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Morphological Studies and Identification of DSE Fungi and Their Role in Sustainable Agriculture: A Systematic Review

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Abstract

The use of endophytic fungi as producers of bioactive compounds is popular among researchers today. One example of endophytic fungi that is currently widely studied regarding its role is DSE fungi. Determining the morphological structure and identification of DSE fungus as well as its function as a sustainable agricultural agent, are the goals of this study. Several scientific papers that are pertinent to the subject matter are gathered, chosen, and reviewed as part of the systematic literature review research methodology. Developing a research question, looking through pertinent literature, choosing studies with eligibility requirements and quality evaluation, and extracting data were the first stages of the study. Based on the data analysis, DSE fungi have the ability to increase plant productivity and resistance to biotic and abiotic stress, as well as their contribution to phytostabilization and nutrient accumulation. In addition, DSE fungi can produce beneficial secondary metabolites, such as growth hormones and bioactive compounds, which support plant health. The use of DSE fungi also has the potential to support plant growth in sustainable agriculture.

Keywords: DSE Fungi, Sustainable Agriculture, Systematic Review

INTRODUCTION

The use of endophytic fungi as producers of bioactive compounds is popular among researchers today. Microorganisms known as endophytic fungi reside within the tissues of plants, including seeds, leaves, flowers, twigs, stems, and roots. Numerous useful substances, such as antiviral, antibacterial, antifungal, plant growth hormones, and pesticide chemicals, can be produced by endophytic fungi. The existence of active compounds such as antibacterial and antifungal in the health sector is very important to overcome diseases caused by fungi or bacteria (Rusli et al., 2020). Endophytic fungi obtain protection and nutrients from host plants, while host plants can benefit from this relationship, such as increased competitive ability and increased resistance to diseases, herbivores, and various types of abiotic stress (Sari, 2020).

DSE fungi, also known as Dark Septate Endophytic fungi, are one type of endophytic fungus whose function is currently the subject of extensive research. One group of endophytic fungi that is known to contribute to plant productivity under biotic and abiotic stress is the DSE fungi, which are a group of species of Ascomycetes fungi (Surono & Narisawa, 2018). DSE fungi have a dark hyphal color, as the name implies, the dark color of the hyphae is due to the presence of melanin content and generally forms a small hyphal mass. DSE fungi can colonize plant roots both internally and externally without causing disease in the host plant (Surono & Nurdebyandaru, 2022).

In the past few decades, studies on endophytic fungi have been carried out to learn more about their interactions with their hosts, the kinds of partnerships they form, and the possible outcomes of these interactions (Santos et al., 2021). As was mentioned in the previous paragraph, there is a subgroup of endophytic fungi called dark-septate endophytic (DSE) fungi. This group includes both sterile and conidial fungi and is probably paraphyletic (Khastini & Jannah, 2021). The majority of research on the interactions between DSE and plants has not found either beneficial or detrimental impacts. Nonetheless, several DSEs have the power to make nutrients more accessible to plants, enabling them to develop at typically faster rates. The type of nutrients present in the soil or substrate may also affect DSEs' capacity to colonize and benefit plants (Santos *et al*., 2021). For instance, when both organic and inorganic nutrient sources were supplied, tomato plants' root and shoot biomass rose, demonstrating the various biostimulant effects of *Periconia macrospinosa* and *Cadophora* sp. Only *Periconia macrospinosa* enhanced the biomass of tomato plants' shoots and roots when organic fertilizer sources were used. (Yakti *et al*., 2019). This systematic review was conducted to determine the morphological structure and identification of DSE fungi and to determine their role as a sustainable source for agriculture.

METHOD

This study is an organized systematic review that was carried out by gathering, choosing, and examining several scholarly works that are pertinent to the subject at hand. Developing a research question, looking through pertinent literature, choosing studies with eligibility requirements and quality evaluation, and extracting data were the first stages of the study. Research questions in this study; what is the role of DSE fungi? and how does it function as a substitute for sustainable agriculture?. “Dark Septate Endophytic Fungi” was the term chosen in the Scopus database for the literature search. The search took place between October and November of 2024.

