Journal of Postharvest Technology
2023, **11**(1): 16-24
www.jpht.in

REVIEW ARTICLE

Synergistic interaction of *Curcuma longa* with its microbiome: a mini review

Verinder Virk*, Himani Deepak, Khushbu Taneja

Department of Microbiology, Kanya Gurukula Campus, Deemed to be University, Haridwar-249407

Received: 28.10.2022 Accepted: 04.01.2023

ABSTRACT

Curcuma longa L., popularly known as Haldi; member of Zingiberaceae family, is one of the most popular and useful herbal medicinal plant. The tremendous research proven that most of the medicinal properties of turmeric are due to the curcumin content in it. Turmeric has other various useful properties such as treatment of wounds, menstrual pain relief, antioxidants, anti-inflammatory, anticancerous, antiulcer, etc. Turmeric healthy rhizomes and roots are continuously in close association with the rhizospheric region and as a result, large number of rhizospheric-associated beneficial microbes interacts with the underground parts of plants. Soil microbes may neutralize the action of flavonoids released from the roots and get entry into the healthy tissues of plants to become endophytes. Rhizospheric and endophytic species either directly or indirectly involved in propounding beneficial impact to the plant. The present review emphasized in order to uncover the mutualistic association of turmeric and its associated microbes. Also the natural products from medicinal plant associated microbes have pharmacological, biological and therapeutic values which might favour mankind in future for drug designing and novel drug formulations.

Keywords: Turmeric, *Curcuma longa*, rhizospheric microbes, endophytes.

Citation: Virk, V., Deepak, H., and Taneja, K. 2023. Synergistic interaction of *Curcuma longa* with its microbiome: a mini review. *Journal of Postharvest Technology,* **11**(1): 16-24.

INTRODUCTION

Plant derived natural products are treasures to humankind since the ages. There are a variety of secondary metabolites produced from plants as a natural defence mechanism against phytopathogen. Medicinal plants play a pivotal role in treatment of variety of ailments. Turmeric, a golden spice, a rhizomateceous herb, derived from the healthy rhizomes of *Curcuma longa* L. turmeric has been used since Ayurveda and is believed to be originated from Southeast Asia. In India, turmeric is popularly known as haldi; haridra in Sanskrit and manjal in south (Kumar et al., 2017). Turmeric is aromatic plant and has flatus-relieving properties. Turmeric has been in use since 2500 years ago as dye and spice. In Ayurvedic system, turmeric is well documented for treatment of hepatic ulcers, antioxidant, treating anorexia, rheumatism, sinusitis, hypotensive, antimutagenic, and antifibrotic (Chattopadhyay et al., 2004). The wonder plant have other preclinical and clinical proven properties such as anti-inflammatory, antidiabetic, antibacterial, antifungal, treatment of Alzheimer's disease, erythrocytopenia, gastrointestinal disorders, wound healing, phlegm removal, etc. In Unani medicinal system, roasted turmeric powder used in liver detoxification (Bhowmik et al., 2022). Turmeric is a sterile plant reaches upto 3 to 6 ft tall with oblonged leaves and cream color flowers. The underground part of plant consists of roots and rhizomes. Rhizome comprises of two parts: mother rhizome and axillary buds or its fingers. Branches arising from mother rhizome can be diagrotropic, arthogeotropic or plagiotropic (Ravindran et al.,

* *For correspondence*: V. Virk (Email: virender.wahla@gkv.ac.in)

ISSN: 2348-4330

2007). Recent advances demonstrated that most of the biological and therapeutical activities of turmeric are due to ar-turmerone, α-turmerone, β-turmerone and essential oils. Curcuminoids and volatile oils may contribute to the proven efficiency of turmeric (Meng et al., 2018). Table 1 showed the various biological activities exhibited by turmeric constituents.

Table 1. Turmeric components and their biological activity.

