sessile spikelet is an awned bisexual floret, whereas the pedicellate is a staminate floret Joy *et al.* (2006), Yogendra *et al.* (2021).

India is one of the leading producers and exporters of lemongrass oil and its products in the world trade. In India, Kerala, Karnataka, Tamil Nadu, Jharkhand, Chhattisgarh, Madhya Pradesh, Assam, Uttar Pradesh, Odisha, Rajasthan, Meghalaya, Nagaland, Tripura, Manipur, Arunachal Pradesh, West Bengal, Uttarakhand and are the major producing states of *C. flexuosus* essential oil; *C. flexuosus* is abundantly cultivated in Hardoi, Banda, Sitapur, Kanpur, Sonbhadra, Mirzapur, Raebareli, Unnao, Lucknow, Jalaun, Jhansi, Hamirpur and Lakhimpur Kheri District of the Uttar Pradesh (Joy *et al.* 2006), Sharma *et al.* 2022). The presence of important phytochemical constituents, including Myrcene, Linalool, Neral, geranial, contributes to its pharmacological activities, which include anti-microbial, anti-ulcer, radioprotective, cardiovascular, antioxidant, anti-allergic, and antidiabetic activities (Naik *et al.* 2010, Singh *et al.* 2011, Mirghani *et al.* 2012, Olorunnisola *et al.* 2014, Adukwu *et al.* 2016, Gao *et al.* 2020, Mukarram *et al.* 2022). *C. flexuosus* is the perennial cash crop as it lies up to 5-7 years from plantation. However, besides this, the crop is affected by various pests and diseases, which cause heavy economic losses to the crop (Yogendra *et al.* 2021, Sharma *et al.* 2022).

Literature reveals that fungal pathogen *Rhizoctonia solani* J.G. Kuhn Synonyms: *Moniliopsis solani* (J.G. Kuhn) R.T. Moore causes leaf blight disease in *Cymbopogon* spp., usually starts from the leaf edge, was irregular in shape, The symptoms which developed on leaves and sheaths were characteristic concentric spots that covered large areas of sheaths and leaves brown to dark brown in color and caused more than half of the leaf, or whole leaf die Singh *et al.* (1997), Baiswar *et al.* (2012), Daghir and Madhi (2020) while leaf spot disease of *C. flexuosus* was caused by phytopathogenic fungi *Curvularia trifolii* (Kauffman) Boedijin (Synonyms: *Brachysporium trifolii* Kauffman) having initial symptoms like, lesions appeared as interveinal chlorosis areas that later turned brown. In severe conditions, whole plants had a "burnt" appearance. Damage was particularly severe on younger leaves and when temperature (28 to 32°C) and humidity increased after the rainy season. Both the fungal pathogens cause severe economic loss by drying and defoliating the lemongrass plant, Singh *et al.* (1997), Zhang *et al.* (2020). Infected slips (planting material) are the primary source of the fungal disease transmission, followed by soil and weather. This infection causes extensive, usually widespread, defoliation after the rain and reduces the herbage, essential oil recovery.

There are many chemical-based fungicides for the prevention and management of fungal pests available in the market, but they are harmful to soil and water health, cattle, and human beings as well as to the agriculturally important microorganisms. After 1990, the consumption of synthetics increased too much; thus, the residue in the soil directly or indirectly affects not only the quality of the food, vegetables and fruit crops but also the medicinal and aromatic crops.

On the other hand, at the same time, some eco-friendly management practices (using viz. micro-organisms, botanicals, and animals) are also available, which are good and safe for the environment and human health. Some researchers have also reported that plant secondary metabolite (s)/ extract (s)/ essential oil (s) have anti-fungal, anti-bacterial and anti-viral properties at different concentrations. Essential oil (s) are obtained from the various aromatic and medicinal plant (s) by the distillation process; for extraction of the essential oil, flower, leaf, stem or root are used. Thus, the distilled essential oil has broad spectrum anti-microbial, anti-nematocidal, anti-repellent, anti-malarial and anti-larvicidal property. Moreover, In the current investigation leaf of the *Ocimum sanctum* was used for the extraction of essential oil(s). different researchers have proved that essential oil has good antifungal activity under *In-vitro* and *In-vivo* analysis.

