Full Length Research Article

Research Journal of Agricultural Sciences
Volume 16; Issue 01 (Jan–Feb 2025); pp 72–75

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

A Brief Overview of Fungal Endophytes Research on Grasses in India

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Received: 06 Dec 2024; Revised accepted: 27 Jan 2025

Abstract

Fungal endophytes are recognized as an important group of organisms with unique biological significance. Fungal endophytes aid in providing abiotic tolerance to plants like drought, temperature and biotic tolerance from insect, pathogenic infections etc. Fungal endophytes produce secondary metabolites like peptides, phenols, alkaloids, polyketides, quinones, steroids, and enzymes, which can be highly beneficial to mankind. There are only a handful of studies on the diversity, bioactivity, and metabolite production of fungal endophytes in grass hosts of India. Mycologists acknowledge the fact that fungal endophyte studies on dicot hosts engage the interest of most researchers but not with a case of grass. This paucity of research on fungal endophytes of grasses needs attention and further study. This short review seeks to compile and offer input into the study of fungal endophyte of grasses in India from 2011 to 2022 and their bioactivity.

***Key words*:** Poaceae, Gramineae, Grass, Diversity, Fungal endophytes, Metabolites

Fungal endophytes research of trees, shrubs and herbs engaged the interest of many mycologists in tropical and temperate regions. Mycologists globally refer to the tropics as a "black box" regard to our knowledge on fungal endophytes [1]. In India not many of plant species have been extensively studied for Fungal endophytes. Microorganisms that reside within plants for some time in their life cycle but do not produce any outward signs of disease are commonly referred to as endophytes [2]. The development of new natural products is thought to be facilitated by fungi and other endophytes, as they have the ability to produce a wide range of bioactive secondary metabolites that have potential uses in industry, medicine, and agriculture [3].

A very small percentage of plant species had their fungal endophyte biodiversity studied, despite the potential advantages of fungal endophytes [4]. Given the country's rich biodiversity, there is immense potential for discovering novel fungal species with unique biochemical properties. However, research on fungal endophytes in India is still in its nascent stages, with much of the microbial diversity yet to be documented. There may a range of 1 to 1.5 million fungal endophyte species in the world, the majority of which has not yet found and investigated [4]. Around 1506 grass species found in India [5], it is estimated that only a small number have been thoroughly examined in terms of their endophytic biology. ungal endophytes are microorganisms that reside within plant tissues for at least a part of their life cycle without causing any noticeable symptoms of disease. Unlike pathogenic fungi, which cause visible harm to plants, endophytic fungi often form symbiotic or neutral associations, potentially benefiting their host by enhancing stress tolerance, promoting growth, or providing resistance against pathogens. These fungi are found in various plant tissues, including leaves, stems, and roots, and their interactions with plants can be influenced by environmental factors, host species, and microbial communities. Understanding fungal endophytes is crucial for harnessing their potential in agriculture, medicine, and biotechnology. Studies suggest that they may play a role in enhancing plant resistance to biotic and abiotic stresses, producing bioactive compounds with pharmaceutical applications, and contributing to sustainable agricultural practices. Exploring the diversity and function of fungal endophytes, especially in underexplored regions, could lead to significant scientific and commercial advancements.

This may be partly because there is a dearth of current data regarding the state of fungal endophyte research in India. Therefore, in order to understand the current situation on fungal endophyte study of grasses and their potential and to identify knowledge gaps for future research, it is necessary to analyze the work that has been done on the fungal endophytes of grasses in India. This review article's goal is to shed light on the fungal endophyte research on grasses that has been done in India. This short review is categorized into: Fungal endophytes reported from different grass hosts and bioactive compounds produced by such fungal endophytes from India.