Compound	Biological Activity	References
Curcumin	Antibacterial, antifungal, antioxidant, antimycobacterial against *M. Smegmtis, M. Simial, M. Kansassi, M. Terrae, M. szulgai*	Cikrikci et al. (2008)
Curcumin	Tick ripelling activity against *Rhipicephalus sanguineus*	Perara et al. (2022)
Turmeric polysaccharides (Glucose, galactose, arabinose components)	Antioxidant activity	Zhu et al. (2021)
Demethoxycurcumin, Bisdemethoxycurcumin	Acetylcholinesterase (AChE) inhibition	Ahmad and Gillani, (2003)
Starch extracted from turmeric powder	Antioxidant, antimicrobial, increased shelf life of food	Maniglia et al. (2022)
Turmeric derived sulfur-functionalized carbon dots	Antioxidant, antibacterial, cytotoxic	Roy et al. (2022)

Medicinal plants are recognized as loaded depository of potent microorganisms associated with host. Rhizospheric microbes interconnect with the root exudates from plants via chemical signal pathways. Microorganisms maintain symbiotic continuum and give rise to complex plant-microbe interaction. This symbiotic regulation resulted into either positive interaction or negative interaction which further causes changes in the genomic structure, metabolism, reproduction, growth pattern and signalling mechanisms of both the involved partners. Microbial partners release small chemical signals, i.e., elicitors which cleave the cell wall of plants and get colonized. These elicitors later trigger plant defence mechanisms in plants, i.e., Plant Triggered Immunity (PTI).

Plant defence response can comprises of microbe-associated molecular patterns (MAMPs), herbivore-associated molecular patterns (HAMPs), pathogen-associated molecular patterns (PAMPs) and damage-associated molecular patterns (DAMPs). Also there are various biotic and abiotic elicitors; bacteria, viruses, fungi, insects, polysaccharides and physical chemical or hormonal factors, which when exposed to plants results in the cascade of signalling pathways for secondary metabolite production (Iman Chankhi et al., 2021).

PGPR ASSOCIATED WITH TURMERIC

Rhizosphere is the most extrusive hotspot for the possible interaction of host and microorganisms. Soil particles adhering to roots and rhizome of *Curcuma longa* usually has higher microbial continuum as compare to the non-rhizospheric soil. Rhizospheric microbial content is qualitatively or quantitatively differ from the total soil bulk. Microcosm of rhizosphere usually metabolizes the rhizo depositions which are rich in carbon compounds, helps the plant combating phytopathogen and act as a biocontrol agent. The successive colonization of beneficial microorganisms produces a variety of secondary metabolites, antibiotics, secretion of extracellular enzyme, siderophores, chelators, etc that limits the bioavailability of nutrients to pathogenic bacteria and fungi. On the other hand, released secondary metabolite also induces resistance to pathogenic strains via increased production of phytoalexins, degradative enzymes and strengthening of epidermal cells (Bending, 2003). Turmeric soil harbours a myriad of nitrogen fixing strains. *Rhizobium pusense* when isolated from the rhizosphere of turmeric shows prominent results in plant growth promoting traits when compared to the control (Chandran, 2018). Kumar et al*. (*2016) reported that *Pseudomonas, Klebsiella*, *Agrobacterium*, *Azotobacter* and *Burkholderia* are the dominant species of turmeric rhizosphere convoluted in plant growth promoting activities. In one study of Sarathambal et al. (2021), inoculation of AM along with the zinc solubilising bacteria have burgeoning effect in enhancing the soil microbial activity of turmeric plant. Application of bioinoculants results in the improved microbial activity which helps to maintain the fertility of soil, plant growth and maintenance of richness of rhizospheric soil. The synergistic action of AM with *Bacillus*, *Chlorflexi*, *Acinetobacteria*, and *Proteobacteria* augment the secretion of phytohormones which later increases the cell signalling cascade. Bacterial species such as *Staphylococcus*, *Pseudomonas*, *Sphingomonas* and *Achromobacter* isolated from the turmeric rhizosphere shoed antagonistic action against pathogenic strains as well as plant growth promoting traits. *Bacillus amyloliquefaciens* found to be effective in suppressing the disease symptoms in the seedlings of *Capsicum annum* (Fassari et al., 2017).

