Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 24 | No. 2 | Article ID B4246 | 2025
Review Research Paper
https://doi.org/10.46488/NEPT.2025.v24i02.B4246
Open Access Journal

Management of Grapevine Fungal Diseases by Using Antagonistic Endophytes - An Environment-Friendly Approach

Akhilesh Chandrapati[1], Jay Prakash Singh[2], Yenda Damodhara Rao[3], Meenakshi Rana[1], Somnath K. Holkar[4] and Seweta Srivastava[1]†

[1]Department of Plant Pathology, School of Agriculture, Lovely Professional University, Phagwara-144 411, Punjab, India
[2]Department of Plant Pathology, SMMTD College, Balia-277001, Uttar Pradesh, India
[3]Department of Plant Pathology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur 208 002, Uttar Pradesh, India
[4]Department of Plant Pathology, ICAR-National Research Centre for Grapes (NRCG), Pune-412307, Maharashtra, India
†Corresponding author: Seweta Srivastava; seweta.21896@lpu.co.in

Abbreviation: Nat. Env. & Poll. Technol.
Website: www.neptjournal.com

Received: 12-07-2024
Revised: 02-09-2024
Accepted: 19-09-2024

Key Words:

Endophytes
Antagonistic properties
Secondary metabolites
Eco-friendly disease management
Defense mechanism in plants

Citation for the Paper:

Chandrapati, A., Singh, J.P., Rao, D. Y., Rana, M., Holkar, S.K. and Srivastava, S. 2025. Management of grapevine fungal diseases by using antagonistic endophytes - An environment-friendly approach. *Nature Environment and Pollution Technology*, 24(2), p. B4246. https://doi.org/10.46488/NEPT.2025.v24i02.B4246

Note: From year 2025, the journal uses Article ID instead of page numbers in citation of the published articles.

ABSTRACT

Grapevine (*Vitis vinifera* L.) is one of the major crops grown commercially throughout the world. In recent years, there have been major losses to grapevine production due to the challenges caused mainly due to fungal diseases like downy mildew, powdery mildew, grey mold, black rot, and anthracnose. In the last few decades, rampant chemical fertilization and bio-magnification of hazardous chemicals have posed a threat to human health and destroyed the health of the soil as well as crops. For effective management of these fungal diseases of grapes, nowadays, many researchers are conducting various studies on endophytes, which are proven to be better bio-control agents to suppress the growth and development of grapevine phytopathogens. Endophytes are eco-friendly, effective, and easy to apply at field levels, making endophyte-based formulations suppress the growth and development of grapevine pathogens without causing any detrimental effects to the beneficial micro-organisms present at the rhizospheric zone of soil and host plants as compared to the traditional fungicides usage. It also competes with these pathogens for nutrition, space, and colonization. It helps in the production of secondary metabolites with antifungal properties for preventing the growth of fungal pathogens that cause damage to the grapevine crop. It also induces a defense mechanism in grapevine crops against disease-causing fungal phytopathogens. In this review article, biocontrol mechanisms of endophytes and their potential application in the management of grapevine fungal diseases have been discussed.

INTRODUCTION

Grapevine is one of the major commercial fruit crops grown across 7.3 million hectares worldwide and is used for juice, wine, raisin production, and fresh consumption (Karlsson & Karlsson 2021). The total productivity of grapevine throughout the world in recent years is about 27.42 million metric tons (Statista 2023). In India the grapevine is regarded as a major revenue-generating commercial fruit crop produced for export to other countries; it is expected that India is producing about 2,46,133 tons of fresh grapes with an income value of 334.79 million dollars. Maharashtra is the leading grapevine-producing state of India, which produces over 81% of total grapevine production in India (Indian Grape Forum 2019). The major grapevine fungal diseases that are causing heavy losses to grapevine production throughout the world are Downy mildew, Powdery mildew, Anthracnose, Grey mold, Black rot, etc (Armijo et al. 2016). Endophytes are pervasive and mainly colonize inside the tissues of 300,000 various plant species without causing any detrimental effects to the plants (Narayanan et al.

2022). These endophytes mainly belong to Ascomycota, Actinobacteria, Basidiomycota, Bacteroidetes, Firmicutes, Proteobacteria, and Zygomycota, which are some major prokaryotic and eukaryotic endophytes that were identified till now (Yakop et al. 2019). These endophytes produce various enzymes, hormones, and secondary metabolites, which cause antagonistic effects and antimicrobial activity that inhibit plants from pathogen infection and play a major role in biotechnology (Gunatilaka 2006). Using these natural symbionts provides a chance to increase the production of grapevine while minimizing the use of hazardous pesticides against pathogens (Srivastava et al. 2023).

Endophytes must slowly adapt to these living conditions by gradually interacting with their host plant, including mutualism and antagonism (Dudeja et al. 2012), and can establish themselves in the plant after a process of molecular crosstalk that produces a cornucopia of favorable modifications for the host (Pavithra et al. 2020, Das et al. 2021, Pavithra et al. 2021, Maurya et al. 2024). These endophytes promote the growth and development of their host plant and help them to adapt to environmental changes, and they produce various compounds to sustain symbiosis between host plant and endophytes (Das & Varma 2009). In the present situation, increasing crop production and maintaining ecological sustainability in an eco-friendly manner is possible by using microbial bio-products that include various types of bio-formulations like bio-fertilizers, bio-pesticides, bio-stimulants, bio-inoculants, etc. (Singh et al. 2016). To sustain the goal of increasing crop production and controlling various diseases throughout the world, there is an urgent need to develop microbe-based bio-formulations that are greener and safer alternatives to agrochemicals (Mishra et al. 2015). These microbe-based bio-formulations are strong in comparison to agrochemicals as the formulation includes a single microbe that interacts with the pathogen directly and suppresses its growth and development, which leads to a decrease in disease rate and improves plant growth (Rodrigo et al. 2011).

GRAPEVINE FUNGAL DISEASES AND THEIR IMPACT ON GRAPE PRODUCTION

The major fungal diseases of grapevine (*Vitis vinifera*) as mentioned in Table 1 are powdery mildew, downy mildew, grey mold, black rot, anthracnose which are caused by these phytopathogens like *Uncinula necator, Plasmopara viticola, Botrytis cinerea, Guignardia bidwelli and Elsinoe ampilina* (Armijo et al. 2016). Downy mildew disease causes severe yield losses to the grapevine in vivo when optimum temperate and humidity are present, which is suitable for survival and increases infection-causing capacity, leading to losses of about 40-90% of grapevine (Toffolatti et al. 2018). Powdery mildew disease causes severe losses to the quality and quantity of grapevine. If not managed properly during high disease pressure years, it leads to yield losses of about 75-100% (Fermaud et al. 2016). Anthracnose disease causes yield losses to crop productivity of grapevine about 10-15% and on highly susceptible grapevine varieties due to severe infection on them, crop losses occur up to 100% (Zhi Li et al. 2021). Grey mold disease causes major economic yield losses to the grapevine, about 20-50% throughout the world at post-harvest season, mainly due to rotting of ripe berries (Fedorina et al. 2022). Black rot disease causes yield losses to the grapevine by about 80% due to the availability of its optimum humid condition to produce its primary inoculum and causes infection to the grapevine (Jackson 2014).

VARIOUS TYPES OF ANTAGONISTIC ENDOPHYTES ASSOCIATED WITH HOST PLANTS

Endophytes can reside inside (intercellular) and outside (intracellular) the cells of the host plant, and they can live inside (systematically) and outside (locally) of the host body in a symbiotic relationship with the host without causing any harm to the host plant (Kusari et al. 2012, Lo Presti et al. 2015, Schulz et al. 2015). Endophytes are found existing all over the places of agricultural ecosystems and natural forests and are mainly present in the plant tissues of spermatophytes, ferns, equisetopsids, mosses, liverworts, lycophytes, hornworts, etc. (Kusari et al. 2012, Jeewon et al. 2013, Doilom et al. 2017, Potshangbam et al. 2017). Clavicipitaceous endophytes live as intracellular symbionts, mainly in various grasses. They are found more in the leaves and stems of mother plants as compared to young plants, and these endophytes are transmitted both vertically and horizontally through sexual or asexual spores and seeds, etc. (Yan et al. 2015, Santangelo et al. 2015). Both the fungal and bacterial endophytes have great potential as bio-control agents as they have antagonistic activity (Table 2), which produces various secondary metabolites like antioxidants, bioactive antimicrobial and antiviral metabolites that help in suppressing the growth of various disease-causing phytopathogens, thus reducing the losses caused by them (Gouda et al. 2016).

De Bary (1866) introduced the endophyte term. He defined it as an organism that grows inside of the plant tissues and has a symbiotic relationship with its host without causing any detrimental effects to its host, sometimes helping in providing essential nutrients for the host for its growth and development. Its types are fungal and bacterial endophytes, which act as both obligate or facultative relationships with

Table 1: List of major fungal diseases of grapevine with their causal organisms and peculiar symptoms.

