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The potential of *Artemisia* spp. plant extracts and endophytic bacteria to increase plant productivity: A review

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Abstract

Artemisia L. (mugwort) plants are known for their diverse bioactive compounds with different biological activities such as antimicrobial, antifungal, antioxidant, and allelopathic properties. Additionally, endophytic bacteria have been found to provide various benefits to host plants including enhancing nutrient uptake, modulating growth and stress-related phytohormones, and targeting pests and pathogens. While there have been numerous research reports on the phytochemical components and biological activity of *Artemisia* plant extracts, little is known about the functional diversity of isolated endophytic bacteria from various *Artemisia* species. The aim of this review was to reveal the potential of *Artemisia* plant extracts and endophytic bacteria with a positive impact on agricultural plant productivity. The present review has emphasised the significant potential of utilising plant extracts and endophytic bacteria associated with *Artemisia* spp. to enhance plant growth and increase crop productivity. Through further research and development, this approach could be deemed as a valuable contribution to sustainable agriculture practices by decreasing the dependence on synthetic inputs such as chemical fertilisers and pesticides.

Keywords: mugwort, endophytic bacteria, plant extracts, plant productivity.

Introduction

To achieve sustainability in agriculture, it should provide the present and future generations with enough food while guaranteeing profitability, environmental health, and social and economic equity. A thorough understanding of the soil complex is essential not only to supply enough food, but also to ensure global environmental sustainability for future generations (Prasad et al., 2020). Low crop productivity and plant attacks by biotic or abiotic stress are common problems in the agriculture industry worldwide. Overusing of chemical fertilisers and chemical pesticides for plant protection polluted the environment and caused an unpredictable effect on the biological composition and properties of the soil, both physically and chemically. They cause loss of soil fertility by deposition of dangerous compounds, so, there is an increasing global demand for introducing eco-friendly approaches in agriculture to provide effective ways for enhancing crop productivity (Baez-Rogelio et al., 2016). In this regard, endophytic microbes are a novel and promising approach to the sustainable agriculture strategy, because they can help reduce environmental pollution caused by chemical pesticides and fertilisers. Beneficial strains of bacteria are a rich source of natural compounds that may enhance crop productivity in a variety of biological ways (Lacava et al., 2022).

Endophytic bacteria live in host plant tissues and benefit the host plant without a harmful effect. They improve host plant growth and enhance their resistance against biotic and abiotic stresses. They can also influence the synthesis of secondary metabolites and bioactive compounds of plants with significant medicinal properties and produce a variety of metabolic functions. Plant resistance is induced by interactions between bacterial endophytes and plants to environmental stress such as drought and heavy metals accumulation. Plant-microbe interactions are one of the broadest areas of study, offering a great potential to develop convenient microbe formulations to replace chemical pesticides in plant protection and increase crop yield. Specific endophytic bacteria that grow and develop in their host plant highlighted the applicability of this beneficial bacteria as an origin of unknown novel bioactive compounds and their significant capability for use in different science areas including agriculture, environmental science, and medicine (Wani et al., 2015; Wu et al., 2021).

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There has been worldwide interest in medicinal plants since ancient times to the present day because traditional medicines have antifungal, antibacterial, and antiviral activity. Medicinal plants are used around the world as therapies for different diseases. The recent evidence indicates that bacterial endophytes can significantly affect the plant metabolism associated with the production of bioactive compounds (Castronovo et al., 2021). The study of Song et al. (2017) found that the endophytic bacterium *Bacillus altitudinis* KX230132.1 isolated from the ginseng plant can significantly enhance the production of the bioactive compound such as ginsenoside. Endophytic bacteria colonising medicinal plants have developed survival strategies to stimulate plant growth and make them resistant to pests and diseases and can be used to address issues concerning cultivated crop plants and provide additional benefits to the agricultural industry (Khan et al., 2017; Tripathi et al., 2022).

The genus *Artemisia* includes a wide range of species and global distribution. *Artemisia* L. species are widely used in the treatment of plant and human diseases as well as in the cosmetic and pharmaceutical industries due to their diverse biological and chemical properties. Furthermore, many species of *Artemisia* are used worldwide as food, spices, condiments, and beverages (Ivănescu et al., 2021; Trendafilova et al., 2021). The presence of various endophytic bacteria in *Artemisia* increases the production of secondary metabolites that activate a defence mechanism in plants. Indeed, endophytic bacteria associated with the *Artemisia* plant are recommended as a feasible biocontrol agent for plant protection (Zheng et al., 2021). The positive effect of *Artemisia* sp. in the field of plant protection is summarised in Figure 1.

This review discusses the potential use of endophytic bacteria as a sustainable approach to enhance crop productivity and replace chemical fertilisers and pesticides in agriculture. The article emphasises the beneficial effect of these bacteria on host plant growth and resistance against biotic and abiotic stress. The review also focuses on the potential use of endophytic bacteria in the production of bioactive compounds in medicinal plants using the genus *Artemisia* as an example. The study highlights the various biological and chemical properties of *Artemisia* species, their global distribution and diverse uses in plant productivity.