Phosphatase activity in soil plays an important role in phosphorous accumulation by plants. Inoculation of turmeric plant with *Glomus*, *Gigaspora*, *Acaulospora* sp. along with *Bacillus megatherium*, *Azospirillum amazonense* and *Azotobacter* either alone or in consortium found to be enhancing the phosphatase activity in the rhizosphere of turmeric plant (Table 2). It is also reported that bacterial colonization affects the root physiology of plant resulting into the alteration of microbial population in the rhizosphere which later enhances the biomass production (Dutta and Neog, 2017). One of such example of providing PGP traits by rhizospheric bacteria is the production of ACC deaminase enzyme (1-aminocyclopropane-1-carboxylic acid) by *Bacillus* sp. ACC deaminase neutralizes the adverse effects of ACC by lowering its concentration and protects the plant from salinity stress. Increased ACC levels resulted into the increased ethylene synthesis (Carmen Orozco-Masqueda, 2020).

Table 2: Bacteria associated with turmeric rhizosphere and their biological activity

Bacteria	Source	Activity	Reference
Bacillus megatherium, pseudomonas fluorescence, Globicitella sulfidifacein	Turmeric Rhizosphere	Antimicrobial activity against human pathogens *E.coli*, *P. aeruginosa* and *S. aureus*	Mandale et al. (2017)
Azotobacter chroococcum	Turmeric rhizosphere	Enhance production of curcumin, increased IAA, NH_3 production, increased shoot and root length.	Kumar et al. (2014)
Pseudomonas plecglossicida, Stenotrophomonas maltophilia, P. putida, *B. cereus, Enterobacter* sp.	Turmeric rhizosphere	IAA production, HCN production, phosphate solubilisation, siderophores production.	Vinayarani and Praksah (2018)

Endophytes Associated With Turmeric

Endophytes are the microorganisms that colonize the inter/intracellular regions of plants, beneath the epidermal layer without showing any deleterious consequences (Schulz and Boyle, 2006). The heterogeneity of endophytes usually depends on the plant age, type of plant tissue, seasonal and environmental changes. The diversity of endophytic microcosm is less in the endopshere region when compared to the rhizospheric soil (Liu et al., 2014). Also the concentration of endophytes is more in roots as compared to stem and leaf phyllosphere. Plants release root exudates which favours the attraction and colonization of impending microflora. Most of the bacteria and fungi take entry via wounds and natural openings in the root system. However, endophytes always do not enter plants via lateral roots and wounds. They may enter plant cells actively by secretion of extracellular enzyme such as cellulose and pectinase (Gupta et al., 2019).

Bacterial and fungal endophytes of turmeric are treasure house for variety of novel secondary metabolites performing biological activities such as antimicrobial, antioxidant, antiparasitic, immunomodulatory (Ferdous et al., 2019), antibacterial. (Elfita et al., 2022), antioxidant, antidiabetic (Jayant and Vijayakumar, 2021) and immunosuppressive activities (Ujam et al., 2021). Various endophytic bacterial species such as *B. altitudinis*, *B. aryabhattai*, *B. wiedmannii*, *P. aeruginosa*, *Burkholderia gladioli* noted for plant growth promotion activity such as nitrogen assimilation, IAA production, phosphorous solubilisation, and siderophores production (Shah et al., 2022). Other PGPR inoculants currently commercialized for the enhancement of plant height and stalk diameter. Moreover, interactions between plant and PGPR have gained a momentum among researchers in order to identify their pattern of association including turmeric. Similar to plant growth promoting rhizobacteria, endophytic bacteria and fungus also exhibit PGP traits and various biological activities as shown in Table 3.

Table 3: Endophytes from turmeric and their biological activities.

Endophytic fungi	Source	Biological activity	References
Penicillium sp.-AgNPs	Turmeric leaves	Antibacterial activity against *P. aeruginosa, K. pneumonia, Salmonella typhimurium, Enterobacter aerogens*	Singh et al. (2013)
Euratium sp.	Turmeric rhizome	Anticancerous activity	Jalgaonwala and Mahajan (2014)
Arthrobotyric follicola, Fusarium verticilliodes	Turmeric roots	Antibacterial activity against *Morganella morganni*	Septiana et al. (2017)
Phoma herbarrum	Turmeric rhizome	Antifungal activity against *Colletotrichum gloeosporiodes*	Gupta et al. (2016)
Endophytic Bacteria			
B. paramycoides, K. quasipneumoniae, K. pneumoniae, Burkholderia lata, Burkholderia metallica, mycorrhizae fungus	-	Plant growth promotion of white turmeric	Simarmata et al. (2021)
Pseudomonas fluorescens (FP7 and TPF5 strains)	Turmeric rhizome	Antibiotic production	Prabhukarthikeyan et al. (2018)