Diseases	Causal organism	Symptoms	References
Downy mildew	*Plasmopara viticola*	Rough circular yellow discoloration and oily spots on leaves. Whitish downy fungal growth appearance on the lower side of leaves and stem (sporulation of fungi). Infected shoot tips turn curl (Shepherd's crook). Severely infected leaves turn yellow to brown and finally get dry and dropdown.	Koledenkova et al. (2022)
Powdery mildew	*Uncinula necator*	Lesions first occur on the lower side of the leaves. Minute orange to black circular structures, *i.e*., cleistothecia, appear on both the upper and lower surfaces of leaves and berries. Affected berries finally dried out and dropped down.	Kunova et al. (2021)
Anthracnose	*Elsinoe ampilina*	It causes small round spots on the surface of leaves. These spots later become holes on leaves (shot-hole appearance). The appearance of deep elongated cankers with a greyish color in the center and with a black border on the stem. Violet color spots with a greyish appearance in the center appearance on berries. Finally, these infected berries dried and dropped prematurely.	Li et al. (2021)
Grey mold	*Botrytis cinerea*	It causes necrotic brown spots. Infected berries are covered with greyish substances consisting of spores of the fungus.	Shen et al. (2021)
Black rot	*Guignardia Bidwell*	It causes small brown lesions with a border of dark marginal rings consisting of black pustules (fruiting body of fungi). Infected berries fist turns white, then purple, and finally turns black color. Severely infected berries are covered by black pustules.	Szabó et al. (2023)
Ripe rot	*Colletotrichum* spp.	It causes tiny, sunken, reddish-brown spots with yellow halos. Infected berries become soft and concentric rings are formed on berries consisting of small fruiting body structures (acervuli). Infected fruits turn from light to brown color. The final stage of infection results in the drying and mummification of decaying berries.	Hsieh et al. (2023)
Angular leaf scorch	*Psuedopezicula tetra*spora	The first appearance of symptoms occurs on leaves. Lesions appear as faint, yellow spots on the leaf surface and leaf veins and later turn to reddish-brown color. At severe infection, death of leaf tissue occurs.	Fischer et al. (2022)
Armillaria root rot	*Armillaria mellea*	The first appearance of symptoms occurs as stunting of shoots. Later white mycelial mat appears below the bark of the plant. At severe infection, and trunk and root of the plant get rotten with a soft and spongy appearance, and its color changes from white to dark brown.	Calamita et al. (2021)
Bot Canker	*Lasiodiplodia theobromae*	Foliar symptoms may be observed as mild chlorosis or wilting due to inhibition of water transport. Berries of infected white-fruited varieties may develop small, flat lesions with pycnidia, with berries turning light brown.	DeKrey et al. (2022)
Phomopsis dieback	*Phomopsis viticola*	Small, black spots on the internodes at the base of developing shoots are probably the most common disease symptom. These spots are usually found on the first three to four basal internodes. It is also known as the "dead arm".	Úrbez-Torres et al. (2013)
Grapevine leaf stripe	*Phaeomoniella chlamydospora* and several species of *Phaeoacremonium*	Foliar symptoms on established grapevines have been widely described and include various types of discoloration, typically interveinal discolorations evolving into necrotic areas resembling "*tiger stripes*".	Serra et al. (2018), Calzarano et al. (2021)
Botryosphaeria dieback	It is caused by several pathogens, primarily *Neofusicoccum parvum, Diplodia seriata, Botryosphaeria stevensii*, and *Botryosphaeria dothidea*.	Symptoms of Botryosphaeria dieback include dead spurs, stunted shoots, and bud mortality.	Kenfaoui et al. (2022)
Eutypa dieback	*Eutypa lata*	It is a major trunk disease in grapevines associated with the heavy loss of production.	Gramaje et al. 2018
Leaf blight/ Fruit rot	*Alternaria alternata, A. vitis*	The disease attacks both leaves and fruits. Small yellowish spots first appear along the leaf margins, which gradually enlarge and turn into brownish patches with concentric rings.	Li et al. (2023)
Grapevine Esca disease colonizing the xylem tissues of vine plants	*Phaeomoniella chlamydospora* *Phaeoacremonium aleophilum*	The typical Esca internal symptoms are vascular discoloration with the production of dark tarry drops and wood necrosis. In leaves, both chlorotic and necrotic areas have typically been described as tiger-striped leaves and later as grapevine leaf stripe disease.	Mugnai et al. 1999, Gramaje et al. 2018

Table 2: Effectiveness of antagonistic endophytes against grapevine phytopathogens.

Endophytes	Effective against grapevine phytopathogens	Reference
Pseudomonas spp.	Phytoplasmas *Botrytis cinerea*	Gamalero et al. (2017) Gruau et al. (2015)
Burkholderia spp.	Phytoplasmas	Bulgari et al. (2014).
Methylobacterium spp.	Phytoplasmas	Bulgari et al. (2014).
Pantoea spp.	Phytoplasmas *Neofusicoccum parvum*	Andreolli et al. (2016) Haidar et al. (2021)
Bacillus spp.	*Botrytis cinerea* *Plasmopara viticola*	Andreolli et al. (2016). Zhang et al. (2017).
B. subtilis strain AG1	*Phaeomoniella chlamydospora* and *Phaeoacremonium aleophilum*	Alfonzo et al. 2009
Bacillus pumilus and *Paenibacillus* sp. (S19)	*Phaeomoniella chlamydospora*	Haidar et al. (2016b)
Pseudomonas *protegens* MP12 strain	*Phaeomoniella chlamydospora* and *Phaeoacremonium aleophilum*	Andreolli et al. (2019)
Brevibacillus spp. *Lysinibacillus* spp. *Nocardioides* spp. *Stenotrophomonas* spp. *Microbacterium* spp.	*Botrytis cinerea*	Andreolli et al. (2016)
Streptomyces anulatus	*Botrytis cinerea*	Vatsa-Portugal et al. (2017)
Paraburkholderia phytofirmans strain PsJN	*Botrytis cinerea*	Ait Barka et al. (2000), MiottoVilanova et al. (2016)
Acinetobacter lwoffi	*Botrytis cinerea*	Verhagen et al. (2011)
Enterobacter spp. *Rahnella aquatilis* *Paenibacillus* spp. *Staphylococcus* spp. *Acremonium* spp. *Alternaria alternata* *Epicoccum nigrum*	*Botrytis cinerea*, *Plasmopara viticola*, *Agrobacterium vitis*, *Xylella fastidiosa*	Pacifico et al. (2019)
Paenibacillus spp.	*Botrytis cinerea*, *Plasmopara viticola*, *Agrobacterium vitis*, *Xylella fastidiosa* *Neofusicoccum parvum*	Pacifico et al. (2019), Haidar et al. (2021)
Albifimbria verrucaria	*Botrytis cinerea*, *Lasiodiplodia theobromae*, *Elsinoe ampelina*	Li et al. (2000)
Beauveria bassiana	*Plasmopara viticola*	Rondot and Reineke (2019)
Cochliobolus, *Bipolaris*, *Fusarium*, *Alternaria*, *Diaporthe*, *Phoma* and *Phomopsis*.	*Alternaria sp*., *Sphaceloma* sp. *And Glomerella* sp.	Felber et al. (2016)
Lophiostoma cortisol (from leaves)	*Botrytis cinerea*	Kulišová et al. (2021)
Alternaria *alternata* and *Fusarium proliferatum*	*Plasmopara viticola*	Mondello et al. (2019), Aleynova et al. (2021)
Acremonium byssoides	*Plasmopara viticola*	Burruano et al. (2008)

the host plant (Brader et al. 2017). These endophytes colonize the plant tissues, both intercellular and intracellular, and have a mutualistic association with the host in their lifetime. Recent studies show that the health, survival, growth, and development of these host plants are mostly dependent on these endophytes (Hardoim et al. 2015, Potshangbam et al. 2017). Obligate endophytes are those that depend on the host plant metabolism for their survival, and their movement inside the plant occurs through different vectors or vertical transmission (Hardoim et al. 2008). Facultative endophytes are those that can survive outside of the host plant for a certain period of their life cycle, and they are mostly associated with host plants as compared to their natural environment in soil (Abreu-Tarazi et al. 2010).

ROLE OF ANTAGONISTIC ENDOPHYTES IN GRAPEVINE FUNGAL DISEASE MANAGEMENT

Endophytes are helpful in plant growth and provide biotic/

abiotic stress resistance by the production and release of secondary metabolites, plant hormones, antibiotics, and biocides, which leads to improving resistance in plants against abiotic stress and various diseases (Lugtenberg & Kamilova 2009, Compant et al. 2013). The endophytic colonization in the grapevine helps the plant to be in an active state to respond to any attack by grapevine disease-causing pathogens (Martinez-Medina et al. 2016, Mauch-Mani et al. 2017). It is proved by many researchers believe that these endophytes help in triggering defense responses in plants, which provide resistant against various fungal, oomycete, bacterial, and viral pathogens and insects (De Vleesschauwer & Höfte 2009, Van der Ent et al. 2009, Pineda et al. 2010). Some endophyte bacteria like Pseudomonas spp. and Bacillus spp. can produce HCN which helps in breaking summer bud dormancy in grapevine (Shameer & Prasad 2018, Sudawan et al. 2016). The endophytic bacteria *Pseudomonas migulae* can act as a biocontrol agent against phytoplasmas which causes grapevine yellows disease in grapevine (Gamalero et al. 2017). The bacterial species associated with induced systemic resistance (ISR), such as *Burkholderia* spp., *Methylobacterium* spp., and *Pantoea* spp. the population increased and helped in triggering defense responses for resistance when phytoplasmas attack the grapevine (Bulgari et al. 2014). The endophytic fungus *Alternaria alternata*, isolated from grapevine leaves, has been reported to be efficacious in controlling downy mildew disease through the production of toxic diketopiperazines metabolites (Musetti et al. 2006, Srivastava et al. 2024). Several other microorganisms, isolated either from rhizosphere or grape fruit surfaces, have also been selected as BCAs over the last decades to control *Plasmopara viticola*, such as *Bacillus subtilis* KS1, *Lysobacter capsici* AZ78, *Trichoderma harzianum* T39 and *Fusarium proliferatum* G6 (Perazzolli et al. 2008, Zhang et al. 2017).

In recent studies, the researchers identified various new potential endophytes as biocontrol agents *in vitro*. Among these potential endophytes, *Bacillus licheniformis* can secrete lipoproteins, which are biocontrol molecules that help in inhibiting the growth and development of various phytopathogenic fungi in grapevine, mainly against *Botrytis cinerea,* which causes grey mold disease in grapevine (Favaro et al. 2016, Nigris et al. 2018). The endophytic bacteria *i.e*., *Bacillus* spp., *Brevibacillus* spp., *Lysinibacillus* spp., *Nocardioides* spp., *Stenotrophomonas* spp., *Microbacterium* spp. and *Pantoea* spp. also exhibits antifungal activity and induce resistance against *Botrytis cinerea* phytopathogen causing grey mold disease in grapevine (Andreolli et al. 2016). The most effective endophytes against *Botrytis cinerea* are *Bacillus* spp., *Pantoea* spp., and *Pseudomonas* spp., respectively. Among them, the bacterial endophyte *Pseudomonas* spp. helps in activating defense responses against *Botrytis cinerea* at both local and systemic levels in grapevine (Trotel-Aziz et al. 2008, Verhagen et al. 2011, Gruau et al. 2015).