Cymbopogon flexuosus Nees ex Steud. (Family-Poaceae), commonly known as lemongrass is

an essential oil-yielding aromatic grass; cultivated mainly in India, Sri Lanka, Pakistan, Maldives, Brazil, China, Taiwan, Guatemala, Argentina, USA, Uganda, Rwanda and other African countries (Joy *et al.* 2006, Sharma *et al.* 2022). *C. flexuosus* essential oil(s) are rich in phytochemical constituents viz., geranial, neral (geranial + neral = citral), geranyl acetate, linalool, caryophyllene, camphene, geraniol (Nath *et al.* 2002, Sarma and Sarma 2005, Yogendra *et al.* 2021).

Moreover, the *Cymbopogon* spp. essential oil shows different biological properties, including antifungal (Singh *et al.* 2011, Gao *et al.* 2020, Yadav *et al.* 2021, Mukarram *et al.* 2022), anti-viral (Mukarram *et al.* 2022), antibacterial (Naik *et al.* 2010, Singh *et al.* 2011, Olorunnisola *et al.* 2014, Adukwu *et al.* 2016, Gao *et al.* 2020, Yadav *et al.* 2021, Mukarram *et al.* 2022), anti-inflammatory (Olorunnisola *et al.* 2014, Gogoi *et al.* 2020, Yadav *et al.* 2022), antioxidant (Mirghani *et al.* 2012, Mukarram *et al.* 2022), insecticidal (Pinheiro *et al.* 2013), analgesic (Almeida 2001), anti-diabetic (Mirghani *et al.* 2012), anticancer (Mukarram *et al.* 2022), Insecticidal (Verma *et al.* 2020), antiseptic (Simic *et al.* 2008). The industrial and therapeutic applications of *C. flexuosus* essential oil are well documented.

The present study aims to determine the *in vitro* antifungal activity of essential oil of *Ocimum sanctum* L. against two major deteriorating fungal pathogens of lemongrass.

MATERIALS AND METHODS

During the frequent field visit of some districts of Lucknow division, it was found that some of the farmers were suffering with less essential oil recovery. Thus, a survey was conducted among different districts of Lucknow division and concluded that oil recovery was reduced due to the leaf spot and leaf blight diseases. Leaf spot disease of *C. flexuosus* is caused by *Curvularia trifolii* (Kauffman) Boedijn, while leaf blight caused by *Rhizoctonia solani* J. G. Kuhn. This disease generally occurs end of the monsoon season. Disease affects the quantity as well as the quality of the herbage and essential oil.

Extraction of essential oil (S)

For the extraction of essential oil 12 kg fresh herbage of *Ocimum sanctum* L. was collected from the experimental farm of CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, Uttar Pradesh, India (27˚15'53" North latitude, 81˚04'22" East longitude, and 87m altitude). The collected plant material was gently washed in tap water to remove dust and foreign particles, followed by shade-dry and chopping in to small pieces. Further, shade-dried herbage of *O. sanctum* was distilled (3 kg/batch in 4 batches) using hydro-distillation method at 100°C for 3-4 hrs in *Clevenger apparatus* (capacity 5 kg) (Clevenger 1928). A clear light yellow colored oil layer obtained on the top of the aqueous distillate was collected in a glass container, impurities and water contents were removed with the help of anhydrous sodium sulphate (Himedia) . The distilled essential oil thus filtered was stored in refrigerator for further experiment. Similarly, the *C. flexuosus* essential oil was also distilled by hydro-distillation using the *Clevenger apparatus* to estimate the quantitative losses. Mature *C. flexuosus* herbage was harvested from the field and taken in to laboratory; followed by washed the sample under tap water. After shed drying, herbage was chopped into small pieces and filled in the Clevenger in a manner so that water and herbage was not more than 50% of its (5L, Clevenger) total capacity (Clevenger 1928). Thus, 3-4 hrs. of distillation process, distilled essential oil was collected in a glass vial and mixed with anhydrous sodium sulphate (Himedia) to remove the contaminants and store in a cool, dark place for analysis (Nath *et al*. 2002, Joy *et al.* 2006, Yogendra *et al.* 2021, Srivastava *et al.* 2021, Maurya *et al.* 2024).