Literature survey revealed that natural habitat of host plant, plant age, type of plant tissue and medium for isolation also influence the diversity of endophytic bacterial communities. Sulistiyani et al. (2014) reported that majority of the bacterial endophytes isolated from the rhizome (38%) than from stem (32%) and leaves (30%). Most of the isolated endophytes belonging to α-Proteobacteria, β-Proteobacteria, γ-Proteobacteria, firmicutes and actinobacteria. As roots are the primary colonization region for endophytes, so endophytic population must be greater in number. Apart from roots, rhizome part of *C. longa* provides a special habitat for diverse group of fungal and bacterial endophytes. Two potential strains of *Paenibacillus* sp. (ClB1 and ClB2) from rhizome have been involved in the indole acetic acid production and could be served as PGP traits to the turmeric plant (Awasthy et al., 2013).

Rhizome rot disease of turmeric is one of the major problem while cultivation of turmeric plant. *Pythium aphanidermatum* is one of the major phytopathogen responsible for causing rhizome rot disease in healthy turmeric plant. The major symptoms caused by *Pythium* sp. includes the drying up of turmeric leaves, decreases root and shoot length, softening of shoots, and rotted rhizomes. However, bacterial endophytes such as *Bacillus* sp., *Pseudomonas* sp., *Citrobacter* sp., and *Klebsiella* sp. isolated from turmeric rhizome found to be inhibitory against *Pythium aphanidermatum*. Conspicuously, Pseudomonas sp. significantly reduced the rhizome rot disease by the production of HCN, siderophores and salicylic acid (Nandini et al., 2018). Another sustainable and ecofriendly approach for disease free turmeric cultivation is the application of *Pseudomonas fluorescens* against *Pythium aphanidermatum*. Inoculation of *P. fluorescens* resulted into the secretion of defence enzymes and helps in yielding the turmeric biomass production (Prabhukarthikeyan et al., 2018).

Endophytic fungi are known to produce a variety of novel bioactive secondary metabolites such as alkaloids, phenols, flavonoids, quinones, steroids, enzymes, which possess higher therapeutical, pharmaceutical, industrial and agricultural significant values. Endophytic fungi are potent source of variety of biological activities ranging from antimicrobial (Gupta et al., 2022), antioxidant (Gautam et al., 2022), anticancerous (Mittal et al., 2021), salt tolerance (Saravi et al., 2022), heavy metal tolerance (Hassan et al., 2022) and plant growth promoting traits (Rigobello and Baron, 2021). There are various reports of fungal endophytes associated with the different parts of turmeric. In one study of Septiana et al. (2017), 11 endophytic fungal strains were isolated from all parts of *Curcuma longa* including *Arthrobotyris follicola* from roots, *Cochliobolus kusanoi*, and *Fusarium solani* from inflorescence, *Daldinia eschscholzii* from leaf, *Fusarium proliferatum* from stem, *Phaesosphaerica ammophilae*, *F. solani*, *F. proliferatum* and *F. oxysporum* from turmeric rhizome. Bustanussalam et al. (2015) isolated 44 endophytic fungal species from asymptomatic parts of *Curcuma longa* from which only 6 endophytic fungal strains were found active in showing antioxidant activity. Moreover, flavonoids, phenols and its derivatives extracted from the endophytic fungal strains are responsible for their antioxidant potential. (Huang et al., 2007; Zhao et al., 2021).

CONCLUSION AND FUTURE PROSPECTS

The use of traditional medicinal plants in the treatment of variety of human ailments has been exploited since ages. Antimicrobial, antioxidant, antidiabetic, immunomodulatory, cardio protective, anticancerous, nephro protective and nutraceutical properties of turmeric have already been reported. From the last few decades, endophytes from medicinal plants have gained much attention as they mimic the host plant and acquire gene from host for novel bioactive secondary metabolite production. It is noteworthy that endophytes from such medicinal plants are rich source of novel compounds. Though, rhizospheric and endophytic microbial strains associated with turmeric makes them potential candidate for their exploitation in plant growth promoting traits as well as in pharmaceutical and medical fields. Moreover, with increasing population, there are some problems associated with mankind such as drug-resistance, less resources, etc. In order to overcome such problems, endophytic microbes from medicinal plants appears to be an alternative source. Endophytes needed to be explored more that they may be used in management of biotic and abiotic stresses, disease management and a potential source of novel compounds that will help in novel drug discovery.