PRISMA (Preferred Reporting Item for Systematic Review and Meta Analysis) is used to choose literature sources based on eligibility requirements. 1) Scientific articles written in English or Indonesian; 2) literature in the form of scientific articles published in journals or proceedings; 3) articles published in 2019–2024; and 4) discussion of scientific articles on the identification of DSE fungi and their role are among the eligibility criteria that comprise the inclusion criteria. Additionally, there are exclusion requirements in the qualifying criteria, such as 1) full-text access to scientific journals and 2) articles that take the form of literature reviews.

Scientific publications that don't fit the above requirements will be disqualified and won't be able to be used in this investigation.

RESULTS AND DISCUSSION

We focused on the identification and role of DSE (Dark Septate Endophytic) fungi as sustainable alternative materials. A systematic review was conducted on several studies related to the role of DSE in various fields. The results obtained from searching articles based on the Scopus database that have been filtered based on the year of publication, with a range of years, namely 2019-2024, or approximately the last five years, were eight articles. 1) scientific articles written in English or Indonesian; 2) literature in the form of scientific articles published in journals or proceedings; 3) articles published in 2019-2024; 4) discussion of scientific articles on the identification of DSE fungi and their role, were the inclusion criteria that were used to select the articles. The two exclusive requirements are: 1) full-text access to scientific journals is not available; and 2) the articles are literature reviews. The articles were assessed and reviewed for the overall content, and there were only seven articles that were considered relevant. These selected articles were then extracted and analyzed. Data analysis in the article was carried out by analyzing the results and discussions related to known fungal species and the role of the DSE of these fungi. The results of data extraction from the articles are presented in Table 1. Review Article Data.

Table 1. Review Article Data

No.	Researcher	Year	Method	The Known Species	Researched Role
1.	Akira Ishikawa, Daisuke Hayasaka, Kazuhide Nara	2024	Isolation, Staining, Molecular (PCR)	N/A	Colonization of fungi symbiotic with *Pinus thunbergii* roots in the establishment of pioneer pine seedlings
2.	K. P. Putri, S. W. Budi R., D. J. Sudrajat, Surono, N. Widyani, N. Yuniarti	2024	Isolation, Purification, Identification	N/A	Effect of DSE fungi on increasing the growth of white jabon plants
3.	Kannaiah Surendirakumar, Radha Raman Pandey,	2022	Isolation, Molecular, Extraction and	*Phoma* sp.	Identification of melanin pigments in DSE of RDSE

No.	Researcher	Year	Method	The Known Species	Researched Role
	Thangavelu Muthukumar, Anbazhagan Sathiyaseelan, Surbala Loushambam, Amit Setiawan		Purification, Characterization, Analysis.		17 fungi with rice roots.
4.	Gustavo Flores-Torres, A. Peneleope Solis-Hernandez, Gilberto Vela Correa, Aida Veronica Rodrigues-Tovar	2022	Isolation, Molecular, Characterization	N/A	Identification of endophytic fungi with pioneer plant species in heavy metal contaminated tailings.
5.	Chen E, Julie A. Blaze, Rachel S. Smith, Shaolin Peng, James E. Byers	2020	Exploration, Molecular	N/A	Colonization of endophytic fungi in improving plant stress tolerance.
6.	Hulse, D. J.	2020	Random Selection, Analysis	N/A	The role of DSE in helping plants adapt to environmental stresses such as salt stress, temperature, humidity, and disease
7.	Santillan-Manjarrez, A. Penélope Solís-Hernández, Patricia Castilla-Hernández, Ignacio E. Maldonado-Mendoza, Gilberto Vela-Correa, Aurora Chimal-Hernández, Claudia Hernández-Díaz, Martha Signoret-Poillon, Diederik van Tuinen, and Facundo Rivera-Becerril	2019	Staining, Identification	N/A	Interactions between DSE fungi in freshwater wetlands