Fungal pathogens

Two major deteriorating plant fungal pathogens of *C. flexuosus, C. trifolii* and *R. solani* are used in the current study. Which were isolated from the diseased plant samples of lemongrass on potato dextrose agar medium; later on, purified and identified morphologically as well as molecular level from CSIR -National Chemical Laboratory, Pune Maharashtra. Thus, the isolated fungal pathogens were re-cultured for detail *In-vitro* analysis on Potato Dextrose Agar medium and preserved at 4°C for detailed investigation (Sung *et al.* 2016, Misawa *et al.* 2017, Ajayi-Oyetunde and Bradley 2018, Ji *et al.* 2019, Coelho *et al.* 2020).

Antifungal activity

Poison food technique

The antifungal activity of *O. sanctum* essential oil was evaluated by poison food technique devised by Grover and Moore (1962) with slight modification of Shukla and Dikshit (2016). The Potato Dextrose Agar (PDA) (Hi-media) medium along with different concentrations of *O. sanctum* oil diluted in 2% of acetone of the required amount of the medium (400, 800, 1200, 1600, 2000, 2400, 2800, 3200 ppm) and poured on sterilized petri plates (90 mm diameter) to get the uniform thickness. Petri plate containing potato Dextrose agar (PDA) medium with an appropriate amount of 2% acetone served as control. Thereafter, mycelial discs (6 mm) of the 5–7-day-old fungal cultures were inoculated inside center of petri plates and sealed with the help of parafilm. All experiments were performed in triplicate and the inoculated petri plates were incubated at 25± 2˚C for 7 days. The colony diameter of the treated and control petri plates was recorded at a regular interval of 24 hrs (Grover and Moore 1962, Singh *et al.* 1997, Philippe *et al.* 2012, Shukla and Dikshit 2016, Gakuubi *et al.* 2017, Maurya *et al.* 2024). The mycelial growth inhibition (MGI %) was calculated using the formula:

Mycelial Growth Inhibition% (MGI) = $[(D_c - D_t) / D_c]x\ 100$

D_c indicates Mean colony diameter in control set
D_t indicates Mean colony diameter in treatment set

Nature of toxicity of the essential Oil

The nature of toxicity of *O. sanctum* essential oil was recorded as fungistatic/ fungicidal at their respective minimum inhibitory concentration (MIC) against the both test pathogenic fungi *C. trifolii* and *R. solani.* This was determined following the method of Shukla *et al*. (1999), Van *et al*. (2006), Batish *et al.* (2008), Maurya *et al.* (2024). For defining antifungal activity, the fungal discs from MIC experimental set were re-inoculated upside down on plain fresh PDA medium. Inoculated petri plates were incubated in BOD at 25 ± 2° C for seven day and noted the readings. Presence of fungal growth on the 7th day indicates fungistatic nature of the essential oil, while absence of fungal growth denoted fungicidal nature of the essential oil. All the experiments were designed in triplicates. The minimum concentration of the essential oil having no fungal growth after 7-day incubation was taken as Minimum Cidal Concentration (MCC) (Maurya *et al.* 2024).

Table 1. Antifungal activity of essential oil of *Ocimum sanctum* against test pathogens.

Concentrations (ppm)	Mycelial growth inhibition (MGI) (%)	
	Curvularia trifolii	*Rhizoctonia solani*
T_1 400	15.68	19.54
T_2 800	33.56	41.72
T_3 1200	76.04	67.81
T_4 1600	82.17	100
T_5 2000	100	100
T_6 2400	100	100
T_7 2800	100	100
T_8 3200	100	100

Statistical analyses

All the above experiments were done in triplicates so the data were expressed as mean ± standard deviation. Analysis of variance was performed by ANOVA using IBM SPSS software (Statistics 20) followed by Tukey's Post Hoc test with $p \leq 0.05$ to determine the significant differences between the results.