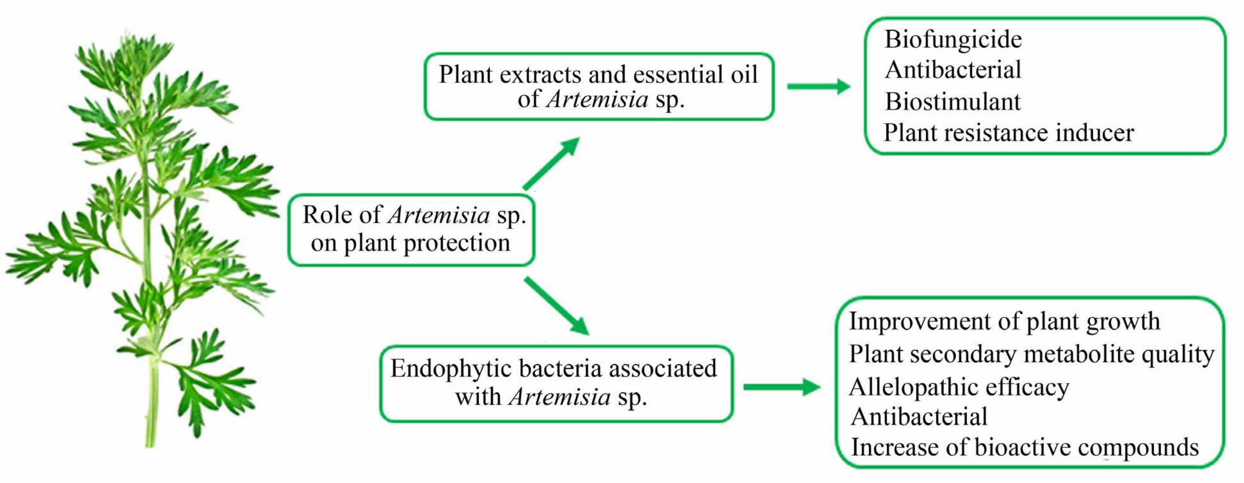

Figure 1. Significance of *Artemisia* medicinal plant for plant protection

Importance of *Artemisia* spp. medicinal plants

The genus *Artemisia* L. of the Asteraceae family is widely distributed with more than 1,000 genera and 20,000 species. This species could cope with abnormal natural conditions (resistance to environmental dryness and harsh climatic conditions, especially long-term droughts and soil salinity). The *Artemisia* plant has a considerable potency and the ability to establish and survive in almost any habitat type such as urban and rural environments, particularly in agricultural fields, roadsides, abandoned yards, and construction sites. Despite the worldwide distribution and extent of *Artemisia*, it is worth recognising that this plant is native to Europe, North America (US and Canada), South America (Brazil), Southeast Asia, South Africa, and the Pacific Islands. Although *Artemisia* is adaptable to a wide range of temperatures, its preferred environment is moist soil. The ability of a species to adapt and survive in both warm and cool environments provides a highly valuable defence mechanism against extinction. The distribution and vegetative and reproductive development of these plants are influenced by geographical location, local climate, and prevailing meteorological conditions (Anibogwu et al., 2021; Lu et al., 2022).

Artemisia plants have the ability to produce valuable bioactive secondary metabolites like artemisinin and essential oil, which can help control pests and microbes and also have medicinal properties. However, the global demand for these metabolites is not being met due to the limited commercial production. Therefore, there is a pressing need to find ways to increase the production of these bioactive compounds (Sayed, Ahmed, 2022). Secondary metabolites are vital compounds for the growth and survival of plants, and they also contribute significantly to the economic value of plants. These compounds are important in helping plants adapt to environmental stressors, both biotic and abiotic in nature (Jansen et al., 2008).

Artemisia has a wide range of bioactivity as a result of many active ingredients or secondary metabolites that act in a variety of ways (Nigam et al., 2019). The images of four *Artemisia* species found in

Lithuania, *A. absinthium*, *A. campestris*, *A. vulgaris*, and *A. dubia*, are shown in Figure 2.

A. absinthium is a plant that grows as a shrub with a stem that is hairy and ribbed. Its leaves are cut into spreading linear-lanceolate segments that are obtuse and hairy on both surfaces (Ahamad et al., 2019). *A. absinthium*, also known as wormwood, is a plant with antimicrobial and antifungal properties. This plant is a rich source of natural bioactive compounds such as phenols and flavonoids (Singh et al., 2012).

Figure 2. Four species of *Artemisia* found in Lithuania: *A. absinthium* (A), *A. campestris* (B), *A. vulgaris* (C), and *A. dubia* (D)

A. campestris is a perennial plant and covered with tomentum. It does not have a noticeable scent and has upright, ovoid-shaped anthodia that are attached directly to the stem (Trifan et al., 2022). *A. campestris* is widely used in folk medicine due to its antioxidant, antidiabetic, nutritional, and edible properties (Zahnit et al., 2022).

A. vulgaris is a herbaceous plant that can reach a height of 2.5 m and a width of 75 cm. It has an intense aroma that is easily released when the leaves are crushed. The common mugwort, scientifically known as *A. vulgaris* L., has a great historical importance in medicine and was called the "mother of herbs" in the Middle Ages. This herbaceous plant is widespread and exhibits considerable variations in morphology and phytochemistry depending on its geographical location. It is widely recognised worldwide. *A. vulgaris* herb contains essential oils, flavonoids, and sesquiterpenoid lactones, which are associated with various biological activities making it a valuable raw material (Ekiert et al., 2020).