Overview of the Role of Dark Septate Endophyte Fungi

DSE fungi are considered fungal species that are reported to have several benefits or beneficial roles (mutualism) with most plant species in different environments. DSE fungi play

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a role, among others, can increase the productivity and growth of host plants without causing pathology, suppressing biotic and abiotic stress in plants (Putri et al., 2024), improving environmental conditions, and helping the absorption of nutrients by plants (Yakti et al., 2018).

DSEs are also reported to contribute as herbicides, insecticides, fungicides, bactericides, producers of secondary metabolites, and growth hormones, phytoremediation (Krestini et al., 2023), melanin melanin producers (Surendirakumar et al., 2022), to biostimulants in several commodities, for example, shallots (Azmi et al., 2022). DSE fungi can also be symbiotic by creating colonization with other fungi, such as AM (Arbuscular Mycorrhiza), which can increase phosphorus absorption. Another example is that these DSE fungi can interact with ECM fungi which can also colonize pioneer plant seedlings such as pine (Ishikawa et al., 2024).

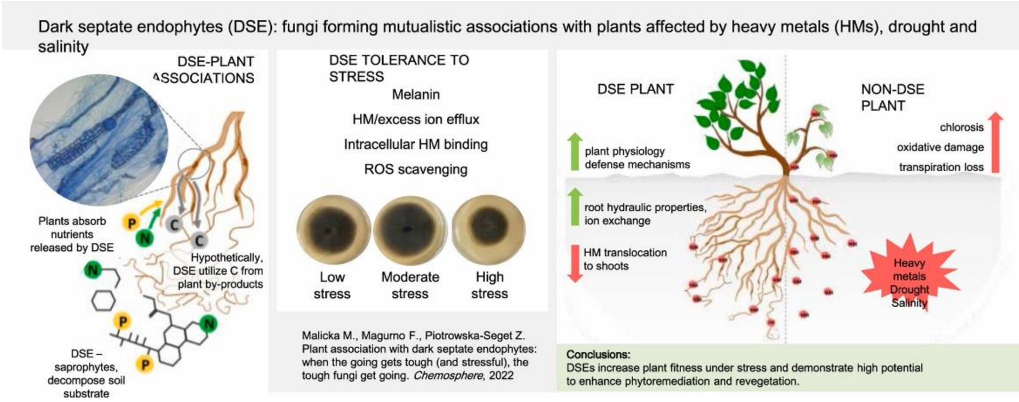

Figure 1. DSE Mechanism in Plants
(Source: Malicka et al., 2022)

The Major Role of Dark Septate Endophyte Fungi in Life

Results from a literature study suggest that fungi colonizing *Pinus thunbergii* were established before the presence of crustose lichens, leaf lichens, and short-lived herbs at the volcanic mudflow site. In extremely stressful conditions, these DSE fungi are believed to have a somewhat neutral or beneficial effect, particularly when there are few sources of mycorrhizal infection in the roots. Increased biomass and nutrient uptake are two outcomes of the DSE symbiosis and AM fungal interaction on seedling establishment. However, the contribution to nutritional status and seedling growth from AM and DSE colonization of pine seedlings growing in the volcanic blowout area was not significant. In contrast, ECM fungi showed a major role as the main symbiotic microbes in the establishment of pioneer pine seedlings.

Research conducted by Putri et al. (2024) describes the role of DSE fungi on plant growth. The plants used are white jabon plants, which are widely cultivated in several regions in Indonesia, such as North Sumatra, Riau, and Central Kalimantan. Endophytic fungi are expected to suppress biotic and abiotic stress in plants. It is said that this endophytic fungus can produce compounds that can function as antibacterial, antifungal, growth-promoting hormones, and insecticides.