RESULTS AND DISCUSSION

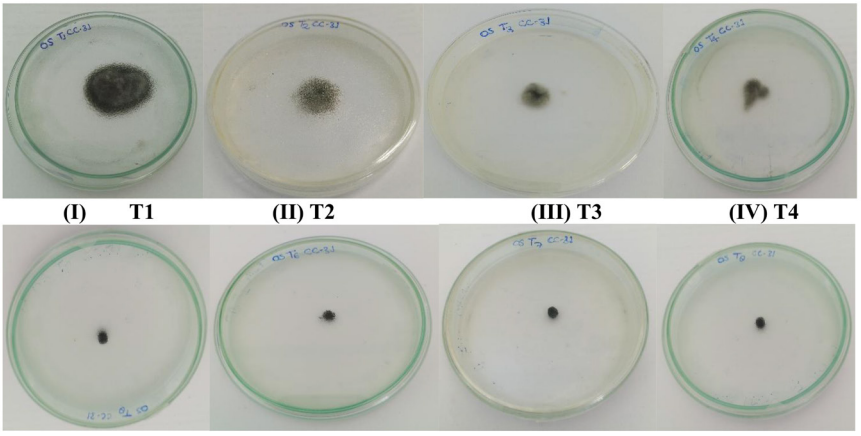
Antifungal Activity

The *in-vitro* antifungal activity of the *O. sanctum* oil was investigated against the plant fungal pathogens *C. trifolii* and *R. solani,* using poison food technique. The result shows that the minimum inhibitory con-

Table 2. Nature of toxicity of the essential oil of *O. sanctum* against test pathogens.

Pathogen	MIC (ppm)	MCC (ppm)
Curvularia trifolii	2000	3200
Rhizoctonia solani	1600	2400

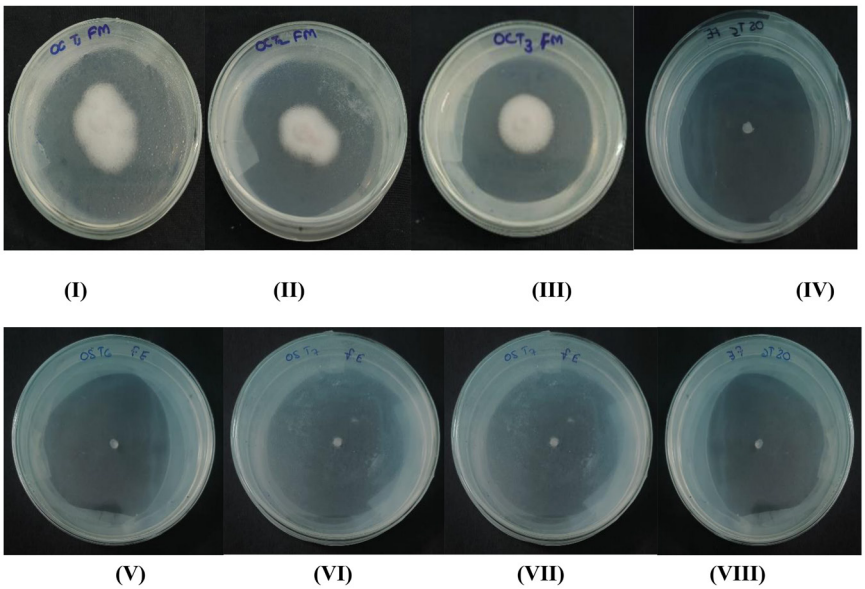
*MIC - Minimum Inhibitory Concentration.
*MCC - Minimum Cidal Concentration.