A. dubia has been chosen as one of the most promising energy crops. In Lithuanian conditions, it produces a high yield – up to 27.6 tons of dry matter per hectare. Researchers have reported the antimicrobial and antioxidant potential and allelopathic properties of this plant (Juteau et al., 2002; Tilvikiene et al., 2015; Černiauskienė et al., 2018).

The genus *Artemisia* is a valuable plant with the ability to survive harsh environmental conditions and produce bioactive secondary metabolites with medicinal properties. These compounds help the plant adapt to environmental stressors and have historically been used in the treatment of various health issues. Different species of *Artemisia* have varying properties and uses. The plant has a significant historical importance in medicine and promising applications in sustainable agriculture, energy, and medicine. However, there is a need to increase the production of these bioactive compounds to meet the global demand.

Beneficial activity of *Artemisia* medicinal plant extracts

The secondary metabolism of medicinal plants has a great importance in their noticeable functional properties. The approximate number of plant secondary metabolites is estimated at 500,000, but only a limited number of them have been studied and identified. Among the many fascinating aspects of biodiversity, natural biodiversity represents numerous untapped opportunities for discovering novel secondary plant metabolites. Plants produce secondary metabolites as a means of defence and to control defence-related signalling pathways to protect themselves from herbivores (Salmerón-Manzano et al., 2020; Divekar et al., 2022). There are beneficial relationships between endophytic bacteria and medicinal plants. Endophytic bacteria can play an important role in modulating the production of bioactive compounds used for medicinal purposes (Wu et al., 2021).

Artemisia plants are known to produce a wide variety of bioactive compounds such as sesquiterpene lactones, flavonoids, phenolic acids, and essential oils, which have different biological activities such as antimicrobial, antiviral, antioxidant, and anticancer properties. *Artemisia* compounds have been shown to possess antimicrobial activity against various microorganisms such as bacteria, fungi, and viruses. However, the type and extent of antimicrobial activity can vary depending on the species of *Artemisia* and the specific compound being tested. Additionally, different species of *Artemisia* may have different biological functional properties. In recent years, the bioactive compounds of *Artemisia* have received increasing attention due to their potential applications in pharmaceuticals, cosmetics, and agricultural products as natural alternatives to synthetic chemicals (Nigam et al., 2019; Mohammed et al., 2022). Artemisinin is a naturally occurring bioactive compound obtained from the leaves of the *Artemisia annua* plant (Anibogwu et al., 2021).

Different factors such as genotype, plant health, location, climatic variables, and growth stage have been discovered to influence the composition of *Artemisia* plant extracts. The natural habitats of *A. absinthium* are found in North and South Africa and Australia. Different parts of this plant have a wide range of bioactive compounds with antiparasitic properties (Ahamad et al., 2019; Khan et al., 2022). Nineteen phenolic compounds were identified from aqueous and ethanolic leaf extracts of *A. absinthium*. It was shown that extracts can be successfully used as effective biostimulants in soybean cultivation and could modulate the defence system of soybean plants. The results of the study indicate that the extracts obtained from *A. absinthium* resulted in a higher yield in farming, which can be explained by the incorporation of phenolic compounds, along with micro- and macroelements (Szparaga et al., 2021). The antioxidant and antimicrobial effects of *A. scoparia* and *A. absinthium* have been confirmed in studies conducted to determine the constituents of essential oils obtained from their leaves (Khan et al., 2022). The potential of allelopathic plants like *A. absinthium* is significant in sustainable and ecological agriculture, as they could control weeds, insects, or pests, while also promoting the growth and development of crops. This makes them a valuable agricultural asset (Majeed et al., 2012).

A. campestris is a fragrant perennial herb found in southern Tunisia. In traditional medicine, the leave extracts of this plant are commonly used for their antimicrobial properties (Nigam et al., 2019). The biofungicidal activity of *A. campestris* extracts on *Fusarium graminearum* was reported by Houicher et al. (2016). The chemical compounds of volatile oil from *A. campestris* have an allelopathic potential against four species: *Daucus carota*, *Cicer arietinum*, *Phaseolus vulgaris*, and *Triticum sativum* (Dhifi et al., 2017). The aqueous leaf extracts of *A. absinthium* reduced the germination percentage of weed seeds such as *Parthenium hysterophorus* (Kapoor et al., 2019). The antibacterial activity of the ethyl acetate extract of *A. absinthium* and *n*-hexane of *A. annua* was studied by researchers (Mohammed et al., 2022). They inhibited the growth of bacterial strains such as S*taphylococcus aureus*, *Salmonella enteritidis*, *Klebsiella pneumoniae*, and *Escherichia coli* in various levels.

A. vulgaris is widespread and well-known for its extremely high concentration of artemisinin. A study on the antibacterial and antifungal activity of different solvent extracts (ethanol, methanol, and hexane) of *A. absinthium*, *A. annua*, and *A. vulgaris* against gram-positive and gram-negative bacteria and one fungal strain highlighted the higher antifungal and antibacterial activity of *A. annua* alcoholic extracts when compared to other species (Poiată et al., 2009; Ekiert et al., 2020). *A. vulgaris* extracts can stimulate potato growth and increase chlorophyll *a* and *b* content in potatoes, therefore, suggesting that it could be used as a novel biostimulant in sustainable agriculture (Findura et al., 2020). *A. vulgaris* essential oil is known to be a strong toxicant that inhibits the growth, development, and reproduction of insects and show insecticidal activity (Gao et al., 2020).