The endophyte *i.e*., *Pseudomonas* spp. Colonize the roots of grapevine and exhibits systemic defense response by transfer of molecular signals from roots to leaves, and it shows distinct defense-related gene expression patterns in roots and leaves of grapevine where some genes are associated with causing cell death and hypersensitive response (HR), which stops the infection from *Botrytis cinerea* from spreading into other cells and tissues of grapevine. It leads to the activation of oxidative burst and production of phytoalexins which helps in reducing the infection caused by *Botrytis cinerea* in grapevine (Gruau et al. 2015). *Streptomyces anulatus* is a potential endophytic plant growth-promoting rhizobacterium (PGPR) that exhibits resistance against *Botrytis cinerea* by activating defense responses in grapevine-like ion fluxes, extracellular alkalinization, protein kinases, oxidative burst, gene expression, and phytoalexin production (Vatsa-Portugal et al. 2017). *Paraburkholderia phytofirmans* is a potential endophytic plant growth-promoting rhizobacterium (PGPR) which helps in the activation of local immune response by inflation of phenolic compounds, ion fluxes, salicylic acid, and defense gene regulation for inhibiting growth and development of grapevine fungal pathogens mainly *Botrytis* cinerea (Compant et al. 2005, Bordiec et al. 2011, MiottoVilanova et al. 2016, Patya et al. 2023).

These all of the above-mentioned bacterial endophytes trigger oxidative bursts in tissues of the leaf, callose deposition in stomata, induction of salicylic acid, jasmonic acid, and pathogenesis-related (PR) genes (PR1, PR2, and PR5) in grapevine when infected by grapevine fungal disease-causing pathogens. (Miotto-Vilanova et al. 2016). Some researchers studied and observed that *Pseudomonas protegens* could colonize inside grapevine tissues, and it helps in inhibiting the growth and development of various phytopathogens such as *P. chlamydo*spor*e, P. aleophilum, B. cinerea, Alternaria alternata,* Asp*ergillus niger, Penicillium expansum*, and *N. parvum* at *in vitro* and *in vivo* (Andreolli et al. 2019). Some bacterial and fungal endophytes such as *Curtobacterium* spp.*, Erwinia* spp.*, Pantoae* spp.*, Pseudomonas* spp.*, Xanthomonas* spp.*, Biscogniauxia* spp.*, Clado*s*porium* spp.*, and Didymella* spp.*,* can produce secondary metabolites (stilbene content) in the grapevine cell suspension under *in vitro* conditions (Aleynova et al. 2021). Grapevine, when inoculated with some endophytes like *Acinetobacter lwoffi*, *Bacillus subtilis*, and *Pseudomonas fluorescens,* is effective in suppressing the growth and development of *Botrytis cinerea,* causing grey mold disease in grapevine due to the help of these endophytes in synthesis of stilbene

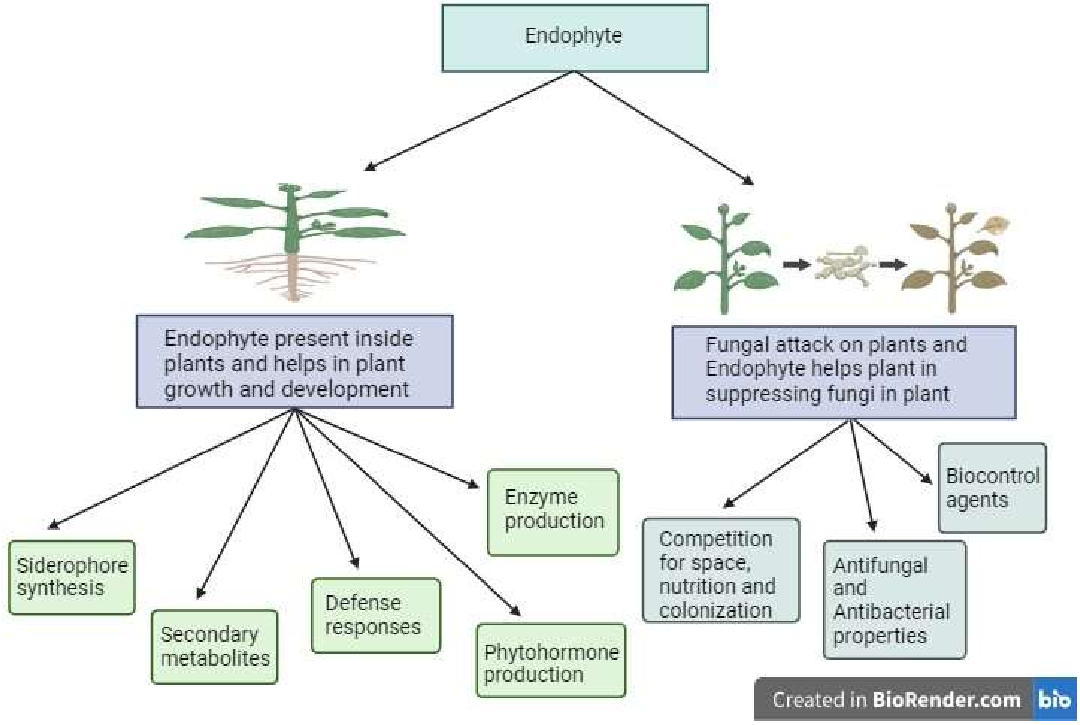
Table 3: Role played by antagonistic endophytes in the management of grapevine diseases.

Endophytes	Role played	Effective against grapevine disease	References
Proteobacteria spp.	Phyto-hormones production	NA	Baldan et al. (2015)
Streptomyces anulatus S37	Activation of protein kinases, induction of defense gene expression, and phytoalexin accumulation	Triggers early and late defense responses, such as ion fluxes, oxidative burst, extracellular alkalinization	Vatsa-Portugal et al. (2017)
Acinetobacter lwoffii	Enzyme Production	Grey mold	Magnin-Robert et al. (2007)
Lophiostoma corticola B. velezensis	Antifungal and antibacterial properties	Grey mold Grey mold, Ripe rot, Downy mildew	Kulisova et al. (2021) Hamaoka et al. (2021)
Bacillus spp. *Variovorax* spp. *Pantoea* spp. *Staphylococcus* spp. *Herbaspillurum* spp. *Sphingomonas* spp.	Biocontrol Agents	Grey mold Downy mildew	Bruisson et al. (2019)
Proteobacteria spp. *Bacillus* spp.	Bio-fertilizers	Grey mold	Baldan et al. (2015)
Proteobacteria spp.	Phosphate solubilization	NA	Baldan et al. (2015)
Penicillium custom *Bacillus* spp.	Siderophore synthesis	Grey mold	Kulisova et al. (2021) Baldan et al. (2015)
Pseudomonas fluorescens	Secondary metabolites production	Grey mold	Gruau et al. (2015)
Aspergillus pseudodeflectus Beauveria bassiana *Aureobasidium pullulans* *Bacillus subtilis* *Paenibacillus* spp.	Defense responses in host plant	Grey mold Downy mildew Grapevine trunk Grapevine trunk Downy mildew	Kulisova et al. (2021) Rondot and Reineke (2019) Pinto et al. (2018) Trotel-Aziz et al. (2019) Hao et al. (2017)
Paenibacillus spp.	Induce resistance in host plants.	Downy mildew	Haidar et al. (2016)
Penicillium, Aspergillus, Mucor, Alternaria, Cephalosporium, and *Geotrichum*	Resveratrol	As an antioxidant compound known to increase resistance to biotic stress	Shi et al. (2012), Yang et al. (2016)
Paraburkholderia phytofirmans strain PsJN	Activation of a local immune response characterized by the accumulation of phenolic compounds, salicylic acid (SA) accumulation, ion fluxes, and defense gene regulation	Grey mold	Miotto-Vilanova et al. (2016)

phytoalexins, resveratrol which help activating metabolite composition and triggering defense mechanism in grapevine (Verhagen et al. 2011). It is observed that the endophyte *Arcopilus aureus* produces high resveratrol content in grapevine. A study was conducted on 53 isolates of potential endophytes obtained from various grapevine varieties to observe the resveratrol content produced by various endophytes. Among the endophytes that produce resveratrol content mainly belong to seven genera, *i.e*., *Aspergillus* spp., *Botryosphaeria* spp., *Penicillium* spp., *Fusarium* spp., *Alternaria* spp., *Arcopilus* spp. and *Lasiodiplodia* spp. (Dwibedi & Saxena 2018). Some important role played by endophytes against grapevine pathogens is mentioned in Table 3.

RECENT APPLICATIONS OF ANTAGONISTIC ENDOPHYTES IN GRAPEVINE FUNGAL DISEASE MANAGEMENT

Nowadays, both fungal and bacterial endophytic applications in agriculture *in vivo* are very beneficial for host plants in which they colonize because these endophytes are eco-friendly with the host plant by promoting growth and development of the plant, act as a biocontrol, help in disease suppression, and stress tolerance, etc (Firdous et al. 2019). Some endophytes application helps the host plants acquire nutrients, production of phytohormones, phytoenzymes, and secondary metabolites, act as biocontrol agents, biofertilizers, exhibit antifungal and antibacterial properties, phosphate



(Source: made by authors).

Fig. 1: Role of endophytes in the growth and development of plants by suppressing the pathogenic microbes.

solubilization, siderophore synthesis, defense responses and induce resistance for suppressing various phytopathogens by inhibiting their growth and development in host plants and prevent them from causing diseases which leads to major losses in crop yield (Santoyo et al. 2016).

Recent studies in endophytes application to grapevine show that some endophytes are helpful in the production of siderophores and exhibit antioxidant and antifungal activity to inhibit grapevine disease-causing pathogens (Fig. 1). Application of *Diatrype stigma*, A*spergillus niger* and *Penicillium crustose* endophytes *in vivo* helps in the production of siderophores in grapevine. Application of *Penicillium crustosum* and A*spergillus pseudodeflectus* endophytes *in vivo* helps in exhibiting antioxidant activity in grapevine. Application of *Lophiostoma corticola,* and *Penicillium crustosum* endophytes *in vivo* helps in exhibiting antifungal activity in grapevine. (Kulisova et al. 2021). Application of *Bacillus subtilis* and *Bacillus pumilus in vivo* acts as a biocontrol agent against downy mildew disease of grapevine caused by *Plasmopara vitcola* and helps in the reduction of disease incidence and severity in grapevine (Zhang et al. 2017).