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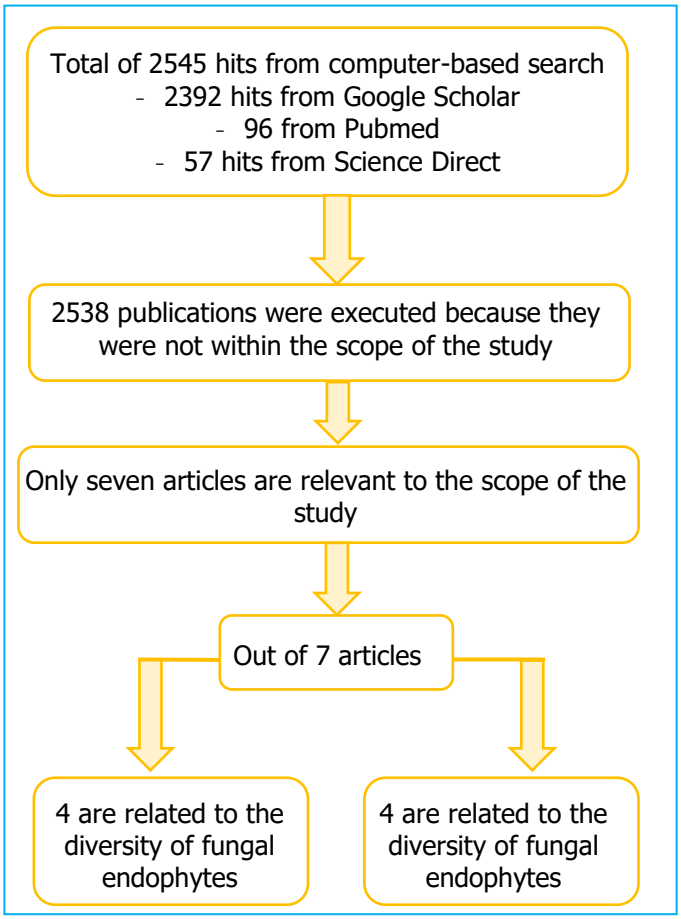
Citation: Venkatesh J, Banu N, Karthi R, Srinivasan S, Lakshmanan M, Girivasan KP, Rajagopal K. 2025. A brief overview of fungal endophytes research on grasses in India. *Res. Jr. Agril. Sci.* 16(1): 72-75.

MATERIALS AND METHODS

For the literature survey of fungal endophytes of grasses, the following search engines were used: Science Direct, PubMed, and Google Scholar. The review study was totally based on the web search. For the literature survey, the following keywords were used: fungal endophytes, endophytic fungi, grass, Poaceae, and Gramineae, followed by different state names and union territories. The search for the articles on the fungal endophytes was carried out between 2011 and 2022.

Selection of research papers

A total of 2545 search results were shown from the web-based search in line with individual states and Union territories of India. Out of 2545, 2392 results came from Google Scholar, 96 results came from PubMed, and 57 results came from Science Direct (Fig 1).



RESULTS AND DISCUSSION

Out of all the above, 2538 results were manually found to be irrelevant because the studies were out of focus of the current review and were removed. Remaining, seven papers were considered relevant to the scope of the study.

Indian states and Union territories involved in fungal endophyte research from 2011 to 2022

In the timeline from 2011 to 2022, researchers from Karnataka have published three research papers, while researchers from Tamil Nadu, Maharashtra, Uttarakhand, and Uttar Pradesh have published one research paper each in the designated scope of study (Fig 2).

The number of publications varies between the states and union territories (Fig 3). However, from 2018 to 2022, papers related to fungal endophytes are gaining momentum. Out of few research under taken on grass species for the fungal endophytes in India all the host so far studied inhabited by fungal endophytes (Table 1).

Among the various group of fungal endophyte isolated from different grass hosts, Hyphomycetes was the dominant group followed by ascomycetes. The reported fungal endophytes belonging to 15 different genera and 25 species were isolated. Of which 18 were Hyphomycetes (64.2%), 8 Ascomycetes (28.5%), 1 Coelomocytes (3.57%) and 1 sterile form (3.57%) (Table 1). Even though Ascomycetes, Hyphomycetes, Coelomocytes were present, Zygomycetes and Basidiomycetes were absent in the grass endophyte study and are usually appear as endophytes in low number in endophyte studies. This observation was consonance with other reports that only few endophytic fungal taxa dominate a single host plant [6-7]. Most of the fungal endophytes reported from grass hosts are already reported as fungal endophytes in dicot plants too [8-9]. Several fungal endophytes like *Aspergillus*, *Penicillium*, *Alternaria*, *Curvularia*, and *Fusarium* commonly occur as epiphytic fungi but are capable of penetrating the superficial layers of epidermis; when do so, they escape strong surface sterilization procedures and grow as fungal endophytes in plates [10]. Hence, it shows that epiphytic fungi also resort to an endophytic mode of life to overcome the competition among epiphytic fungi on the surface of the leaf, stem, root, etc. for existence, nutrition, and to avoid adverse environmental conditions [11]. Additionally, *Pestalotiopsis*, *Curvularia*, *Chaetomium*, *Aspergillus*, *Alternaria*, and *Trichoderma* are reported as multi-host endophytic fungi because of their widespread distribution in plants of different ecosystems [12-13]. Few fungal endophytes have such a wide distribution that transcends host taxonomic and geographic boundaries, but their full study remains unexplored. Many fungal endophytes of grasses are reported from India are showing different relationships with hosts like saprophytic, parasitic, pathogenic, weak pathogenic, and symbiotic [14].