(I) T1 (II) T2 (III) T3 (IV) T4

(V) T5 (VI) T6 (VII) T7 (VIII) T8

Fig 1 A: Mycelial growth of *Curvularia trifolii* at different concentrations against *O. sanctum*



(I) (II) (III) (IV)

(V) (VI) (VII) (VIII)

Fig 1 B: Mycelial growth of *Rhizoctonia solani* at different concentrations against *O. sanctum* EO

Fig. 1 (A and B). Growth inhibition of fungal pathogens (A) *Curvularia trifolii* (B) *Rhizoctonia solani* by using essential oil of *O. sanctum* at dose of (i) T_1 (400 ppm), (ii) T_2 (800 ppm), (iii) T_3 (1200 ppm), (iv) T_4 (1600 ppm), (V) T_5 (2000 ppm), (VI) T_6 (2400 ppm), ,(VII) T_7 (2800 ppm) and (VIII) T_8 (3200 ppm).

centration (MIC) of the *O. sanctum* oil was recorded 2000 ppm, and 1600 ppm against the test pathogens *C. trifolii* and *R. solani* respectively. Further, the minimum fungicidal concentration (MCC) of the oil was recorded 3200 ppm against *C. trifolii*, however, in case of *R. solani*, it was 2000 ppm (Figs. 1-2 and Tables 1-2).

Further literature shows that Siva *et al.* (2016) reported the aqueous and acetone extract of *O. sanctum* L. were found to be sensitive against many plant fungi such as *Alternaria tenuis, Helminthosporium* sp. and *Curvularia penniseli.* Kahkonen *et al.* (1999) concluded that essential oil of tulsi was effective against the plant fungal pathogens such

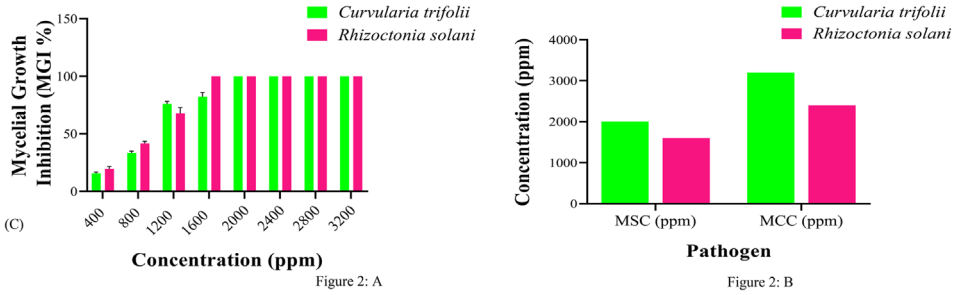


Fig. 2. Effects of different concentration (s) of *Ocimum sanctum* EOs on *C. trifolii* and *R. solani* (A) Antifungal activity of EO at different concentrations showing percent inhibition of mycelia growth, (B) Minimum inhibitory concentration (MIC) and minimum cidal concentration (MCC) of EO against both the test pathogens.

as *Alternaria solani, Candida guillermondii, Colletotricum capsici, Curvularia* sp. *Fusarium solani,* and *Helminthosporium oryzae.* Essential oil of tulsi along with Eugenol check the growth of *Aspergillus flavus.* Singh *et al*. (2010) reported that Tulsi leaves shows strong antifungal activity against *Aspergillus* spp. while Eseential oil of *O. gratissimum* L. shows strong efficacy against *Candida* spp. Comparing with the results of present investigations, the literature reveals antifungal efficacy of *O. sanctum* against several fungal pathogens. However, majority of the studies were focused upto *in-vitro* evaluation. The present investigation showing the fungicidal activity of *O. sanctum* oil against *R. solani* at 2400 ppm and *C. trifolii* at 3200 ppm concentration(s) by poison food technique prompts us go to the pot and field trials, and the related work are under progress. Constituents of the natural essential oil(s) varying in both ways qualitatively as well as quantitatively depends upon the environment, soil and cultivar, the technology to manage fungal phytopathogens.

CONCLUSION

The findings of the present investigation reveal that MIC of *O. sanctum* oil against the test fungal pathogen (s) *C. trifolii* was recorded 2000 ppm while its MCC was 3200 ppm. Similarly, the MIC and MCC of the *O. sanctum* oil against *R. solani* were recorded as 1600 ppm and 2400 ppm, respectively. Hence, the present findings of antifungal activities of basil essential oil could be used for detailed *in-vitro* investigations; further the results of *in-vitro* findings can be utilized at pot and field levels and if found effective, could be an alternative to synthetic fungicides.

ACKNOWLEDGMENT

The authors are thankful to the authorities and Head, Department of Botany, University of Lucknow as well as the Director, CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, Farm Incharge, CSIR-CIMAP Lucknow, India for providing the research facilities during the investigations.