Application of some endophytes like *Pantoea agglomerans*, *Enterobacter* spp., *Rahnella aquatilis*, *Pseudomonas* spp., *Paenibacillus* spp., *Staphylococcus* spp., *Bacillus* spp., *Burkholderia phytofirmans*, *Acremonium* spp., *Alternaria alternata,* and *Epicoccum nigrum* can act as bio-control agents for effective control of various grapevine diseases i.e. grey mold, crown gall, pierce, and downy mildew (Pacifico et al. 2019). In recent days, many endophytic bacteria like *Streptomyces* spp., *Pseudomonas fluorescens*, *Bacillus* spp., *Pantoea agglomerans*, *Acinetobacter aeruginosa*, *Burkholderia phytofirmans*, and *Rahnella aquatilis* when applied at *in vivo* these can trigger defense responses and activate secondary metabolites in grapevine which help in effective defense mechanism against various disease-causing pathogens of grapevine. (Compant et al. 2013). It is observed that the application of both *Pantoea agglomerans* and *Paenibacillus* sp helps in the control of grapevine trunk disease caused *by Neofusicoccum parvum*. (Haidar et al. 2021). The potential roles and mechanisms of the main endophytes involved in the biotic stress tolerance of grapevine are given in Table 4.

A survey was conducted on various vineyards and observed that there are about 381 culturable bacteria isolated from the inner portion of stems and leaves. Of these isolated bacteria, 30% belongs to genus *Bacillus* spp., and the latter include *Paenibacillus* spp., *Microbacterium* spp.,

Table 4: Potential roles and mechanisms of main endophytes involved in biotic stress tolerance of grapevine.

Pathogen	Endophytes	Mechanism associated with the tolerance	Reference
Botrytis cinerea	*Acinetobacter lwoffi* (PTA-113 and PTA-152), *Pseudomonas fluorescens* (PTA-268 and PTA-CT2), *Pantoea agglomerans* (PTA-AF1 and PTA-AF2), *Bacillus subtilis* (PTA-271).	Induced the activities of lipoxygenase (LOX), phenylalanine ammonia-lyase (PAL), β-1,3 glucanase, and chitinase. Induced the oxidative burst. Accumulated the stress-related metabolites phytoalexin (trans-resveratrol and trans-ε-viniferin.	Magnin-Robert et al. (2007) Trotel-Aziz et al (2008) Verhangen et al. (2011)
	Ulocladium atrum *Pseudomonas fluorescens* (PTA-CT2).	Enhanced chitinase activity. Regulated the expression of defense-related genes in leaf and root, including those with transcriptional factor functions (JAZ9, NAC1, and ERF1), of secondary metabolism (PAL, STS, LOX9, ACCsyn, GST, CHS, CHI, LAND, and ANR), and PR proteins (PR1, PR2, PR3, PR5, and PR6).	Ronseaux et al. (2013) Gruau et al. (2015)
	Bukholderia phytofirmans (PsJN).	Induced callose deposition and H_2O_2 production. Primed the expression of PR1, PR2, PR5, and JAZ in bacterized plantlets after pathogen challenge. Modulated carbohydrate metabolism.	Miotto-Vilanova et al. (2016)
	Bacillus subtilis (BBG-127, BBG-131, Bs2504, and BBG-125).	Treatment with *Bacillus subtilis* strains with non-producing lipopeptides, overproducing surfactin, overproducing plipastatin, and overproducing mycosubtilin differentially activated the plant's innate immune response. Modulated genes encode a chitinase (chit4c), a protease inhibitor (pin), a salicylic acid (SA) regulated marker (W17.3), and a glucanase (gluc).	Farace et al. (2015)
	Microbacterium imperial (Rz19M10) *Kocuria erythromyxa* (Rt5M10) *Terribacillus saccharophilus* (Rt17M10)	Induced a systemic response that triggers increases in monoterpenes, sesquiterpenes, tocopherols, and membrane sterols (enhanced antioxidant capacity).	Salomon et al. (2016)
	Streptomyces annulus (S37)	Induced rapid and transient generation of H_2O_2, extracellular alkalinization, and activation of two mitogen-activated protein kinases (MAPKs) followed by the expression of LOX9, PAL, STS, and GST genes in primed cells. Induced defenses modulated by Ca^{2+} signaling.	Vatsa-Portugal et al. (2017)
Botrytis cinerea, *Plasmopara viticola*, *Xiphinema index* nematodes	*Paenibacillus* spp. strain (B2)	Modulated the expression of defense-related genes CHI, PAL, STS, GST, and LOX and pathogenesis-related protein PR-6. Reduced nematode root infection associated with the expression of genes resistant to nematodes Hero and Hs 1^{pro-1}.	Hao et al. (2017)
Rhizobium vitis (Ti) VAT03-9 (tumorigenic)	*Rhizobium vitis* (ARK-1)	Co-inoculation of ARK-1 with a Ti strain (VATO3-9) into grapevine shoots suppressed the expression of the virulence genes VirA, VirD3, and VirG of VAT03-9.	Kawaguchi et al. (2019)
Flavescence dorée phytoplasma	*Pseudomonas migulae* (8R6)	Production of 1-aminocyclopropane-1-carboxylate (ACC) deaminase enzyme helps the plant to regulate the level of the stress-related hormone ethylene.	Gamalero et al. (2017).
Diplodia seriata (strains F98.1 and Ds99.7) (Botryosphaeria dieback)	*Aureobasidium pullulans* strain (Fito-F278)	Modulated genes encoded for plant defense proteins: PR protein 6 (PR-6) and β-1,3 glucanase (Gluc), detoxification and stress tolerance: haloacid dehalogenase hydrolase (Hahl), α-crystalline heat shock protein (HSP), β1,3- glucanase (GST5), phenylpropanoid pathway: (STS) cell wall (fascAGP) and water stress (Pip2.2).	Pinto et al. (2018).

Table Cont....

Pathogen	Endophytes	Mechanism associated with the tolerance	Reference
Neofusicoccum parvum (Botryosphaeria dieback)	*Bacillus subtilis* (PTA-271)	Antagonized *Neofusicoccum parvum* by delaying its mycelial growth and detoxifying both (R)-mellein and (-) teremutin. Primed defense genes including PR2 (β-1,3 glucanase), NCED2 (involved in ABA synthesis), and PAL at systemic level after pathogen inoculation.	Trotel-Aziz et al. (2019).
Phaeomoniella chlamydospora (Trunk diseases)	*Paenibacillus* spp. (S19) *Bacillus pumilus* (S32)	Induced resistance against trunk disease fungi: induced the expression of defense-related genes PR1, PR10, CHIT3, PAL, STS, CHS, ANTS, CALS, GST, and GLU.	Haidar et al. (2016).

Staphylococcus spp., *Micrococcus* spp., *Stenotrophomonas* spp., *Variovorax* spp., *Curtobacterium* spp. and *Agrococcus* spp., etc (Baldan et al. 2014). These are the major endophytic bacteria in the grapevine that provide both environmental and economic benefits by exhibiting plant growth-promoting hormones, providing required nutrients to the host plant, activating various beneficial microorganisms in soil rhizosphere, protecting host plant against biotic stress (pathogen) attack by aggressively competing against them for nutrient, space, and colonization. These endophytes are eco-friendly and improve the environment surrounding the grapevine without causing any detrimental effects on the soil microbiome in the rhizospheric zone. (Marasco et al. 2018).

Some endophytes like *Bacillus* spp., *Pseudomonas* spp., and *Micrococcus* spp., exhibit beneficial effects to resist various abiotic stresses like arsenic contamination, high temperature, drought, chilling, and salinity, respectively (Pacifico et al. 2019, Parashar & Mudgal 2024). The bacterial endophyte *Paraburkholderia phytofirmans* slowly gathers trehalose in grapevine to resist various abiotic stress by forming a gel during cellular dehydration to stop excess water loss from the host plant (Fernandez et al. 2012). *Pseudomonas* spp. is an endophytic bacteria that helps grapevine in resisting against cold conditions by inducing various PR (Pathogenesis) genes that encode chitinase, phenylalanine ammonia-lyase (PAL), lipoxygenase (LOX), and glucanase. Some endophytes can convert detoxification compounds into signaling molecules by decreasing ROS (Reactive oxygen species) concentration with the help of some genes, which particularly encode the enzymes in ROS accumulation in grapevine (Theocharis et al. 2012).

The bacterial endophyte *Bacillus licheniformis* can able to exhibit various secondary metabolites such as monoterpenes (antioxidant activity) and sesquiterpenes (antimicrobial activity) in grapevine to protect the host plant from various abiotic stress (Salomon et al. 2014). *Bacillus licheniformis* is an endophytic bacteria that produces catenoids (antioxidants) in the grapevine that help the host plant survivability under various extremely unfavorable conditions to stop both plant growth and development; it may be due to abiotic/biotic/ environmental changes (Cohen et al. 2018). It is observed that bacterial endophytes like *Bacillus licheniformis* and *Pseudomonas fluorescens* can able to encode genes that induce the expression of ABA synthesis and signaling pathways in grapevine plants (Salomon et al. 2014). Some endophytic fungi like *Septaglomus deserticola*, *Funneliformis mosseae*, *Rhizoglomus intraradices*, *Rhizoglomus clarum*, and *Glomus aggregatum* can alter ABA metabolism when these endophytes are inoculated into grapevine so that they can survive effectively under drought condition (Torres et al. 2018).

Recently, many endophytes have been observed that can help grapevine accumulate protective molecules like melatonin, proline, and carotenoids, which are activated when the host plant suffers from various abiotic stress to help survive through that stress condition (Liu & Brettell 2019). Certain endophytes from grapevine orchards that have been isolated for further investigation can modify the chemical and physical characteristics of both leaves and berries as they ripen. Particularly, fungal endophytes alter the modify the total content of reduced sugar, total flavonoids, total phenols, resveratrol, and PAL activity in grapevine. These endophytes can determine the quality of wine and other edible products produced from grapevine (Yang et al. 2016). Some endophytes, when inoculated, help in enhancing growth and development, improving fruit quality and yield of grapevine, which help in relieving farmers' economic burden by improving profits gained with each fruit sold in the market (Huang *et al*. 2018). some of the endophytes can exhibit secondary metabolites inside grapevine, which lowers the cost of buying pesticides to control various grapevine diseases and improves economic value by large-scale production of grapevine (Suryanarayanan et al. 2009).