Fungal endophyte	Host	Reference
Fusarium equiseti	*Bambusa balcooa* (Poaceae)	[14]
Alloteropsis cimcina: *Aspergillus niger*, *Aspergillus terreus*, *Chaetomium* sp., *Myrothecium verrucaria*, *Penicillium pinophilum*, *Pestalotiopsis microspora*, *Setosphaeria rostrata*, *Talaromyces pinophilum*, *Trichoderma* sp. ***Heteropogan concortus***: *Chaetomium subaffine*, *Cochliobolus geniculatus*, *Corynespora cassiicola*, *Fusarium decemcellulare*	*Alloteropsis cimicina* (Poaceae) *Heteropogon contortus* (Poaceae)	[4]
Alternaria alternata, *Aspergillus fumigatus*, *Aspergillus glaucus*, *Aspergillus nidulans*, *Aspergillus niger*, *Aspergillus terreus*, *Chaetomium globosum*, *Chrysonilia sitophila*, *Curvularia brachyspora*, *Curvularia lunata*, *Fusarium culmorum*, *Fusarium oxysporum*, *Trichoderma* sp., Sterile forms	*Spinifex littoreus* (Poaceae)	[2]

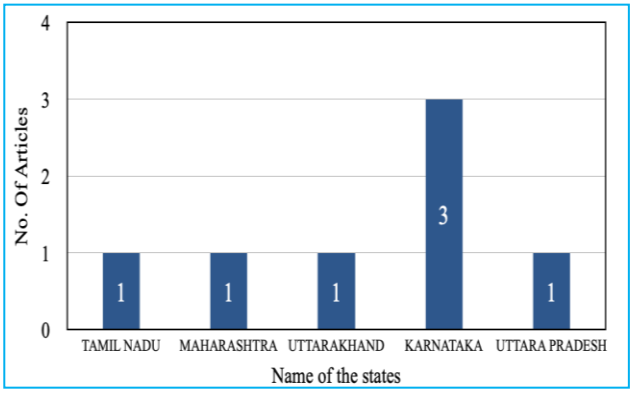


Fig 2 Number of articles published on fungal endophytes of grasses in different states of India

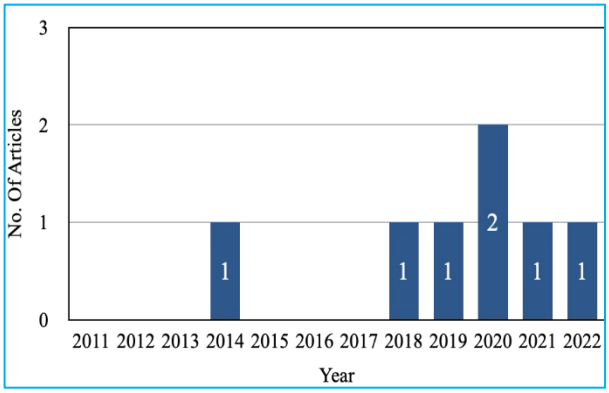


Fig 2 Number of publications in every year

Compounds isolated from fungal endophytes and their bioactivity

Mycologists are drawn to study fungal endophytes not just for their diversity but also for their potential to generate novel, bioactive compounds. These includes antimicrobials, antibiotics, insecticidal agents, anticancer agents, and so forth. *Curvularia tsudae* a fungal endophyte isolated from the *Cynodon dactylon* (L.) Pers produced following compounds such as sulfadimidine, scopoletin, hydroquinone, 5-bromovanillin, isofraxidin, 4-hydroxycoumarin and dilauryl 3,3′-thiodipropionate, celecoxib, (E)-ranitidine, butabarbital, dextramycin, citrinin, berberine, umbelliferone, hexanal, jasmonic acid, curvularin, sclerotiorin, aspirin, esculetin which shows the varied bioactivities such as antifungal, antioxidant, anti-inflammatory, analgesic, antibiotic, antimicrobial, anti-cancer, anti-pyretic, anti-coagulant, antibacterial, anti-tumour and plant growth promotion. Some new compounds such as Methyl 4,6-dideoxy-4-((2,4- dihydroxybutanoyl) amino)-2-O-methylhex-opyranoside and 4,6-dichloro-N-phenyl-1,3,5-triazin-2-amine; 7,7-dimethyl-10-oxo-5,6,7,8,9,10-hexahyd-robenzo (8) annulen-5-yl trifluoroacetate and methyl N-((9H-fluoren-9-yl-methoxy) carbonyl) phenylalanyl phenyl alaninate and 2-chloro-5-(5-(3- chlorophenyl)-1,3-oxazol-2-yl)-4-(trifluoromethyl) pyridine was also identified and their bioactivity is unknown [15].