REFERENCES

Adukwu EC, Bowles M, Jones VE, Bone H (2016) Antimicrobial activity, cytotoxicity and chemical analysis of lemongrass essential oil (*Cymbopogon flexuosus)* and pure citral. *Appl Microbiol Biotechno*l 100 : 9619–9627. DOI 10.1007/s00253-016-7807-y

Ajayi-Oyetunde OO, Bradley CA (2018) *Rhizoctonia solani*: Taxonomy, population biology and management of rhizoctonia seedling disease of soybean. *Plant Pathology* 67 (1) : 3-17.

Almeida R (2001) Plants with central analgesic activity. *Phytomedicine* 8 : 310–322. https://doi.org/10.1078/0944-7113-00050

Baiswar P, Chandra S, Kumar R, Ngachan SV (2012) First report of Leaf Blight of *Basella alba* caused by *Rhizoctonia solani* AG 1-IB in India. *Plant Dis* 96 (6) : 911. doi: 10.1094/PDIS-02-12-0178-PDN.

Batish DR, Singh HP, Kohli RK, Kaur S (2008) Eucalyptus essential oil as a natural pesticide. *Forest Ecology and Management* 256 (12) : 2166-2174.

Clevenger JF (1928) Apparatus for volatile oil determination, description of new type. *The Journal of the American Phar-*

maceutical Association 17 : 345-349. https://doi.org/10.1002/jps.3080170407

Coelho L, Borrero C, Bueno-Pallero FA, Guerrero C, Fonseca F, Reis M, Dionisio L (2020) First report of *Curvularia trifolii* causing Curvularia blight in *Agrostis stolonifera* in south of Portugal. *Plant Disease* 104 (1) : 292.

Daghir GM, Madhi QH (2020) First report of Leaf blight disease caused by *Rhizoctonia solani* Kühn on ornamental plants in Iraq. *Int J Agricult Stat Sci* 16 (1): In prees.

Gakuubi MM, Maina AW, Wagacha JM (2017) Antifungal activity of essential oil of **Eucalyptus camaldulensis** Dehnh. against selected *Fusarium* spp. *Int J Microbiol*: 8761610. doi: 10.1155/2017/8761610.

Gao S, Liu G, Li J, Chen J, Li L, Li Z, Zhang X, Zhang S, Thorne RF, Zhang S (2020) Antimicrobial activity of lemongrass essential oil (*Cymbopogon flexuosus*) and its active component citral against dual-species biofilms of *Staphylococcus aureus* and *Candida* Species. *Front Cell Infect Microbiol* 10 : 603858. doi: 10.3389/fcimb.2020.603858

Gogoi R, Loying R, Sarma N, Begum T, Pandey SK, Lal M (2020) Comparative analysis of *In-Vitro* biological activities of methyl eugenol rich *Cymbopogon khasianus* Hack., leaf essential oil with pure methyl eugenol compound. *Current Pharmaceutical Biotechnology* 21 (10) : 927-938 DOI: https://doi.org/10.2174/1389201021666200217113921

Grover RK, Moore JD (1962) Toximetric studies of fungicides against brown spot organism *Sclerotia fructicola* and *S. laxa. Phytopathology* 52 : 876-880.

https://tradestat.commerce.gov.in/eidb/ecom.asp Department of Commerce, Ministry of Commerce and Industry, Government of India.

Ji J, Wang T, Xu X, Wang XY, Wu QQ, Li WY, Kan YC, Yao LG (2019) First report of *Colletotrichum siamense* causing leaf spot on Redbud in China. *Plant Disease* 103 (3): In prees.

Joy PP, Mathew S, Skaria BP, Mathew G, Joseph A, Sreevidya PP (2006) Lemongrass Aromatic and Medicinal Plants Research Station Odakkali, Asamannoor, Kerala, India pp 32.