REFERENCES

Ahmed, T. and Gilani, A.H., 2009. Inhibitory effect of curcuminoids on acetylcholinesterase activity and attenuation of scopolamine-induced amnesia may explain medicinal use of turmeric in Alzheimer's disease. Pharmacology Biochemistry and Behavior, 91(4): 554-559.

Ashfaq, M., Ali, Q., Haleem, A., Ullah, A., Umar, A., Ullah, I. and AHMED, S., 2022. Orange-Brown Pigment Production from an Endophytic Fungus Aspergillus Sp. N11 and its Potential Pharmaceutical Applications.

Aswathy, A.J., Jasim, B., Jyothis, M. and Radhakrishnan, E.K., 2013. Identification of two strains of Paenibacillus sp. as indole 3 acetic acid-producing rhizome-associated endophytic bacteria from Curcuma longa. 3 Biotech, 3(3): 219-224.

Rachman, F., Septiana, E., Lekatompessy, S.J., Widowati, T., Sukiman, H.I. and Simanjuntak, P., 2015. Screening for Endophytic Fungi from Turmeric Plant (Curcuma longa L.) of Sukabumi and Cibinong with Potency as Antioxidant Compounds Producer. Pakistan Journal of Biological Sciences: PJBS, 18(1): 42-45.

Chattopadhyay, I., Biswas, K., Bandyopadhyay, U. and Banerjee, R.K., 2004. Turmeric and curcumin: Biological actions and medicinal applications. Current Science. 44-53.

Cikrikci, S., Mozioglu, E. and Yilmaz, H., 2008. Biological activity of curcuminoids isolated from Curcuma longa. Records of Natural Products, 2(1): 19.

del Carmen Orozco-Mosqueda, M., Glick, B.R. and Santoyo, G., 2020. ACC deaminase in plant growth-promoting bacteria (PGPB): an efficient mechanism to counter salt stress in crops. Microbiological Research, 235: 126439.

Dutta, S.C. and Neog, B., 2016. Accumulation of secondary metabolites in response to antioxidant activity of turmeric rhizomes co-inoculated with native arbuscular mycorrhizal fungi and plant growth promoting rhizobacteria. Scientia Horticulturae, 204: 179-184.

ELFITA, E., WIDJAJANTI, H., SETIAWAN, A. and KURNIAWATI, A.R., 2022. Antibacterial activity of endophytic fungi isolated from the stem bark of jambumawar (Syzygiumjambos). Biodiversitas Journal of Biological Diversity, 23(1).

Ferdous, K.J., Afroz, F., Islam, M.R., Mazid, M.A. and Sohrab, M.H., 2019. Isolated endophytic fungi from the plant Curcuma longa and their potential bioactivity—a review. Pharmacology & Pharmacy, 10(5): 244-270.

Gautam, V.S., Singh, A., Kumari, P., Nishad, J.H., Kumar, J., Yadav, M., Bharti, R., Prajapati, P. and Kharwar, R.N., 2022. Phenolic and flavonoid contents and antioxidant activity of an endophytic fungus Nigrosporasphaerica (EHL2), inhabiting the medicinal plant Euphorbia hirta (dudhi) L. Archives of Microbiology, 204(2): 1-13.

Gupta, A., Verma, H., Singh, P.P., Singh, P., Singh, M., Mishra, V. and Kumar, A., 2019. Rhizome endophytes: roles and applications in sustainable agriculture. In Seed endophytes (405-421). Springer, Cham.

Gupta, S., Choudhary, M., Singh, B., Singh, R., Dhar, M.K. and Kaul, S., 2022. Diversity and biological activity of fungal endophytes of ZingiberofficinaleRosc. with emphasis on Aspergillus terreus as a biocontrol agent of its leaf spot. Biocatalysis and Agricultural Biotechnology, 39: 102234.