The results also reported that several types of fungi included in the DSE fungi category play a role in the growth of white jabon plants. This is evidenced by the ability of these DSE fungi to increase plant growth. The identified fungal isolates are also expected to have other benefits for these plants. The fungal isolate is expected to not only be able to induce plant resistance in vitro, but also show its ability in vivo.

Another study also said that DSE fungi of the RDSE 17 type contain melanin pigments. Phoma-type fungi generally appear in plants as phytopathogens and saprophytes in the soil or on other plants. The melanin present in this type of fungus is considered a natural source of antioxidants as a free radical scavenger associated with the roots of *Oryza sativa* (rice). Furthermore, this data is applied in the manufacture of various commercial products. In the study of Manjarrez et al. (2019) reported that DSE fungi can increase the accumulation of phosphorus (P) in the rhizosphere, which contributes to the availability of P for plants.

The analysis found that DSE fungi have a potential role in phytostabilization by increasing plant tolerance to stress conditions and assisting the accumulation of heavy metals such as Pb, Cd, and Zn in roots. DSE fungi also contribute to metal translocation to plant shoots, which supports the phytostabilization process. In addition, DSE fungi can synthesize secondary metabolites that play a role in ecological interactions and promote plant health. Fungal colonies, both AM (Arbuscular Mycorrhiza) and DSE, showed positive effects on the studied plant species by increasing tolerance to stressful conditions and improving plant growth. Fungal colonization aids the accumulation of nutrients and heavy metals in the roots, which supports plant adaptation in mine waste-affected environments. Moreover, these interactions can improve the overall health of plants, strengthening their ability to withstand unfavorable conditions (Torres et al., 2021).

Other studies have reported that fungal colonization with roots, especially DSE, positively affects the survival of Avicennia germinans by increasing tolerance to stress, including freezing stress. These fungi help improve seedling quality and improve plant-soil interactions, which can enhance plant fitness. However, low colonization can inhibit the growth and survival of this species. After 4 months of soil treatment, DSE colonization on Avicennia germinans showed variable results, with colonization levels ranging between 0% and <5%. This suggests that soil treatments have a significant impact on DSE colonization, which may affect seedling growth and survival. In addition, low DSE colonization may indicate challenges in plant adaptation to the given environmental conditions (Chen et al., 2020).

Research results reported by Hulse (2020). Showed that DSE fungi can help plants adapt to environmental stresses such as salt stress, temperature, humidity, and disease by increasing plant tolerance to these conditions. Research shows that these fungi provide protective properties that increase the ability of plants to survive adverse conditions.

From the overall analysis of the article, it is mentioned that dark-septate endophytic fungi (DSE) have shown their influence in overcoming or reducing adverse impacts in agriculture, such as biotic and abiotic stress, growth promotion, symbiotic relationships with plants and mycorrhiza, and reduced nutrient availability in the soil (Huertas *et al*., 2024). DSE belongs to the Ascomycota group, which can colonize roots in various plants. The interaction between DSE Fungi and host plants is very important for the survival of these plants in nature. Especially in environments that are vulnerable to various factors such as abiotic stress, including drought, salinity, and cold temperatures. DSE will form a complex, continuous network, improve nutrient transport below the soil, encourage plants to secrete hormones and enzymes, and assist in nutrient and water uptake (Li *et al*., 2023). Therefore, the use of DSE fungi will be a good option for crop management in the face of today's environmental challenges, as well as an alternative that supports sustainable agriculture.

CONCLUSION

Based on the data from the analysis, DSE fungi have the ability to increase plant productivity and resistance to biotic and abiotic stress, as well as their contribution to phytostabilization and nutrient accumulation. In addition, DSE fungi can produce beneficial secondary metabolites, such as growth hormones and bioactive compounds, which support plant health, so their use can support plants in facing challenges in sustainable agriculture.

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