Kahkonen MP, Hopia AI, Vuorela HJ, Rauha JP, Pihlaja K, Kujala, TS Heinonen M (1999) Antioxidant activity of plant extracts containing phenolic compounds. *J Agric Food Chem* 47 (10) : 395462. DOI: https://doi.org/10.1021/jf9901461

Maurya A, Yadav H, Sharma R, Verma AK, Mindala DP, Shukla AC, Srivastava RK (2024) Antifungal efficacy and phytochemical characterization of citronella (*Cymbopogon winterianus* Jowitt ex Bor) essential oil against fungal pathogens causing severe diseases in *Mentha arvensis* L. *Journal of Essential Oil-Bearing Plants* 27 (1) : 230-240. DOI: 10.1080/0972060X.2024.2302111

Mirghani MES, Liyana Y, Parveen J (2012) Bioactivity analysis of lemongrass (*Cymbopogan citratus*) essential oil. *International Food Research Journal* 19 (2) : 569-575.

Misawa T, Kayamori M, Kurose D, Sasaki J, Toda T (2017) First report of *Rhizoctonia* disease of lily caused by *Rhizoctonia solani* AG-11 in Japan. *Journal of General Plant Pathology* 83 : 406-409.

Mukarram M, Choudhary S, Khan MA, Poltronieri P, Khan MMA, Ali J, Kurjak D, Shahid M (2022) Lemongrass essential oil components with antimicrobial and anticancer activities. *Antioxidants* 11 (1) : 20. DOI: https://doi.org/10.3390/antiox11010020

Naik MI, Fomda BA, Jaykumar E, Bhat JA (2010) Antibacterial activity of lemongrass (*Cymbopogon citratus*) oil against some selected pathogenic bacterias. *Asian Pacific Journal of Tropical Medicine* 3 (7) : 535-538.

Nath SC, Sarma KK, Vajezikova I, Leclercq PA (2002) Comparison of volatile inflorescence oils and taxonomy of certain *Cymbopogon taxa* described as *Cymbopogon flexuosus* (Nees ex Steud.) Wats. *Biochemical Systematics and Ecology* 30 (2) : 151-162. https://doi.org/10.1016/S0305-1978(01)00066-7

Olorunnisola SK, Asiyanbi HT, Hammed AM, Simsek S (2014) Biological properties of lemongrass: An overview. *International Food Research Journal* 21 (2) : 455.

Philippe S, Souaibou F, Guy A *et al.* (2012) Chemical composition and Antifungal activity of essential oil of fresh leaves of *Ocimum gratissimum* from Benin against six mycotoxigenic fungi isolated from traditional cheese wagashi. *Research Journal of Biological Sciences* 1 : 22–27.

Pinheiro PF, de Queiroz VT, Rondelli VM, Costa AV, Marcelino TdeP, Pratissoli D (2013) Insecticidal activity of citronella grass essential oil on *Frankliniella schultzei* and *Myzus persicae. Ciênc Agrotec* pp 37.

Sarma A, Sarma Tarun Ch (2005) Studies on the morphological characters and yields of oil and citral of certain lemongrass [*Cymbopogon flexuosus* (Steud) (Wats) accessions grown under agro-climatic conditions of Northeast India. *Journal of Essential Oil Bearing Plants* 8 (3) : 250–257. doi:10.1080/0972060x.2005.10643454

Sharma RS, Kumar Y, Bhise RN, Choudhri HPS, Verma DK, Srivastava RK, Kumar S (2022) Economics of lemongrass cultivation in Jharkhand state. *Economic Affairs* 67 (04) : 505-510.

Shukla AC, Dikshit A (2016) Protocols in Medicinal and Aromatic Plants, (Eds) Today & Tomorrow's Printers and Publishers, New Delhi. India.

Shukla RS, Singh HB, Kalra A, Singh VP, Kumar S (1999) Occurrence of dual infection by *Puccinia menthae* and *Alternaria alternata* on *Mentha arvensis* in Tarai region of Uttar Pradesh. *J Med Plant Sci* 21 : 311-315.