BIOFORMULATION

Role of Endophyte-Based Bioformulation in Sustainable Agriculture

Bioformulations are microbial-based products consisting of beneficial microbes called endophytes, which help in improving plant growth, supply nutrients to plants, and control various diseases caused by phytopathogens in an eco-friendly manner without causing any detrimental effects to the beneficial microbes in the rhizospheric zone and host plants (Burragoni & Jeon 2021). The bio-formulation process in agriculture involves the selection of beneficial microbial strains and a suitable carrier. An appropriate carrier is a vehicle that houses latent live microorganisms and provides a supportive niche to the microbial population (Khan et al. 2023). A bioformulation of an endophyte is said to be good when it is effective, non-polluting, readily biodegradable, with high water retention capacity and sufficient shelf life (Chaudhary et al. 2020).

Endophytic bioformulation products can serve as a sustainable substitute for chemical fertilizers and pesticides. This is because chemical fertilizers can decrease soil fertility when used excessively, increase the possibility of pathogen mutation, and cause resistance to pesticides altogether (Arora & Mishra 2016, Sharma et al. 2023). Bioformulation products comprise active ingredients and inert ingredients. The active ingredient may be living microbe, spores, and their products, which should be in living conditions. It also requires some inert ingredients, *i.e*., peat, talc, vermiculate, carboxymethylcellulose, and polymers like xantham gum and diatomaceous earth, for bioformulation to be developed successfully. The inert carrier-based bioformulations helped insert antagonistic microbial cells into both the rhizospheric region and plant system through both foliar and soil application for a longer duration (Ardakani et al. 2010, Jorjani et al. 2011). Some additives, i.e., gum, silica gel, methyl-cellulose, and starch, help protect these endophyte bio-formulated products from extreme environmental conditions, which also improve the physical, chemical, and nutritional properties of these products (Schisler et al. 2004).

Nowadays, endophyte-based bioformulation products are essential in sustainable agriculture to protect crops from phytopathogens and decrease disease-prone agricultural zones because of the resistance risk of pathogen mutation caused by using pesticides. Additionally, these bio-formulations either directly or indirectly enhance plant growth and development in their native environments (Lugtenberg & Kamilova 2009). There are also some limitations in successfully producing endophyte-based bioformulation products as we know that they consist of living microbes, so extreme care should be taken to maintain microbial load and vigor without contamination of the original product, which determines the quality of the product sold to the market (Kashyap et al. 2023). The development of these products is highly constricted due to a lack of advanced technology, instruments, lack of knowledge, improper distribution, inexperienced manpower, technical difficulties, and importation laws, which leads to a loss of endophyte viability and decreases the efficacy of these products. Some other major limitations are high production costs and inconsistent performance. These living endophyte cells used in making bioformulations are highly sensitive to external factors, and the person handling them should follow caution during culture, distribution, and application (Arora & Mishra 2016, Xia et al. 2022).

LIMITATIONS OF ENDOPHYTES IN SUSTAINABLE AGRICULTURE

Many endophytes are uncultured and unidentified because databases for endophytes and their metabolites are still unavailable (Xia et al. 2022). Endophytes show specific characteristics towards certain plant species, and they may not act the same on the other plant species, which limits their effectiveness in the application of various crops in the world. Their effectiveness is influenced by some environmental factors like temperature, moisture, and soil characteristics, etc respectively. Their compatibility with agricultural requirements like fertilizers and pesticides is to be considered till now. Some combinations may be synergistic, while some may be antagonistic (Watts et al. 2023). It requires large investments to develop and commercialize endophytic products through numerous research, production, and marketing methods. It may be a challenge for the product to get profits exceeding its initial investment as the small-scale farmers cannot afford it if the price is higher. It is a complex and time-consuming process to get approval from regulatory governing bodies regarding endophytic products as they change from region to region and its landscape navigation difficulty by regulatory bodies limits its commercialization. Even with the recent accomplishments and advancements in endophyte research, there is still a knowledge gap. The relationship between endophytes and plants is still developing, and our understanding of their means of action, long-term impacts, and molecular interactions with the host plant is limited. Their risk in introducing into agricultural systems without proper knowledge about them is more as we must face the unknown consequences (Kaur et al. 2023).

In the quadritrophic system involving fruits, pathogens, and endophytes, the host faces limitations in terms of nutrition and space (Kashyap et al. 2023). Competition with pathogenic microorganisms for niche and nutrition, namely niche exclusion, is a promising mechanism for the use of endophytes in plant disease control (Liarzi & Ezra 2013). Both endophytes and pathogens rely on essential nutrients such as nitrogen, carbon, macro, and micronutrients for their survival (Kumari et al. 2022). However, after the application of microbial biocontrol agents, these agents compete with the target pests or pathogens for space and nutrients by colonizing the same ecological niches or habitats as the target organisms, such as plant surfaces, soil, or water, and trying to establish themselves and proliferate. The biocontrol agents can out-compete the pests or pathogens by utilizing available resources more efficiently, depriving them of essential nutrients, or occupying physical spaces that prevent their establishment. In addition to competing with the target organisms, microbial biocontrol agents may also compete with the native microbial communities (Kumari et al. 2022). Native microorganisms are naturally present in ecosystems and play important roles in nutrient cycling, disease suppression, and maintaining ecosystem balance. The introduction of biocontrol agents can disrupt the existing microbial communities and create competition for resources (Kumar et al. 2020). Endophytes might also be ineffective when the disease is caused by a high presence of pathogens (Lahlali et al. 2014).

FUTURE ASPECTS OF ENDOPHYTES

We must explore, identify, and characterize various new species of endophytes to improve our understanding of their habitat, mode of action, how they interact with host plants, they will have any beneficial effect on that host plant or not as we explore various plant species, we can find novel endophytes with unique characteristics as we know that the endophytes are plant specific. We know that there are many microorganisms in the world. Some may be beneficial to some plants, and the remaining may be harmful to other plants. These beneficial microorganisms we name them as endophytes as their role in plant growth and development is diverse. To create products from these endophytes and apply them at the in vivo level for sustainable agriculture, we must first examine their properties and the impact they will have on the plant to which we intend to apply them.

Additionally, we need to gain a deeper understanding of the molecular interactions between the endophyte and the host plant to gain insight into potential future applications. For conducting molecular studies, we can use techniques such as transcriptomics, proteomics, and metabolomics to know the signaling pathways and gene regulation they do inside the plant. Now, as our understanding of these endophytes improves, we must select endophytes that are beneficial to a specific plant, and we can make bioformulation products of these endophytes, which can improve their survival, colonization, and efficacy on targeted plants when applied *in vivo*. These endophytes-based products are new as they have no records of their effectiveness in reducing abiotic/biotic stress in plants. So, we must investigate their efficacy under real-world conditions long-term to check their effectiveness in reducing the effect of both abiotic/biotic stress on targeted plants so we can apply them risk-free in sustainable agriculture. As the application of these endophytes-based products increases day by day, there is a need for some guidelines and safety standards should be framed by the regulatory bodies so that we can follow these guidelines. Following that these safety standards can be commercialized into the market to be used in agricultural practices.

CONCLUSIONS

In the past three decades, remarkable progress has been made in research on plant disease resistance mechanisms and plant-microbe interactions. Endophytes, colonizing plant tissues, are regarded as naturally occurring agents in plant disease suppression. Most of their success is attributed to the production of a vast array of metabolites. In this review, we studied the management of various fungal diseases of grapevine with the help of various endophytes (may be bacterial or fungal), which are eco-friendly. These endophytes also play a major role in growth and development of grapevine by acquiring nutrients, production of phytohormones, phytoenzymes, secondary metabolites, acting as biocontrol agents, phosphate solubilization, siderophore synthesis, defense responses, and inducing resistance for suppressing various phytopathogens by inhibiting their growth and development in host plants and prevent them from causing diseases which leads to major losses in crop yield of grapevine. Some endophytes help in reducing abiotic stress in the grapevine. Endophytes are reliable and environmentally friendly in plant disease management and crucial for sustainable agriculture. However, to truly achieve their large-scale commercial production and application, we still have some challenges to overcome. Biocontrol effects of endophytes are not stable in field trials. It is necessary to elevate the exploitation of endophytes and their metabolites in the biological control of plant diseases to the multi-omics level as a promising research frontier.

REFERENCES

Abreu-Tarazi, M.F., Navarrete, A.A. Andreote, F.D., Almeida, C.V., Tsai, S.M. and Almeida, M. 2010. Endophytic bacteria in long-term in vitro cultivated “axenic” pineapple microplants revealed by PCR–DGGE. *World Journal of Microbiology and Biotechnology*, 26, pp.555-560. DOI

Ait Barka, E., Belarbi, A., Hachet, C., Nowak, J. and Audran, J.C. 2000. Enhancement of in vitro growth and resistance to grey mold of *Vitis vinifera* co-cultured with plant-promoting rhizobacteria. *FEMS Microbiology Letters*, 186, pp.91–95. DOI

Aleynova, O.A., Suprun, A.R., Nityagovsky, N.N., Dubrovina, A.S. and Kiselev, K.V. 2021. The influence of the grapevine bacterial and fungal endophytes on biomass accumulation and stilbene production by the in vitro cultivated cells of *Vitis amurensis* Rupr. *Plants*, 10, p.1276. DOI

Alfonzo, A., Conigliaro, G., Torta, L., Burruano, S. and Monschetti, G. 2009. Antagonism of *Bacillus subtilis* strain AG1 against vine wood fungal pathogens. *Phytopathologia Mediterranea*, 48, pp.155–158. DOI

Andreolli, M., Lampis, S., Zapparoli, G., Angelini, E. and Vallini, G. 2016. Diversity of bacterial endophytes in 3 and 15-year-old grapevines of *Vitis vinifera* cv. Corvina and their potential for plant growth promotion and phytopathogen control. *Microbiological Research*, 183, pp.42-52. DOI

Andreolli, M., Zapparoli, G., Angelini, E., Lucchetta, G., Lampis, S. and Vallini, G. 2019. *Pseudomonas protegens* MP12: a plant growth-promoting endophytic bacterium with broad-spectrum antifungal activity against grapevine phytopathogens. *Microbiological Research*, 219, pp.123–131. DOI