The insecticidal properties and repellent activity of *A. dubia* essential oil and extracts against pests have been reported by researchers, and the investigation of their mechanism of action survey explained their effect on stomach toxicity, contact toxicity, and antifeeding activity of insects. Researchers suggest that *A. dubia* has the potential to be used as a biopesticide (Liang et al., 2018). The study of the effect of aqueous extracts from different plant parts (roots, stems, and leaves) of *A. dubia* on seed germination of some winter crops such as *Triticum aestivum*, *Brassica campestris*, and several related weeds such as *Bidens pilosa*, *Ageratum conyzoides*, and *Galinsoga parviflora* highlighted the allelopathic effect and herbicidal properties of this plant extract on weed germination and seedling growth (Mallik et al., 2015).

Researchers have investigated the toxicity and physiological effect of essential oil obtained from *A. annua* on *Glyphodes pyloalis*, a type of the insect pest that affects mulberry plants. The results of the study show that the essential oil can be a safe and effective alternative to synthetic pesticides in the control of this pest (Oftadeh et al., 2021).

The secondary metabolism of medicinal plants has a vital influence on their functionality, and the diversity of flora offers opportunities for discovering new secondary metabolites. *Artemisia* plants are known for their various bioactive compounds, which exhibit different biological activities. However, the efficacy of antimicrobial activity may vary depending on the species of *Artemisia* and the specific compound used. Several factors such as genotype, plant health, location, climatic variables, and growth stage influence the composition of *Artemisia* plant extracts. Applications of these plant extracts in increasing plant productivity need to be further investigated.

Endophytic bacteria of *Artemisia* spp.

Endophytes are microorganisms including bacterial and fungal species that colonise internal plant tissues without any side effects or diseases in host plants. They are generally considered to play a crucial role in host adaptation to biotic stresses and adverse environmental conditions (Perreault, Laforest-Lapointe, 2022). Endophytic bacteria refer to a category of bacteria that inhabit and grow inside plants providing several benefits to host plants under normal and challenging conditions. These bacteria enhance nutrient uptake and regulate growth and stress-related phytohormones thus directly benefitting the host plants. Additionally, they help in improving plant health indirectly by using antibiotics, hydrolytic enzymes, nutrient limitation, and priming plant defences to target pests and pathogens (Afzal et al., 2019). The variety and population composition of endophytic bacteria is now being discovered through molecular analysis and the sequencing of whole or different parts of their genomes. A common sequencing method is 16S ribosomal RNA (rRNA) sequencing, which is used to identify and classify endophytic bacteria. Most endophytic bacteria belong to Proteobacteria, Actinobacteria, Firmicutes, and Bacteroidetes phyla, which are some of the most common bacterial phyla found in plant-associated microbial communities.

Some endophytic bacteria have an effective influence on the ecological and evolutionary function of plants. It has been discovered that medicinal plants can be strongly influenced by their interactions with specific bacterial endophytes. The genetic traits and health status of the host plant influence the endophytic bacteria's distribution and population structure (Cernava, Berg, 2022). Furthermore, endophytic microbiomes have been considered a source of bioactive metabolites to improve sustainable agriculture as well as to mitigate the effect of global climate change. Any changes in the diversity of plant endophytic communities can have a significant impact on plant growth regulation and environmental adaptation (Alibrandi et al., 2020). Endophytic bacteria can significantly change the production and concentration of secondary metabolites in various areas of medicinal plants or promote their production and based on that find different biological applications. Endophytes have been studied for a variety of purposes from investigating their interaction with host plants and effects on plant and soil health (Raimi, Adeleke, 2021; Masocha et al., 2022).

The endophytic bacteria have the ability to solubilise phosphates making them more readily available to the plant, which can increase plant growth and productivity. They could synthesise and release compounds such as indole-3-acetic acid (IAA), which is a plant hormone that can stimulate root growth and development. This hormone can also help the plant to tolerate abiotic stresses such as drought and salinity. In addition, endophytic bacteria can produce siderophores, which are iron-chelating compounds that compete for iron with pathogens. This can help the plant to resist pathogen attack and increase its ability to tolerate biotic stress (Xia et al., 2022).

Endophytic bacteria isolated from *A. annua* belonged to different genera within four phyla, Proteobacteria, Firmicutes, Actinobacteria, and Bacteroidetes, which have been found to stimulate plant growth by producing IAA and 1-aminocyclopropane-1-carboxylate (ACC), and nitrogen fixation. The most common bacterial phyla found in *A. annua* are Proteobacteria and Firmicutes. Two of the identified bacterial endophytes, isolated from *A. annua*, *Bacillus selenatarsenatis*, and *Achromobacter xylosoxidans*, significantly improved seed germination in pot trials. In addition, some bacterial strains belonging to *Actinobacteria* phyla demonstrated promising antimicrobial activities. These results suggest that the identified endophytic bacteria can potentially be used as biofertilisers and biocontrol agents in agricultural practices to enhance plant growth and productivity while reducing the use of chemical fertilisers and pesticides (Husseiny et al., 2021). Different endophytic bacteria were isolated from different parts of *A. annua*: *Agrobacterium*, *Pasteurella*, *Pseudomonas*, and *Flavobacterium* species from roots (Liu et al., 2011), *Bacillus*, *Pseudomonas*, *Pasteurella*, and *Pantoea* species from leaves (Liu et al., 2011), and *Bacillus subtilis*, *Bacillus licheniformis*, *Bacillus sonorensis*, *Bacillus tequilensis*, *Burkholderia* spp., and *Acinetobacter pittii* from seeds (Tripathi et al., 2020).