Gupta, S., Kaul, S., Singh, B., Vishwakarma, R.A. and Dhar, M.K., 2016. Production of gentisyl alcohol from Phomaherbarum endophytic in Curcuma longa L. and its antagonistic activity towards leaf spot pathogen Colletotrichum gloeosporioides. Applied biochemistry and biotechnology, 180(6): 1093-1109.

Hassan, A., Pariatamby, A., Ossai, I.C., Ahmed, A., Muda, M.A., Barasarathi, J. and Hamid, F.S., 2022. Synergistic association of endophytic fungi enhances tolerance, growth, and heavy metal uptake of Alocasiacalidora in landfill contaminated soil. Applied Soil Ecology, 170: 104307.

Huang, W.Y., Cai, Y.Z., Xing, J., Corke, H. and Sun, M., 2007. A potential antioxidant resource: endophytic fungi from medicinal plants. Economic Botany, 61(1): 14-30.

Jalgaonwala, R.E. and Mahajan, R.T., 2014. Production of anticancer enzyme asparaginase from endophytic Eurotium sp. isolated from rhizomes of Curcuma longa. European Journal of Experimental Biology, 4(3): 36-43.

Jayant, K.K. and Vijayakumar, B.S., 2021. In-Vitro anti-oxidant and anti-diabetic potential of endophytic fungi associated with Ficus religiosa. Italian Journal of Mycology, 50: 10-20.

Kumar, A., Singh, A.K., Kaushik, M.S., Mishra, S.K., Raj, P., Singh, P.K. and Pandey, K.D., 2017. Interaction of turmeric (Curcuma longa L.) with beneficial microbes: a review. 3 Biotech, 7(6): 1-8.

Kumar, A., Singh, R., Giri, D.D., Singh, P.K. and Pandey, K.D., 2014. Effect of Azotobacterchroococcum CL13 inoculation on growth and curcumin content of turmeric (Curcuma longa L.). International Journal of Current Microbiology and Applied Sciences, 3(9): 275-283.

Kumar, A., Singh, R., Yadav, A., Giri, D.D., Singh, P.K. and Pandey, K.D., 2016. Isolation and characterization of bacterial endophytes of Curcuma longa L. 3 Biotech, 6(1): 1-8.

Kuttan, R., Bhanumathy, P., Nirmala, K. and George, M.C., 1985. Potential anticancer activity of turmeric (Curcuma longa). Cancer Letters, 29(2): 197-202.

Mandale, S.D., Dagar, V. and Dagar, V., 2017. Antimicrobial activity of rhizospheric bacteria of Curcuma longa (Turmeric) producing metabolites against human pathogens. Journal of Pharmacy and Biological Sciences, 12: 37-42.

Maniglia, B.C., Silveira, T.M.G. and Tapia-Blácido, D.R., 2022. Starch isolation from turmeric dye extraction residue and its application in active film production. International Journal of Biological Macromolecules, 202: 508-519.

Meng, F.C., Zhou, Y.Q., Ren, D., Wang, R., Wang, C., Lin, L.G., Zhang, X.Q., Ye, W.C. and Zhang, Q.W., 2018. Turmeric: A review of its chemical composition, quality control, bioactivity, and pharmaceutical application. Natural and Artificial Flavoring Agents and Food Dyes, 299-350.

Mittal, L., Akther, T., Camarillo, I.G. and Sundararajan, R., 2021. Turmeric-silver-nanoparticles for effective treatment of breast cancer and to break CTX-M-15 mediated antibiotic resistance in Escherichia coli. Inorganic and Nano-Metal Chemistry, 51(6): 867-874.

Nandini, M., Ruth, C. and Gopal, K., 2018. In vivo screening of turmeric (Curcuma longa L.) germplasm of different duration groups against rhizome rot caused by Pythium and Fusarium spp. International Journal Of Plant Sciences, 13(1): 26-34.

Passari, A.K., Lalsiamthari, P.C., Leo, V.V., Mishra, V.K., Yadav, M.K., Gupta, V.K. and Singh, B.P., 2018. Biocontrol of Fusarium wilt of Capsicum annuum by rhizospheric bacteria isolated from turmeric endowed with plant growth promotion and disease suppression potential. European Journal of Plant Pathology, 150(4): 831-846.