Ardakani, S.S., Heydari, A., Khorasani, N. and Arjmandi, R. 2010. Development of new bioformulations of *Pseudomonas fluorescens* and evaluation of these products against damping-off of cotton seedlings. *Journal of Plant Pathology*, 92, pp.83-88. DOI

Armijo, G., Schlechter, R., Agurto, M., Muñoz, D., Nuñez, C. and Arce-Johnson, P. 2016. Grapevine pathogenic microorganisms: Understanding infection strategies and host response scenarios. *Frontiers in Plant Science*, 7, p.382. DOI

Arora, N.K. and Mishra, J. 2016. Prospecting the roles of metabolites and additives in future bioformulations for sustainable agriculture. *Applied Soil Ecology*, 107, pp.405-407. DOI

Baldan, E., Nigris, S., Populin, F., Zottini, M., Squartini, A. and Baldan, B. 2014. Identification of culturable bacterial endophyte community isolated from tissues of *Vitis vinifera* “Glera”. *Plant Biosystems: An International Journal Dealing with All Aspects of Plant Biology*, 148, pp.508-516. DOI

Baldan, E., Nigris, S., Romualdi, C., D’Alessandro, S., Clocchiatti, A., Zottini, M. and Baldan, B. 2015. Beneficial bacteria isolated from grapevine inner tissues shape *Arabidopsis thaliana* roots. *PLOS ONE*, 10, p.e0140252. DOI

Bordiec, S., Paquis, S., Lacroix, H., Dhondt, S., Ait Barka, E., Kauffmann, S., Jeandet, P., Mazeyrat-Gourbeyre, F., Clement, C., Baillieul, F. and Dorey, S., 2011. Comparative analysis of defense responses induced by the endophytic plant growth-promoting rhizobacterium *Burkholderia phytofirmans* strain PsJN and the non-host bacterium *Pseudomonas syringae* pv. *pisi* in grapevine cell suspensions. *Journal of Experimental Botany*, 62, pp.595-603. DOI

Brader, G., Compant, S., Vescio, K., Mitter, B., Trognitz, F., Ma, L.J. and Sessitsch, A., 2017. Ecology and genomic insights into plant-pathogenic and plant-nonpathogenic endophytes. *Annual Review of Phytopathology*, 55, pp.61-83. DOI

Bruisson, S., Zufferey, M., L’Haridon, F., Trutmann, E., Anand, A., Dutartre, A., Vrieze, M.D. and Weisskopf, L., 2019. Endophytes and epiphytes from the grapevine leaf microbiome as potential biocontrol agents against phytopathogens. *Frontiers in Microbiology*, 10, p.2726. DOI

Bulgari, D., Casati, P., Quaglino, F. and Bianco, P.A., 2014. The endophytic bacterial community of grapevine leaves is influenced by sampling date and the phytoplasma infection process. *BMC Microbiology*, 14, pp.1-11. DOI

Burragoni, S.G. and Jeon, J., 2021. Applications of endophytic microbes in agriculture, biotechnology, medicine, and beyond. *Microbiological Research*, 245, p.126691. DOI

Burruano, S., Alfonzo, A., Lo Piccolo, S., Conigliaro, G., Mondello, V., Torta, L., Moretti, M. and Assante, G., 2008. Interaction between *Acremonium byssoides* and *Plasmopara viticola* in *Vitis vinifera*. *Phytopathologia Mediterranea*, 47, pp.122–131. DOI

Calamita, F., Imran, H.A., Vescovo, L., Mekhalfi, M.L. and La Porta, N., 2021. Early identification of root rot disease by using hyperspectral reflectance: The case of pathosystem grapevine/*Armillaria*. *Remote Sensing*, 13, p.2436. DOI

Calzarano, F., Pagnani, G., Pisante, M., Bellocci, M., Cillo, G., Metruccio, E.G. and Di Marco, S., 2021. Factors involved in Tiger-stripe foliar symptom expression of esca of grapevine. *Plants*, 10, p.1041. DOI

Chaudhary, T., Dixit, M., Gera, R., Shukla, A.K., Prakash, A., Gupta, G. and Shukla, P., 2020. Techniques for improving formulations of bioinoculants. *3 Biotech*, 10, pp.1–9. DOI

Cohen, A.C., Dichiara, E., Jofré, V., Antoniolli, A., Bottini, R. and Piccoli, P., 2018. Carotenoid profile produced by *Bacillus licheniformis* Rt4M10 isolated from grapevines grown at high altitude and their antioxidant activity. *International Journal of Food Science & Technology*, 53, pp.2697-2705. DOI

Compant, S., Brader, G., Muzammil, S., Sessitsch, A., Lebrihi, A. and Mathieu, F. 2013. Use of beneficial bacteria and their secondary metabolites to control grapevine pathogen diseases. *Biological Control*, 58, pp.435-455. DOI

Compant, S., Reiter, B., Sessitsch, A., Nowak, J., Clément, C. and Ait Barka, E. 2005. Endophytic colonization of *Vitis vinifera* L. by plant growth-promoting bacterium *Burkholderia* spp. Strain PsJN. *Applied and Environmental Microbiology*, 71, pp.1685-1693. DOI

Das, A. and Varma, A. 2009. Symbiosis: The Art of Living. *Symbiotic Fungi: Principles and Practices*, 1, pp.1-28. DOI

Das, A.K., Chosdon, T., Nawale, R., Koder, S.B., Bhosale, R.K., Rana, M. and Srivastava, S. 2021. Role of rhizospheric microbiome against soil-borne pathogens. *Biopesticides International*, 17, pp.1–15. DOI

De Vleesschauwer, D. and Höfte, M. 2009. Rhizobacteria-induced systemic resistance. *Advances in Botanical Research*, 51, pp.223-281. DOI

DeKrey, D.H., Klodd, A.E., Clark, M.D. and Blanchette, R.A. 2022. Grapevine trunk diseases of cold-hardy varieties grown in Northern Midwest vineyards coincide with canker fungi and winter injury. *PLOS ONE*, 17, e0269555. DOI

Doilom, M., Manawasinghe, I.S., Jeewon, R., Jayawardena, R.S., Tibpromma, S., Hongsanan, S., Meepol, W., Lumyong, S., Jones, E.B.G. and Hyde, K.D. 2017. Can ITS sequence data identify fungal endophytes from cultures? A case study from *Rhizophora apiculata*. *Mycosphere*, 8, pp.1869–1892. DOI

Dudeja, S.S., Giri, R., Saini, R., Suneja-Madan, P. and Kothe, E. 2012. Interaction of endophytic microbes with legumes. *Journal of Basic Microbiology*, 52, pp.248-260. DOI

Dwibedi, V. and Saxena, S. 2018. *Arcopilus aureus*, a resveratrol-producing endophyte from *Vitis vinifera*. *Applied Biochemistry and Biotechnology*, 186, pp.476-495. DOI

Favaro, G., Bogialli, S., Di Gangi, I.M., Nigris, S., Baldan, E., Squartini, A., Pastore, P. and Baldan, B. 2016. Characterization of lipopeptides produced by *Bacillus licheniformis* using liquid chromatography with accurate tandem mass spectrometry. *Rapid Communications in Mass Spectrometry*, 30, pp.2237-2252. DOI

Fedorina, J., Tikhonova, N., Ukhatova, Y., Ivanov, R. and Khlestkina, E. 2022. Grapevine gene systems for resistance to Gray mold *Botrytis cinerea* and Powdery mildew *Erysiphe necator*. *Agronomy*, 12, p.499. DOI

Felber, A.C., Orlandelli, R.C., Rhoden, S.A., Garcia, A., Costa, A.T., Azevedo, J.L. and Pamphile, J.A. 2016. Bioprospecting foliar endophytic fungi of *Vitis labrusca* Linnaeus, Bordô and Concord cv. *Annals of Microbiology*, 66, pp.765–775. DOI

Fermaud, M., Smits, N., Merot, A., Roudet, J., Thiery, D., Wéry, J. and Delbac, L. 2016. New multipest damage indicator to assess protection strategies in grapevine cropping systems. *Australian Journal of Grape and Wine Research*, 22, pp.450-461. DOI

Fernandez, O., Vandesteene, L., Feil, R., Baillieul, F., Lunn, J.E. and Clément, C. 2012. Trehalose metabolism is activated upon chilling in grapevine and might participate in *Burkholderia phytofirmans*-induced chilling tolerance. *Planta*, 236, pp.355-369. DOI

Firdous, J., Mona, R. and Muhamad, N. 2019. Endophytic bacteria and their potential application in agriculture: A review. *Indian Journal of Agricultural Research*, 53, pp.1-7. DOI

Fischer, M., 2022. *Pseudopezicula tracheiphila* (Rotbrenner). *CABI Compendium*, 45251. DOI

Gamalero, E., Marzachì, C., Galetto, L., Veratti, F., Massa, N., Bona, E., Novello, G., Glick, B. R., Ali, S., Cantamessa, S., D'Agostino, G. and Berta, G. 2017. A 1-Aminocyclopropane-1-carboxylate (ACC) deaminase-expressing endophyte increases plant resistance to *Flavescence dorée* phytoplasma infection. *Plant Biosystems: International Journal of Plant Biology*, 151, pp.331-340. DOI

Gouda, S., Das, G., Sen, S.K., Shin, H.S. and Patra, J.K. 2016. Endophytes: A treasure house of bioactive compounds of medicinal importance. *Frontiers in Microbiology*, 7, p.1538. DOI

Gramaje, D., Úrbez-Torres, J.R. and Sosnowski, M.R. 2018. Managing grapevine trunk diseases with respect to etiology and epidemiology: Current strategies and prospects. *Plant Disease*, 102, pp.12-39. DOI

Gruau, C., Trotel-Aziz, P., Villaume, S., Rabenoelina, F., Clément, C., Baillieul, F. and Aziz, A. 2015. *Pseudomonas fluorescens* PTA-CT2 triggers local and systemic immune response against *Botrytis cinerea* in grapevine. *Molecular Plant-Microbe Interactions*, 28, pp.1117-1129. DOI

Gunatilaka, A.L. 2006. Natural products from plant-associated microorganisms: Distribution, structural diversity, bioactivity, and implications of their occurrence. *Journal of Natural Products*, 69, pp.509-526. DOI