B. subtilis and *Stenotrophomonas* spp., which are isolated from the roots of *A. annua*, were discovered to enhance the absorption of nitrogen and phosphorus by the plant and stimulate the growth of shoots and leaves (Awasthi et al., 2011). The endophytic *Pseudonocardia* spp. strain YIM 63111 was obtained from the sterilised tissue of the medicinal plant *A. annua*. It has been demonstrated that this endophytic actinobacteria effectively improves artemisinin biosynthesis in *A. annua*. Thus, the use of the *Pseudonocardia* spp. strain YIM 63111 was suggested as a promising strategy for increasing artemisinin production in plants (Li et al., 2012). The researchers reported a positive activity of endophytic bacteria isolated from *A. annua* on the growth inhibition of *Cercospora janseana* that causes narrow brown spots in rice (Anjani, Yunus, 2019).

Table. Endophytic bacteria of *Artemisia* spp. and their activities

Species	Isolated endophytic bacteria	Activity	References
Artemisia annua	*Bacillus selenatarsenatis* *Achromobacter xylosoxidans*	Improve seed germination	Husseiny et al., 2021
	B. subtilis *Stenotrophomonas* spp.	Promote the growth of shoots and leaves	Awasthi et al., 2011
	Pseudonocardia spp.	Increase artemisinin production in plants	Li et al., 2012
Artemisia nilagirica	*Chromobacterium violaceum* *Burkholderia* spp.	Antibacterial properties	Ashitha et al., 2019

A. nilagirica includes a wide range of endophytic bacteria; *Chromobacterium violaceum* and *Burkholderia* spp. can produce bioactive compounds with antibacterial properties (Ashitha et al., 2019).

The endophytic bacteria isolated from *Artemisia* sp. and their activities are presented in the Table.

Artemisia species have been shown to contain a high diversity of endophytic microorganisms. This diversity may provide a wider range of bioactive compounds that could be useful for agricultural and pharmaceutical purposes. The unique chemical composition of *Artemisia* plants can promote the growth of specific endophytes that produce bioactive compounds with desirable properties.

Auxins have a signalling role in facilitating communication between plants and microbes. Some endophytic microbes have been found to produce IAA, which is important for root growth, cell enlargement and division. The production of IAA by endophytic microbes is thought to be an important factor that contributes to the expansion of cotyledon cells, increased yield, more root tips, longer roots, and greater root surface area during the growth of seedlings and plants (Yousef, 2018; Choudhury et al., 2021). The importance of endophytic inoculants in improving of plant growth is well known, and a wide range of research has been done on different plants. However, there is limited knowledge about the endophytic bacteria associated with different species of *Artemisia*, their beneficial effect on plant and the mechanism of action. According to the reported research, most of the endophytic bacteria isolated from *Artemisia* spp. belong to the genus *Bacillus* and most of the past research has focused on *A. annua*. Extensive studies were done on plant extracts of different species of *Artemisia* spp. that confirm the potential of this plant for utilisation in sustainable agriculture. Endophytic bacteria and *Artemisia* plant extracts can have a positive effect on plant growth and stress tolerance, and their combination can provide even greater benefits to agricultural plants.

Conclusion

The biochemical activities of plant bacteria are diverse, and there is limited research on the isolation and biological activity of endophytic bacteria from different species of *Artemisia* L. (mugwort) medicinal plants.

Further research is needed to determine the functional diversity of isolated endophytic bacteria from various plant sections and their significance as plant growth stimulators and regulators of bioactive compound production. Discovering endophytic bacteria associated with *Artemisia* spp. can potentially increase secondary metabolite pro duction in medicinal plants and improve sustainable agricultural practices and crop productivity.

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References

Afzal I., Shinwari Z. K., Sikandar S., Shahzad S. 2019. Plant beneficial endophytic bacteria: Mechanisms, diversity, host range and genetic determinants. Microbiological Research, 221: 36–49. https://doi.org/10.1016/j.micres.2019.02.001

Ahamad J., Mir S. R., Amin S. A. 2019. Pharmacognostic review on *Artemisia absinthium*. International Research Journal of Pharmacy, 10: 25–31. https://doi.org/10.7897/2230-8407.10015

Alibrandi P., Schnell S., Perotto S., Cardinale M. 2020. Diversity and structure of the endophytic bacterial communities associated with three terrestrial orchid species as revealed by 16S rRNA gene metabarcoding. Frontiers in Microbiology, 11: 604964. https://doi.org/10.3389/fmicb.2020.604964

Anibogwu R., Jesus K., Pradhan S., Pashikanti S., Mateen S., Sharma K. 2021. Extraction, isolation, and characterization of bioactive compounds from *Artemisia* and their biological significance: A review. Molecules, 26 (22): 6995. https://doi.org/10.3390/molecules26226995

Anjani K., Yunus H. A. 2019. Endophytic bacteria of *Artemisia* as biological control agent for *Cercospora* leaf spot in paddy. AGRI BIO Research Publication, 35 (2): 320–324.