Perera, W.J., Senadeera, P., Perera, P.P. and Kulatunge, D.R., 2022. Identification of Extracts Responsible for the Effect of Tick Reppeling Activity of Turmeric. Open Journal of Applied Sciences, 12(1): 51-58.

Prabhukarthikeyan, S.R., Keerthana, U. and Raguchander, T., 2018. Antibiotic-producing Pseudomonas fluorescens mediates rhizome rot disease resistance and promotes plant growth in turmeric plants. Microbiological Research, 210: 65-73.

Ravindran, P.N., Babu, K.N. and Sivaraman, K., 2007. Turmeric: the genus Curcuma. CRC press.

Baron, N.C. and Rigobelo, E.C., 2022. Endophytic fungi: a tool for plant growth promotion and sustainable agriculture. Mycology, 13(1): 39-55.

Roy, S., Ezati, P., Rhim, J.W. and Molaei, R., 2022. Preparation of turmeric-derived sulfur-functionalized carbon dots: antibacterial and antioxidant activity. Journal of Materials Science, 57(4): 2941-2952.

Sarathambal, C., Dinesh, R., Srinivasan, V., Sheeja, T.E., Jeeva, V. and Manzoor, M., 2022. Changes in Bacterial Diversity and Composition in Response to Co-inoculation of Arbuscular Mycorrhizae and Zinc-Solubilizing Bacteria in Turmeric Rhizosphere. Current Microbiology, 79(1): 1-9.

Saravi, H.B., Gholami, A., Pirdashti, H., Firouzabadi, M.B., Asghari, H. and Yaghoubian, Y., 2022. Improvement of salt tolerance in Stevia rebaudiana by co-application of endophytic fungi and exogenous spermidine. Industrial Crops and Products, 177: 114443.

Septiana, E., Sukarno, N. and Simanjuntak, P., 2017. Endophytic fungi associated with turmeric (Curcuma longa L.) can inhibit histamine-forming bacteria in fish. HAYATI Journal of Biosciences, 24(1): 46-52.

Shah, D., Khan, M.S., Aziz, S., Ali, H. and Pecoraro, L., 2021. Molecular and biochemical characterization, antimicrobial activity, stress tolerance, and plant growth-promoting effect of endophytic bacteria isolated from wheat varieties. Microorganisms, 10(1): 21.

Simarmata, R., Nurjanah, L., Sylvia, J.R.L. and Widowati, T., 2021, May. The role of endophytic bacteria and mycorrhizae fungus as plant growth inducer of white turmeric. In IOP Conference Series: Earth and Environmental Science, 759(1): 012025). IOP Publishing.

Singh, D., Rathod, V., Ninganagouda, S., Herimath, J. and Kulkarni, P., 2013. Biosynthesis of silver nanoparticle by endophytic fungi Pencillium sp. isolated from Curcuma longa (turmeric) and its antibacterial activity against pathogenic gram negative bacteria. Journal of Pharmacy Research, 7(5): 448-453.

Sulistiyani, T.R., Lisdiyanti, P. and Lestari, Y., 2014. Population and diversity of endophytic bacteria associated with medicinal plant Curcuma zedoaria. Microbiology Indonesia, 8(2): 4-4.

Ujam, N.T., Ajaghaku, D.L., Okoye, F.B. and Esimone, C.O., 2021. Antioxidant and immunosuppressive activities of extracts of endophytic fungi isolated from Psidium guajava and Newbouldialaevis. Phytomedicine Plus, 1(2): 100028.

Vinayarani, G. and Prakash, H., 2018. Growth promoting rhizospheric and endophytic bacteria from Curcuma longa L. as biocontrol agents against rhizome rot and leaf blight diseases. The Plant Pathology Journal, 34(3): 218.

Zhao, S., Wu, X., Duan, X., Zhou, C., Zhao, Z., Chen, H., Tang, Z., Wan, Y., Xiao, Y. and Chen, H., 2021. Optimal extraction, purification and antioxidant activity of total flavonoids from endophytic fungi of Conyzablinii H. Lév. PeerJ, 9: e11223.

Zhu, Z., Chen, J., Chen, Y., Ma, Y., Yang, Q., Fan, Y., Fu, C., Limsila, B., Li, R. and Liao, W., 2022. Extraction, structural characterization and antioxidant activity of turmeric polysaccharides. LWT, 154: 112805.