Haidar, R., Amira, Y., Roudet, J., Marc, F. and Patrice, R. 2021. Application methods and modes of action of *Pantoea agglomerans* and *Paenibacillus* spp. to control the grapevine trunk disease-pathogen, *Neofusicoccum parvum*. *OENO One*, 55(3), pp.1-16. DOI

Haidar, R., Roudet, J., Bonnard, O., Dufour, M.C., Corio-Costet, M.F., Fert, M., Gautier, T., Deschamps, A. and Fermaud, M. 2016. Screening and modes of action of antagonistic bacteria to control the fungal pathogen *Phaeomoniella chlamydospora* involved in grapevine trunk diseases. *Microbiological Research*, 192, pp.172-184. DOI

Hamaoka, K., Aoki, Y. and Suzuki, S., 2021. Isolation and characterization of endophyte *Bacillus velezensis* KOF112 from grapevine shoot xylem as a biological control agent for fungal diseases. *Plants*, 10, p.1815. DOI

Hao, Z., Van Tuinen, D., Wipf, D., Fayolle, L., Chataignier, O., Li, X., Chen, B., Gianinazzi, S., Gianinazzi, P., Vivienne, and Adrian, M., 2017. Biocontrol of grapevine aerial and root pathogens by *Paenibacillus* sp. strain B2 and paenimyxin in vitro and in planta. *Biological Control*, 109, pp.42-50. DOI

Hardoim, P.R., van Overbeek, L.S. and van Elsas, J.D., 2008. Properties of bacterial endophytes and their proposed role in plant growth. *Trends in Microbiology*, 16, pp.463-471. DOI

Hardoim, P.R., Van Overbeek, L.S., Berg, G., Pirttilä, A.M., Compant, S., Campisano, A., Doring, M. and Sessitsch, A., 2015. The hidden world within plants: ecological and evolutionary considerations for defining functioning of microbial endophytes. *Microbiology and Molecular Biology Reviews*, 79, pp.293-320. DOI

Hsieh, T.F., Shen, Y.M., Huang, J.H., Tsai, J.N., Lu, M.T. and Lin, C.P., 2023. Insights into grape ripe rot: A focus on the *Colletotrichum gloeosporioides* species complex and its management strategies. *Plants*, 12, p.2873. DOI

Huang, L.H., Yuan, M.Q., Ao, X.J., Ren, A.Y., Zhang, H.B. and Yang, M.Z., 2018. Endophytic fungi specifically introduce novel metabolites into grape flesh cells in vitro. *PloS One*, 13, p.e0196996. DOI

Indian Group Forum, 2019. Indian Grape Forum. Retrieved, November 2019, from https://www.freshplaza.com/article/9164030/indian-grape-forum-2019-to-launch-november-17th.

Jackson, R.S., 2014. Vineyard practice. *Wine Science*, pp.143-306.

Jeewon, R., Ittoo, J., Mahadeb, D., Jaufeerally-Fakim, Y., Wang, H.K. and Liu, A.R., 2013. DNA-based identification and phylogenetic characterization of endophytic and saprobic fungi from *Antidesma madagascariense*, a medicinal plant in Mauritius. *Journal of Mycology*, pp.1-10. DOI

Jorjani, M., Heydari, A., Zamanizadeh, H.R., Rezaee, S. and Naraghi, L., 2011. Development of *Pseudomonas fluorescens* and *Bacillus coagulans*-based bio formulations using organic and inorganic carriers and evaluation of their influence on growth parameters of sugar beet. *Journal of Biopesticides*, 4, p.180. DOI

Karlsson, P. and Karlsson, B., 2021. Vineyard Area In The World In 2020, A Detailed Look [WWW Document]. Forbes. Available at https://www.forbes.com/sites/karlsson/2021/12/28/vineyard-area-in-the-world-in-2020-a-detailed-look/.

Kashyap, N., Singh, S.K., Yadav, N., Singh, V.K., Kumari, M., Kumar, D., Shukla, L., Bhardwaj, N.K. and Kumar, A., 2023. Biocontrol screening of endophytes: applications and limitations. *Plants*, 12, p.2480. DOI.

Kaur, G., Patel, A., Dwibedi, V. and Rath, S.K., 2023. Harnessing the action mechanisms of microbial endophytes for enhancing plant performance and stress tolerance: current understanding and future perspectives. *Archives of Microbiology*, 205, p.303. DOI.

Kenfaoui, J., Lahlali, R., Mennani, M., Radouane, N., Goura, K., El Hamss, H., El Ghadraoui, L., Fontaine, F., Tahiri, A., Barka, E.A. and Amiri, S., 2022. Botryosphaeria Dieback (Lasiodiplodia viticola): An imminent emerging threat to Moroccan vineyards. *Plants*, 11, p.2167. DOI.

Khan, A., Singh, A.V., Gautam, S.S., Agarwal, A., Punetha, A., Upadhayay, V.K., Kukreti, B., Bundela, V., Jugran, A.K. and Goel, R., 2023. Microbial bioformulation: a microbial-assisted biostimulating fertilization technique for sustainable agriculture. *Frontiers in Plant Science*, 14, p.1270039. DOI.

Koledenkova, K., Esmaeel, Q., Jacquard, C., Nowak, J., Clément, C. and Ait Barka, E., 2022. *Plasmopara viticola*, the causal agent of downy mildew of grapevine: from its taxonomy to disease management. *Frontiers in Microbiology*, 13, p.889472. DOI.

Kulišová, M., Vrublevskaya, M., Lovecká, P., Vrchotová, B., Stránská, M., Kolařík, M. and Kolouchová, I., 2021. Fungal endophytes of *Vitis vinifera*—plant growth promotion factors. *Agriculture*, 11, p.1250. DOI.

Kumari, M., Kamat, S., Dixit, R., Pandey, S., Giri, V.P. and Mishra, A., 2021. Microbial formulation approaches in postharvest disease management. *Food Security and Plant Disease Management*, pp.279-305. DOI.

Kumari, M., Qureshi, K.A., Jaremko, M., White, J.F., Singh, S.K., Sharma, V.K., Singh, K.K., Santoyo, G., Puopolo, G. and Kumar, A., 2022. Deciphering the role of endophytic microbiome in postharvest disease management of fruits: opportunity areas in commercial up-scale production. *Frontiers in Plant Science*, 13, p.1026575. DOI.

Kunova, A., Pizzatti, C., Saracchi, M., Pasquali, M. and Cortesi, P., 2021. Grapevine powdery mildew: fungicides for its management and advances in molecular detection of markers associated with resistance. *Microorganisms*, 9, p.1541. DOI.

Kusari, S., Hertweck, C. and Spiteller, M., 2012. Chemical ecology of endophytic fungi: origins of secondary metabolites. *Chemistry & Biology*, 19, pp.792-798. DOI.

Lahlali, R., McGregor, L., Song, T., Gossen, B.D., Narisawa, K. and Peng, G., 2014. *Heteroconium chaetospira* induces resistance to clubroot via upregulation of host genes involved in jasmonic acid, ethylene, and auxin biosynthesis. *PLOS One*, 9, p.e94144. DOI.

Li, H., Ding, J., Liu, C., Huang, P., Yang, Y., Jin, Z. and Qin, W., 2023. Carvacrol treatment reduces decay and maintains the postharvest quality of red grape fruits (*Vitis vinifera* L.) inoculated with *Alternaria alternata*. *Foods*, 12, p.4305. DOI.

Li, Z., Chang, P., Gao, L. and Wang, X., 2000. The endophytic fungus *Albifimbria verrucaria* from wild grape as an antagonist of *Botrytis cinerea* and other grape pathogens. *Phytopathology*, 110, pp.843-850. DOI.

Li, Z., DosSantos, R.F., Gao, L., Chang, P. and Wang, X., 2021. Current status and future prospects of grapevine anthracnose caused by *Elsinoe ampelina*: An important disease in humid grape-growing regions. *Molecular Plant Pathology*, 22, pp.899-910. DOI

Liarzi, O. and Ezra, D., 2013. Endophyte-mediated biocontrol of herbaceous and non-herbaceous plants. In: *Advances in endophytic research*. Springer, pp.335-369. DOI.

Liu, H. and Brettell, L.E., 2019. Plant defense by VOC-induced microbial priming. *Trends in Plant Science*, 24, pp.187-189. DOI.

Lo Presti, L., Lanver, D., Schweizer, G., Tanaka, S., Liang, L., Tollot, M., Zuccaro, A., Reissmann, S. and Kahmann, R., 2015. Fungal effectors and plant susceptibility. *Annual Review of Plant Biology*, 66, pp.513-545. DOI.

Lugtenberg, B. and Kamilova, F., 2009. Plant-growth-promoting rhizobacteria. *Annual Review of Microbiology*, 63, pp.541–556. DOI

Magnin-Robert, M., Trotel-Aziz, P., Quantinet, D., Biagianti, S. and Aziz, A., 2007. Biological control of *Botrytis cinerea* by selected grapevine-associated bacteria and stimulation of chitinase and β-1,3-glucanase activities under field conditions. *European Journal of Plant Pathology*, 118, pp.43–57. DOI

Marasco, R., Rolli, E., Fusi, M., Michoud, G. and Daffonchio, D., 2018. Grapevine rootstocks shape underground bacterial microbiomes and networking but not potential functionality. *Microbiome*, 6, p.17. DOI

Martinez-Medina, A., Flors, V., Heil, M., Mauch-Mani, B., Pieterse, C.M., Pozo, M.J., Ton, J., van Dam, N.M. and Conrath, U., 2016. Recognizing plant defense priming. *Trends in Plant Science*, 21, pp.818–822. DOI

Mauch-Mani, B., Baccelli, I., Luna, E. and Flors, V., 2017. Defense priming: An adaptive part of induced resistance. *Annual Review of Plant Biology*, 68, pp.485–512. DOI

Maurya, S., Ntakirutimana, R., Debnath, B., Rana, M., Kaushik, D. and Srivastava, S., 2024. *Trichoderma* and their secondary metabolites – A potential approach in plant disease management. *Biopesticides International*, 20, pp.21–33. DOI

Mendes, R., Kruijt, M., DeBruijn, I., Dekkers, E., VanDerVoort, M., Schneider, J.H., Piceno, Y.M., DeSantis, T.Z., Andersen, G.L., Bakker, P.A.H.M. and Raaijmakers, J.M., 2011. Deciphering the rhizosphere microbiome for disease-suppressive bacteria. *Science*, 332, pp.1097–1100. DOI