Ashitha A., Midhun S. J., Sunil M. A., Nithin T. U., Radhakrishnan E. K., Mathew J. 2019. Bacterial endophytes from *Artemisia nilagirica* (Clarke) Pamp., with antibacterial efficacy against human pathogens. Microbial Pathogenesis, 135: 103624. https://doi.org/10.1016/j.micpath.2019.103624

Awasthi A., Bharti N., Nair P., Singh R., Shukla A. K., Gupta M. M., Darokar M. P., Kalra A. 2011. Synergistic effect of *Glomus mosseae* and nitrogen fixing *Bacillus subtilis* strain Daz26 on artemisinin content in *Artemisia annua* L. Applied Soil Ecology, 49: 125–130. https://doi.org/10.1016/j.apsoil.2011.06.005

Baez-Rogelio A., Morales-García Y. E., Quintero-Hernández V., Muñoz-Rojas J. 2016. Next generation of microbial inoculants for agriculture and bioremediation. Microbial Biotechnology, 10 (1): 19–21. https://doi.org/10.1111/1751-7915.12448

Castronovo L. M., Vassallo A., Mengoni A., Miceli E., Bogani P., Firenzuoli F., Fani R., Maggini V. 2021. Medicinal plants and their bacterial microbiota: A review on antimicrobial compounds production for plant and human health. Pathogens, 10 (2): 106. https://doi.org/10.3390/pathogens10020106

Cernava T., Berg G. 2022. The emergence of disease-preventing bacteria within the plant microbiota. Applied and Environmental Microbiology, 24 (8): 3259–3263. https://doi.org/10.1111/1462-2920.15896

Černiauskienė Z., Raila A. J., Zvicevičius E., Kadžiulienė Z., Tilvikienė V. 2018. Analysis of *Artemisia dubia* Wall. growth, preparation for biofuel and thermal conversion properties. Renewable Energy Journal, 118: 468–476. https://doi.org/10.1016/j.renene.2017.11.024

Choudhury A. R., Choi J., Walitang D. I., Trivedi P., Lee Y., Sa T. 2021. ACC deaminase and indole acetic acid producing endophytic bacterial co-inoculation improves physiological traits of red pepper (*Capsicum annum* L.) under salt stress. Journal of Plant Physiology, 267: 153544. https://doi.org/10.1016/j.jplph.2021.153544

Dhifi W., Ben Haj Jilani I., Bellili S., Jazi S., El Beyrouthy M., Mnif W. 2017. Essential oil chemical characterization and allelopathic potential of *Artemisia campestris* L. growing in Tunisia. Journal of Microbiology, Biotechnology and Food Sciences, 7 (3): 302–305. https://doi.org/10.15414/jmbfs.2017/18.7.3.302-305

Divekar P. A., Narayana S., Divekar B. A., Kumar R., Gadratagi B. G., Ray A., Singh A. K., Rani V., Singh V., Singh A. K., Kumar A., Singh R. P., Meena R. S., Behera T. K. 2022. Plant secondary metabolites as defense tools against herbivores for sustainable crop protection. International Journal of Molecular Sciences, 23 (5): 2690. https://doi.org/10.3390/ijms23052690

Ekiert H., Pajor J., Klin P., Rzepiela A., Ślesak H., Szopa A. 2020. Significance of *Artemisia vulgaris* L. (common mugwort) in the history of medicine and its possible contemporary applications substantiated by phytochemical and pharmacological studies. Molecules (Basel, Switzerland), 25 (19): 4415. https://doi.org/10.3390/molecules25194415

Findura P., Kocira S., Hara P., Pawłowska A., Szparaga A., Kangalov P. 2020. Extracts from *Artemisia vulgaris* L. in potato cultivation preliminary research on biostimulating effect. Agriculture, 10: 356. https://doi.org/10.3390/agriculture10080356

Gao S., Zhang K., Wei L., Wei G., Xiong W., Lu Y., Zhang Y., Gao A., Li B. 2020. Insecticidal activity of *Artemisia vulgaris* essential oil and transcriptome analysis of *Tribolium castaneum* in response to oil exposure. Frontiers in Genetics, 11: 589. https://doi.org/10.3389/fgene.2020.00589

Houicher A., Hechachna H., Özogul F. 2016. *In vitro* determination of the antifungal activity of *Artemisia campestris* essential oil from Algeria. International Journal of Food Properties, 19 (8): 1749–1756. https://doi.org/10.1080/10942912.2015.1107734

Husseiny S., Dishisha T., Soliman H. A., Adeleke R., Raslan M. 2021. Characterization of growth promoting bacterial endophytes isolated from *Artemisia annua* L. South African Journal of Botany, 143: 238–247. https://doi.org/10.1016/j.sajb.2021.07.042

Ivănescu B., Burlec A. F., Crivoi F., Roșu C., Corciovă A. 2021. Secondary metabolites from *Artemisia* genus as biopesticides and innovative nano-based application strategies. Molecules, 26: 3061. https://doi.org/10.3390/molecules26103061

Jansen M. A. K., Hectors K., O'Brien N. M., Guisez Y., Potters G. 2008. Plant stress and human health: Do human consumers benefit from UV-B acclimated crops? Plant Science, 175: 449–458. https://doi:10.1016/j.plantsci.2008.04.010

Juteau F., Masotti V., Bessière J. M., Dherbomez M., Viano J. 2002. Antibacterial and antioxidant activities of *Artemisia annua* essential oil. Fitoterapia, 73 (6): 532–535. https://doi.org/10.1016/S0367-326X(02)00175-2