Alloteropsis cimicina a summer grass harbored a series of compounds such as ranitidine; betaine; aspirin; 4-aminonicotinic acid; nootkatone; caffeic acid; thioridazine; (E)-p-coumaric acid; Nobiletin and its associated fungal endophyte *Penicillium pinophilum* produced different compounds such as L-isoleucine; maltol; phenacetin; esculetin; scopoletin; eugenol; dextramycin; citrinin; sulfamethazine; polygodial; diisobutylphthalate; hexadecanamide; phthalic acid; umbelliferone; (22E)-stigmasta-5,22-dien-3-ol; N-(2,3-dimethylphenyl)-2((5-phenyl-1H-imidazol-2-yl)sulfanyl) acetamide; cinnamic acid; mesalazine N-(5-bromo-2-pyridinyl)-1-naphthamide and bilirubin. Some compounds which are common in both the host and the fungal endophyte are 4-hydroxycoumarin; 4-methoxycinnamic acid; acetophenone; asarone; dioctyl phthalate; isophorone; l-tyrosine; zearalenone [16]. Similar observations were made in several non-grass host plants **t**hat fungal endophyte produces same compound as host. Fungal endophyte isolated from a halophytic grass such as *Trichoderma atroviride*, *Alternaria infectoria*, *Alternaria chlamydospora*, *Microsphaeropsis arundinis*, *Didymosphaeria variabile*, and *Chaetomium globosum* which is inoculated into the host species *Triticum aestivum L.* to improve the salt-stress tolerance and showed positive results on salt-stress tolerance [17]. Our review on grass fungal endophytes shown that metabolites can be synthesized by fungal endophytes of grasses which has multiple role in host physiology. Therefore, investigating grass fungal endophytes may open up new avenues for the hunt for novel compounds. Considering their importance, Mycologists should focus their attention on the diversity of fungal endophytes in tropical grasses since there's a good source of metabolites and some of the identified fungal endophytes may be new to science that are unknown to mycologists.

CONCLUSION

Research on fungal endophytes in India is very limited, which may be due to various factors. Some of the reason could be the relatively low awareness and understanding of the importance of fungal endophytes in plant health and ecosystem dynamics. Moreover, research priorities in the country may be more focused on immediate agricultural challenges, climate change, stem cell technology, medical biotechnology, and nanotechnology, leaving less room for exploration of less well-known aspects such as fungal endophytes and their importance in forest management, agricultural crop management, etc. To promote research in this area, it would be essential to raise awareness about the potential benefits of fungal endophytes in grass hosts. Many fungal endophytes are difficult to culture in laboratory settings; most of them are sterile, non-sporulating, and slow-growing. So, studying them under controlled conditions is difficult. These challenges hinder comprehensive investigations into their life cycles, physiology, and genetics. Fungal endophytes often show host specificity, forming symbiotic relationships with specific grass species. This can make it puzzling to generalize findings across different grass hosts and ecosystems. Abiotic factors like temperature, light, soil, stress, and biotic factors like physiological conditions and tissue types also influence the fungal endophyte distribution. Hence, understanding these complex ecological dynamics requires interdisciplinary research and long-term monitoring. Bioprospecting potential because fungal endophytes has been a source of bioactive substances with pharmaceutical and agricultural applications. The study of grass-associated fungal endophytes presents opportunities for bioprospecting and discovering novel bioactive compounds that may have medicinal or agricultural significance. Understanding how fungal endophytes contribute to the fitness and stress tolerance of host grasses is crucial. Some endophytes can enhance resistance to abiotic stresses, such as drought or nutrient deficiency. So, understanding these mechanisms can provide insights into potential applications for improving crop resilience. Endophytes are essential to the conservation and

biodiversity of ecosystems. Studying fungal endophytes in grasses contributes to our understanding of biodiversity conservation. Because few fungal endophytes may play key roles in maintaining the health and diversity of natural grassland ecosystems, studying fungal endophytes in grasses offers opportunities for educational outreach.

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