Miotto-Vilanova, L., Jacquard, C., Courteaux, B., Wortham, L., Michel, J., Clément, C., Barka, E.A. and Sanchez, L., 2016. *Burkholderia phytofirmans* PsJN confers grapevine resistance against *Botrytis cinerea* via a direct antimicrobial effect combined with better resource mobilization. *Frontiers in Plant Science*, 7, p.1236. DOI

Mishra, J., Tewari, S. and Singh, S., 2015. Biopesticides: Where do we stand? *Plant Microbe Symbiosis*. DOI

Mondello, V., Spagnolo, A., Larignon, P., Clement, C. and Fontaine, F., 2019. The phyto-protection potential of *Fusarium proliferatum* for control of *Botryosphaeria* dieback pathogens in grapevine. *Phytopathologia Mediterranea*, 58, pp.293–306. DOI

Mugnai, L., Graniti, A. and Surico, G., 1999. Esca (Black Measles) and Brown wood-streaking: Two old and elusive diseases of grapevines. *Plant Disease*, 83, pp.404–418. DOI

Musetti, R., Vecchione, A., Stringher, L., Borselli, S., Zulini, L., Marzani, C., D'Ambrosio, M., Sanità di Toppi, L. and Pertot, I., 2006. Inhibition of sporulation and ultrastructural alterations of grapevine downy mildew by the endophytic fungus *Alternaria alternata*. *Phytopathology*, 96, pp.689–698. DOI

MuthuNarayanan, M., Ahmad, N., Shivanand, P. and Metali, F., 2022. The role of endophytes in combating fungal- and bacterial-induced stress in plants. *Molecules*, 27, p.6549. DOI

Nigris, S., Baldan, E., Tondello, A., Zanella, F., Vitulo, N., Favaro, G., Guidolin, V., Bordin, N., Telatin, A., Barizza, E., Marcato, S., Zottini, M., Squartini, A., Valle, G. and Baldan, B., 2018. Biocontrol traits of *Bacillus licheniformis* GL174, a culturable endophyte of *Vitis vinifera* cv. Glera. *BMC Microbiology*, 18, pp.1–16. DOI

Pacifico, D., Squartini, A., Crucitti, D., Barizza, E., LoSchiavo, F., Muresu, R., Carimi, F. and Zottini, M., 2019. The role of the endophytic microbiome in the grapevine response to environmental triggers. *Frontiers in Plant Science*, 10, p.1256. DOI

Parashar, M. and Mudgal, G., 2024. The Prostrate Spurge-isolated PGPB endophytes, EP1-AS and EP1-BM, can tolerate high levels of salinity and heavy metals and allow wheat growth under these stressors. *Natural Environment and Pollution Technology*, 23(2). DOI

Patya, U., Kumar, V., Singh, M. and Singh, K., 2023. Plant growth-promoting efficacy of endophytic fungi isolated from the terrestrial plants of North India. *Natural Environment and Pollution Technology*, 22(3). DOI

Pavithra, G., Bindal, S., Rana, M. and Srivastava, S., 2020. Role of endophytic microbes against plant pathogens: A review. *Asian Journal of Plant Science*, 9, pp.54–62. DOI

Pavithra, G., Manda, R.R., Addanki, V.A. and Srivastava, S., 2021. Evaluation of isolated endophytes, bio-agents, and fungicides against anthracnose of chilli. *Biopesticides International*, 17, pp.143–149. DOI

Perazzolli, M., Dagostin, S., Ferrari, A., Elad, Y. and Pertot, I., 2008. Induction of systemic resistance against *Plasmopara viticola* in grapevine by *Trichoderma harzianum* T39 and benzothiadiazole. *Biological Control*, 47, pp.228–234. DOI

Pineda, A., Zheng, S.J., van Loon, J.J., Pieterse, C.M. and Dicke, M., 2010. Helping plants to deal with insects: The role of beneficial soil-borne microbes. *Trends in Plant Science*, 15, pp.507–514. DOI

Pinto, C., Custódio, V., Nunes, M., Songy, A., Rabenoelina, F., Courteaux, B., Clement, C., Gomes, A.C. and Fontaine, F., 2018. Understand the potential role of *Aureobasidium pullulans*, a resident microorganism from the grapevine, in preventing the infection caused by *Diplodia seriata*. *Frontiers in Microbiology*, 9, p.3047. DOI

Potshangbam, M., Devi, S.I., Sahoo, D. and Strobel, G.A., 2017. Functional characterization of endophytic fungal community associated with *Oryza sativa* L. and *Zea mays* L. *Frontiers in Microbiology*, 8, p.325. DOI

Rondot, Y. and Reineke, A., 2019. Endophytic *Beauveria bassiana* activates the expression of defense genes in the grapevine and prevents infections by grapevine downy mildew *Plasmopara viticola*. *Plant Pathology*, 68, pp.1719-1731. DOI

Salomon, M.V., Bottini, R., de Souza Filho, G.A., Cohen, A.C., Moreno, D., Gil, M. and Piccoli, P., 2014. Bacteria isolated from roots and rhizosphere of *Vitis vinifera* retard water losses, induce abscisic acid accumulation, and synthesis of defense-related terpenes in in vitro cultured grapevine. *Physiologia Plantarum*, 151, pp.359-374. DOI

Santangelo, J.S., Turley, N.E. and Johnson, M.T., 2015. Fungal endophytes of *Festuca rubra* increase in frequency following long-term exclusion of rabbits. *Botany*, 93, pp.233-241. DOI

Santoyo, G., Moreno-Hagelsieb, G., del Carmen Orozco-Mosqueda, M. and Glick, B.R., 2016. Plant growth-promoting bacterial endophytes. *Microbiological Research*, 183, pp.92-99. DOI

Schisler, D.A., Slininger, P.J., Behle, R.W. and Jackson, M.A., 2004. Formulation of *Bacillus* spp. for biological control of plant diseases. *Phytopathology*, 94(11), pp.1267-1271. DOI

Schulz, B., Haas, S., Junker, C., André, N. and Schobert, M., 2015. Fungal endophytes are involved in multiple balanced antagonisms. *Current Science*, 108(1), pp.39-45.

Serra, S., Ligios, V., Schianchi, N., Prota, V.A. and Scanu, B., 2018. Expression of grapevine leaf stripe disease foliar symptoms in four cultivars in relation to grapevine phenology and climatic conditions. *Phytopathologia Mediterranea*, 57, pp.557-568. DOI

Shameer, S. and Prasad, T.N.V.K.V., 2018. Plant growth-promoting rhizobacteria for sustainable agricultural practices with special reference to biotic and abiotic stresses. *Plant Growth Regulation*, 84, pp.603-615. DOI

Sharma, I., Raina, A., Choudhary, M., Apra, Kaul, S. and Dhar, M.K., 2023. Fungal endophyte bioinoculants as a green alternative towards sustainable agriculture. *Heliyon*, 9, e19487. DOI

Shen, F., Wu, W., Han, X., Wang, J., Li, Y. and Liu, D., 2021. Study on the occurrence law and green control of grape grey mold from the perspective of ecological balance. *Bioengineered*, 12, pp.779-790. DOI

Shi, J., Zeng, Q., Liu, Y. and Pan, Z., 2012. *Alternaria* sp. MG1, a resveratrol-producing fungus: Isolation, identification, and optimal cultivation conditions for resveratrol production. *Applied Microbiology and Biotechnology*, 95, pp.369-379. DOI

Singh, D.P., Singh, H.B. and Prabha, R., 2016. Microbial inoculants in sustainable agricultural productivity. *Springer*, 2, p.308. DOI

Srivastava, S., Aspak Rana, M., Katyayani, K.K.S., Kaushik, D., Kumar, R., Shukla, M., Kumar, S., Manda, R.R. and Singh, V.P., 2023. Exploring the bioefficacy of endophytic bacteria against important plant pathogens. *Journal of Biopesticides*, 16(1), pp.79-99. DOI

Srivastava, S., Rana, M., Sarma, B.K. and Meshram, S., 2024. Endophyte-mediated modulation of secondary metabolism in crops for biotic stress management. In: *Plant Endophytes and Secondary Metabolites*. Elsevier Inc., pp.205-233. DOI

Statista, 2024. Grape production worldwide 2024 [WWW Document]. Statista. Available at: https://www.statista.com/statistics/237600/world-grape-production-in-2007-by-region/

Sudawan, B., Chang, C.S., Chao, H.F., Ku, M.S. and Yen, Y.F., 2016. Hydrogen cyanamide breaks grapevine bud dormancy in the summer through transient activation of gene expression and accumulation of reactive oxygen and nitrogen species. *BMC Plant Biology*, 16, pp.1-18. DOI

Suryanarayanan, T.S., Thirunavukkarasu, N., Govindarajulu, M.B., Sasse, F., Jansen, R. and Murali, T.S., 2009. Fungal endophytes and bioprospecting. *Fungal Biology Reviews*, 23, pp.9-19. DOI

Xia, Y., Liu, J., Chen, C., Mo, X., Tan, Q., He, Y., Wang, Z., Yin, J. and Zhou, G., 2022. The multifunctions and prospects of endophytes and their metabolites in plant disease management. *Microorganisms*, 10, p.1072. DOI

Yakop, F., Taha, H. and Shivanand, P., 2019. Isolation of fungi from various habitats and their possible bioremediation. *Current Science*, 116, pp.733-740.

Yan, J.F., Broughton, S.J., Yang, S.L. and Gange, A.C., 2015. Do endophytic fungi grow through their hosts systemically? *Fungal Ecology*, 13, pp.53-59. DOI

Yang, M.Z., Ma, M.D., Yuan, M.Q., Huang, Z.Y., Yang, W.X., Zhang, H.B., Huang, L.H., Ren, A.Y. and Shan, H., 2016. Fungal endophytes as a metabolic fine-tuning regulator for wine grapes. *PLOS ONE*, 11, e0163186. DOI

Zhang, X., Zhou, Y., Li, Y., Fu, X., and Wang, Q., 2017. Screening and characterization of endophytic *Bacillus* for biocontrol of grapevine downy mildew. *Crop Protection*, 96, pp.173-179. DOI