Kapoor D., Rinzim, Tiwari A., Sehgal A., Landi M., Brestic M., Sharma A. 2019. Exploiting the allelopathic potential of aqueous leaf extracts of *Artemisia absinthium* and *Psidium guajava* against *Parthenium hysterophorus*, a widespread weed in India. Plants, 8 (12): 552. https://doi.org/10.3390/plants8120552

Khan A. L., Gilani S. A., Waqas M., Al-Hosni K., Al-Khiziri S., Kim Y. H., Ali L., Kang S. M., Asaf S., Shahzad R., Hussain J., Lee I. J., Al-Harrasi A. 2017. Endophytes from medicinal plants and their potential for producing indole acetic acid, improving seed germination, and mitigating oxidative stress. Zhejiang University Science, 18 (2): 125–137. https://doi.org/10.1631/jzus.B1500271

Khan F. A., Khan N. M., Ahmad S., Nasruddin Aziz R., Ullah I., Almehmadi M., Allahyani M., Alsaiari A. A., Aljuaid A. 2022. Phytochemical profiling, antioxidant, antimicrobial and cholinesterase inhibitory effects of essential oils isolated from the leaves of *Artemisia scoparia* and *Artemisia absinthium*. Pharmaceuticals, 15 (10): 1221. https://doi.org/10.3390/ph15101221

Lacava P. T., Bogas A. C., Cruz F. D. 2022. Plant growth promotion and biocontrol by endophytic and rhizospheric microorganisms from the tropics: A review and perspectives. Frontiers in Sustainable Food Systems, 6: 796113. https://doi.org/10.3389/fsufs.2022.796113

Li J., Zhao G. Z., Varma A., Qin S., Xiong Z., Huang H. Y., Zhu W. Y., Zhao L. X., Xu L. H., Zhang S., Li W. J. 2012. An endophytic *Pseudonocardia* species induces the production of artemisinin in *Artemisia annua*. PLoS ONE, 7 (12): e51410. https://doi.org/10.1371/journal.pone.0051410

Liang J. Y., Guo S. S., Zhang W. J., Geng Z. F., Deng Z. W., Du S. S., Zhang J. 2018. Fumigant and repellent activities of essential oil extracted from *Artemisia dubia* and its main compounds against two stored product pests. Natural Product Research, 32 (10): 1234–1238. https://doi.org/10.1080/14786419.2017.1331227

Liu J. H., Wu L. F., Zhang H. W. 2011. Isolation and preliminary identification of endophytes from *Artemisia annua* Linn. Amino Acids Biotic Resources, 33 (4): 27–30. https://doi.org/10.14188/j.ajsh.2011.04.004

Lu L. L., Jiao B. H., Qin F., Xie G., Lu K.-Q., Li J.-F. Sun B., Li M., Ferguson D. K., Gao T.-G., Yao Y.-F., Wang Y.-F. 2022. *Artemisia* pollen dataset for exploring the potential ecological indicators in deep time. Earth System Science Data, 14 (9): 3961–3995. https://doi.org/10.5194/essd-14-3961-2022

Majeed A., Chaudhry Z., Muhammad Z. 2012. Allelopathic assessment of fresh aqueous extracts of *Chenopodium album* L. for growth and yield of wheat (*Triticum aestivum* L.). Pakistan Journal of Botany, 44 (1): 165–167.

Mallik B. D., Acharya B. D., Saquib M., Chettri M. K. 2015. Allelopathic effect of *Artemisia dubia* extracts on seed germination and seedling growth of some weeds and winter crops. Ecoprint: An International Journal of Ecology, 21: 23–30. https://doi.org/10.3126/eco.v21i0.11901

Masocha V. F., Liu H., Zhan P., Wang K., Zeng A., Shen S., Schneider H. 2022. Bacterial microbiome in the phyllo-endosphere of highly specialized rock spleenwort. Frontiers in Plant Science, 13: 891155. https://doi.org/10.3389/fpls.2022.891155

Mohammed S., Dekabo A., Hailu T. 2022. Phytochemical analysis and anti-microbial activities of *Artemisia* spp. and rapid isolation methods of artemisinin. AMB Express Journal, 12: 17. https://doi.org/10.1186/s13568-022-01346-5

Nigam M., Atanassova M., Mishra A. P., Pezzani R., Devkota H. P., Plygun S., Salehi B., Setzer W. N., Sharifi-Rad J. 2019. Bioactive compounds and health benefits of *Artemisia* species. Natural Product Communications, 14 (7). https://doi.org/10.1177/1934578X19850354

Oftadeh M., Sendi J. J., Ebadollahi A., Setzer W. N., Krutmuang P. 2021. Mulberry protection through flowering-stage essential oil of *Artemisia annua* against the lesser mulberry pyralid, *Glyphodes pyloalis* Walker. Foods, 10: 210. https://doi.org/10.3390/foods 100202

Perreault R., Laforest-Lapointe I. 2022. Plant-microbe interactions in the phylalosphere: Facing challenges of the anthraxocene. International Society for Microbial Ecology, 16: 339–345. https://doi.org/10.1038

Poiată A., Tuchiluș C., Ivănescu B., Ionescu A., Lazăr M. I. 2009. Antibacterial activity of some *Artemisia* species extract. Revista Medico-Chirurgicala, 113 (3): 911–914. PMID: 20191854