Simic A, Rančic A, Sokovic MD, Ristic M, Grujic-Jovanovic S, Vukojevic J, Marin PD (2008) Essential oil composition of *Cymbopogon winterianus* and *Carum carvi* and their antimicrobial activities. *Pharm Biol* 46 : 437–441. https://doi.org/10.1080/13880200802055917

Singh BR, Singh V, Singh RK, Ebibeni N (2011) Antimicrobial activity of lemongrass (*Cymbopogon citratus*) oil against microbes of environmental, clinical and food origin. *International Research of Pharmacy and Pharmacology* 1 (9) : 228-236.

Singh HB, Kalra A, Patra NK (1997) Sheath rot and leaf blight - a new disease of Java citronella caused by *Rhizoctonia solan*i. *Bulletin OEPP/EPPO Bulletin* 27 : 269-271.

Singh V, Amdekar S, Verma O (2010) *Ocimum Sanctum* (Tulsi): Bio-pharmacological activities. *Webmed central Pharmacology* 1 (10) : WMC001046. DOI: 10.9754/journal.wmc.2010.001046

Siva M, Shanmugam KR, Shanmugam B, Venkata SG, Ravi S, Sathyavelu RK, Mallikarjuna K (2016) *Ocimum sanctum*: a review on the pharmacological properties. *Int J Basic Clin Pharmacol* 5 (3) : 558-565.

DOI: http://dx.doi.org/10.18203/2319-2003.ijbcp20161491

Srivastava A, Gupta S, Singh S, Verma RS, Srivastava RK, Gupta AK, Lal RK (2021) Genetic variability and elite line selection for high essential oil and nepetalactone content in Catmint (*Nepeta cataria* L.). *American Journal of Plant Sciences* 12 (7) : In prees.

Sung CH, Koo JH, Kim JH, Yoon JH, Lee JH, Shim KY, Kwak YS. Chang SW (2016) First report of Curvularia leaf blight caused by *Curvularia trifolii* on Creeping bentgrass in Korea. *Weed Turfgrass Science* 5 (2) : 101-104.

Unal F, Tulek S, Bingol MU, Ozturk O, Egerci Y, Kurbetli I, . Dolar FS (2020) Identification and pathogenicity studies of white clover (*Trifolium repens* L.) fungi on turfgrass areas in Turkey. *Plant Protection Bulletin/Bitki Koruma Bülteni* 60 (1) : In prees.

Van Zyl RL, Seatlholo ST, Van Vuuren SF, Viljoen AM (2006) The biological activities of 20 nature identical essential oil constituents. *Journal of Essential Oil Research* 18 (1) : 129-133.

Verma RS, Verma SK, Tandon S, Padalia RC, Darokar MP (2020) Chemical composition and antimicrobial activity of Java citronella (*Cymbopogon winterianus* Jowitt ex Bor) essential oil extracted by different methods. *J. Essent Oil Res* 32 (5) : 449–455. https://doi.org/10.1080/10412905.2020.1787885

Yadav H, Kumar V, Sharma RS, Shukla AC, Srivastava RK (2021) Management of diseases, uses, biological and pharmacological activities of essential oil of basil (*Ocimum basilicum* L.): A review. *Journal of Medicinal and Aromatic Plant Sciences* 43 (1-2) : 64-71.

Yadav H, Verma RP, Yadav MK, Srivastava RK (2022) Introduction of sweet basil (*Ocimum basilicum* L.) as a short duration annual aromatic crop in Assam for enhancing the income of farmers of the North-East Region. *Journal of Medicinal and Aromatic Plant Sciences* 44 (3-4) : 111-114.

Yogendra ND, Nazeer M, Eresha, Yadav MK, Baskaran K, Pragadheesh VS, Jnanesha AC, Srinivas KVNS (2021) Comparative morphological assessment of lemongrass (*Cymbopogon* spp.) cultivars for oil yield, chemical composition and quality parameters under Southern region of India. *Madras Agric J* 108 (1-3) : 1-8. DOI: https://doi.org/10.29321/MAJ.10.000564

Zhang Q, Yang ZF, Cheng W, Wijayawardene NN, Hyde KD, Chen Z, Wang Y (2020) Diseases of *Cymbopogon citratus* (Poaceae) in China: *Curvularia nanningensis* sp. nov. *MycoKeys* 63: 49-67. doi: 10.3897/mycokeys.63.49264.