Prasad M., Srinivasan R., Chaudhary M., Mahawer S. M., Jat L. K. 2020. Endophytic bacteria: Role in sustainable agriculture. Microbial Endophytes, 2020: 37–60. https://doi.org/10.1016/B978-0-12-818734-0.00003-6

Raimi A., Adeleke R. 2021. Bioprospecting of endophytic microorganisms for bioactive compounds of therapeutic importance. Archives of Microbiology, 203 (5): 1917–1942. https://doi.org/10.1007/s00203-021-02256-z

Salmerón-Manzano E., Garrido-Cardenas J. A., Manzano-Agugliaro F. 2020. Worldwide research trends on medicinal plants. International Journal of Environmental Research and Public Health, 17 (10): 3376. https://doi.org/10.3390/ijerph17103376

Sayed T. E., Ahmed E. 2022. Improving artemisinin and essential oil production from *Artemisia* plant through *in vivo* elicitation with gamma irradiation nano-selenium and chitosan coupled with bio-organic fertilizers. Frontiers in Energy Research, 10: 996253. https://doi.org/10.3389/fenrg.2022.996253

Singh R., Verma P. K., Singh G. 2012. Total phenolic, flavonoids and tannin contents in different extracts of *Artemisia absinthium*. Journal of Intercultural Ethnopharmacology, 1 (2): 101–104. https://doi.org/10.5455/jice.20120525014326

Song X., Wu H., Yin Z., Lian M., Yin C. 2017. Endophytic bacteria isolated from *Panax ginseng* improves ginsenoside accumulation in adventitious ginseng root culture. Molecules, 22: 837–849. https://doi.org/10.3390/molecules22060837

Szparaga A., Kocira S., Kapusta, I., Zaguła G. 2021. Prototyping extracts from *Artemisia absinthium* L. for their biostimulating properties yield-enhancing, and farmer income-increasing properties. Industrial Crops and Products, 160: 113125. https://doi.org/10.1016/j.indcrop.2020.113125

Tilvikiene V., Kadziuliene Z., Raila A., Zvicevicius E., Liaudanskiene I., Volkaviciute Z., Pociene L. 2015. *Artemisia dubia* Wall. A novel energy crop for temperate climate zone in Europe. Proceedings of the 23rd European Biomass Conference and Exhibition. Vienna, Austria, p. 147–150.

Trendafilova A., Moujir L. M., Sousa P. M. C., Seca A. M. L. 2021. Research advances on health effects of edible *Artemisia* species and some sesquiterpene lactones constituents. Foods, 10 (1): 65. https://doi.org/10.3390/foods10010065

Trifan A., Czerwińska M. E., Mardari C., Zengin G., Sinan K. I., Korona-Glowniak I., Skalicka-Woźniak K., Luca S. V. 2022. Exploring the *Artemisia* genus: An insight into the phytochemical and multi-biological potential of *A. campestris* subsp. *lednicensis* (Spreng.) Greuter & Raab-Straube. Plants, 11 (21): 2874. https://doi.org/10.3390/plants11212874

Tripathi A., Awasthi A., Singh S., Sah K., Maji D., Patel V. K., Verma R. K., Kalra A. 2020. Enhancing artemisinin yields through an ecologically functional community of endophytes in *Artemisia annua*. Industrial Crops and Products, 150: 112375. https://doi.org/10.1016/j.indcrop.2020.112375

Tripathi A., Pandey P., Tripathi S. N., Kalra A. 2022. Perspectives and potential applications of endophytic microorganisms in cultivation of medicinal and aromatic plants. Frontiers in Plant Science, 13: 985429. https://doi.org/10.3389/fpls.2022.985429

Wani Z. A., Ashraf N., Mohiuddin T., Riyaz-Ul-Hassan S. 2015. Plant-endophyte symbiosis, an ecological perspective. Applied Microbiology and Biotechnology, 99: 2955–2965. https://doi.org/10.1007/s00253-015-6487-3

Wu W., Chen W., Liu S., Wu J., Zhu Y., Qin L., Zhu B. 2021. Beneficial relationships between endophytic bacteria and medicinal plants. Frontiers in Plant Science, 12: 646146. https://doi.org/10.3389/fpls.2021.646146

Xia Y., Liu J., Chen C., Mo X., Tan Q., He Y., Wang Z., Yin J., Zhou G. 2022. The multifunction and prospects of endophytes and their metabolites in plant disease management. Microorganisms, 10 (5): 1072. https://doi.org/10.3390/microorganisms10051072

Yousef N. M. 2018. Capability of plant growth-promoting rhizobacteria (PGPR) for producing indole acetic acid (IAA) under extreme conditions. European Journal of Biological Research, 8 (4): 174–182. https://doi.org/10.5281/zenodo.1412796

Zahnit W., Smara O., Bechki L., Bensouici C., Messaoudi M., Benchikha N., Larkem I., Awuchi C. G., Sawicka B., Simal-Gandara J. 2022. Phytochemical profiling, mineral elements, and biological activities of *Artemisia campestris* L. grown in Algeria. Horticulturae, 8: 914. https://doi.org/10.3390/horticulturae8100914

Zheng L. P., Li X. P., Zhou L. L., Wang J. W. 2021. Endophytes in *Artemisia annua* L.: New potential regulators for plant growth and artemisinin biosynthesis. Plant Growth Regulation, 95: 293–313. https://doi.org/10.1007/s10725-021-00751-3