

Review Article

Mechanism of Antagonistic Bioagents in Controlling of Root-Knot Nematodes (*Meloidogyne* sp.): A review

Abstract

Root-knot nematodes are among the most significant pathogenic organisms due to their global distribution, capacity for destruction, and economic importance. Antagonistic bioagents are a more effective alternative to synthetic pesticides in the suppression of root-knot nematodes. Bioagents reduce the use of synthetic chemicals, which are hazardous to both humans and the environment. Despite this, some bioagents, such as fungi and bacteria have unknown mechanisms. This review discusses the nematophagous bacteria and fungi that have been discovered so far, including *Pochonia*, *Trichoderma* sp., *Pseudomonas* sp., and *Bacillus* sp., with an overview of the current advances in research regarding their molecular and biochemical control mechanisms. Biological control agents (BCAs), as valuable ecological enemies of nematode infestations, use a range of mechanisms, such as parasitism, nutrient competition, toxin production, induce systemic resistance to antibiotics, enzymes, and enhance plant health. They suppress nematodes directly, improve plant growth, and facilitate the colonization and activities of antagonistic microbes in the rhizosphere. Understanding the molecular basis of BCAs suppression mechanisms provide the basis for their future incorporation into phytopathogen or plant disease control management. This study reviews the current threat posed by the root-knot nematode, biological control, antagonistic bioagents, and their mechanisms, and the future perspectives in modern agricultural sustainability to provide a basis for the broad control of root-knot nematodes.

Keywords: Root-knot nematodes, biological control, mechanism, biological control agents, plant-parasitic nematodes

Introduction

Plant-parasitic nematodes (PPNs) are among the most dangerous plant pathogens, exacerbating plant diseases and interfering with crop development, contributing to economic loss (Subedi et al., 2020; Ahmad et al., 2021a). PPNS, or Phytonematodes, are parasitic worms that spend part of their lives in the soil, causing damage to plant tissues while feeding (Sato et al., 2019). They are also known to attack diverse portions of vascular plants, with the majority feeding on or in plant roots and the minority feeding on aerial parts (Mitiku, 2018). PPNS are major threats to the world's food supply, accounting for at least 12.3% of global food production loss each year (Singh et al., 2019a). One of the most significant worms associated with PPNS is the root-knot nematode (*Meloidogyne* sp.). Root-knot nematode (RKN) is the most significant PPN species on the planet and its among the top five primary plant pathogens (Abd-Elgawad, 2020; Karuri et al., 2017; Mukhtar, 2018). Of these, the root-knot nematodes are possibly the most important because of their global distribution, destructive capacity, and economic importance (Khan et al., 2020). They are thought to be the most dangerous nematodes on the planet. They affect over 5000 plant species and cause economic losses in a variety of crops (Costa et al., 2019; Perpétuo et al., 2021). Worms are widely regarded as the most damaging eggplant pests (Aydinli and Mennan, 2016). *Meloidogyne incognita*, *M. arenaria*, *M. hapla*, and *M. javanica* are the most common species of phytophagous RKNs in the genus *Meloidogyne* (Hussain and Mukhtar, 2019; Murata et al., 2020; Leong et al., 2021). *Meloidogyne* sp. threatens over 2000 plant species, including tobacco (*Nicotiana tabacum*), coffee (*Coffea arabica*), tomato (*Solanum lycopersicum*), Niebe (*Vigna sinensis*), kenaf (*Hibiscus cannabinus* L.), sugar cane (*Saccharum officinarum*), tea (*Camellia sinensi*), carrot (*Daucus carota*), melon (Lima et al., 2017). Chemical nematicides and resistant cultivars have traditionally been used to manage *Meloidogyne* sp. (Jones, 2016; Pretorius, 2018). Synthetic agrochemicals, which are made up of inorganic or organic compounds, have been the most successful technique in modern agricultural production for controlling plant diseases and pathogens, protecting crop quality, and increasing production because of their affordability, easy handling, and efficacy. While nematodes can be effectively managed with nematicides, their use is restricted because of their limited-term consequences: increased prices, nematode resistance establishment, environmental and health risks, toxic effects, and negative impacts on ecosystems. The use of microorganisms as biocontrol agents of

Comment [G1]: Misgana

Comment [G2]: a or b ????

Comment [G3]: Ribeiro Costa

Comment [G4]: Mukhtar and Hussain

PPNs can replace chemical control. Bioagents are considered to be both safe and affordable (Mukhtar et al., 2017). Over the last few decades, biocontrol using rhizosphere bioagents (e.g. bacteria and fungi) has been effective in improving plant growth and influencing nematode reproduction via a variety of mechanisms, like producing growth regulators, bioactive compounds, and enzymes that act directly on nematodes (Rocha et al., 2019; Hussain et al., 2020a). Biological control agents (BCA) appear to be a promising tool for controlling phytopathogens. This study aims to review the current threat of root-knot nematode infection on crops, biological control, antagonistic bioagents, and their mechanisms, and future directions in agriculture to provide a basis for the broad management of root-knot nematodes.

Comment [G5]: 2020a a ???

The current threat of root-knot nematode (RKNs) infection on crops

RKNs are among the most significant pathogenic organisms due to their global distribution, capacity for destruction, and economic importance (Khan et al., 2020). Diseases caused by PPNs, cost the global economy over \$150 billion annually (Sivasubramaniam et al. 2020; Seong et al., 2021), with RKNs responsible for more than half of these losses (Silva et al., 2021). The quality and quantity of plant production output can be negatively affected by PPNs, pests, and diseases (Holajjer et al., 2020; Perpétuo et al., 2021). RKNs are one of the globe's most devastating nematode groups, causing substantial economic harm to a vast number of arable crops in tropical and subtropical environments (Janssen et al., 2016; Karuri et al., 2017). RKNs are rhizosphere parasitic nematodes that infest over 5000 species of plants around the world, including a variety of vegetables, commercial crops, shrubs, and trees (Costa et al. 2019). According to a recent study, the top ten parasitic nematode taxa in molecular plant pathology are ranked by scientific and commercial significance (Sanchez Monge et al., 2015). Tomato, carrot, melon, tobacco, kenaf, sugar cane, tea, and coffee are just a few of the over 2000 plant species susceptible to *Meloidogyne* sp., which poses the most economically significant threat to agricultural crop output (Tranier et al., 2014; Postnikova et al., 2015). Even though the host range of many RKNs overlaps, not every RKN pathogen may attack the same plants. *Meloidogyne* sp. is widely regarded as the most destructive worm parasite of eggplant (Ye et al., 2019, Yergaliyev et al., 2020). Their infection begins with root penetration by second-stage juveniles (J2), which hatch in the soil from eggs left in egg masses on infected roots by females (Arshad et al., 2021; Bridge and Starr, 2019). Chlorosis (yellowing), rotting, wilting, root galling, early leaf shedding with

Comment [G6]: 2020 a or b ??

Comment [G7]: Did not appear in the reference list.

Comment [G8]: Ribeiro Costa

Comment [G9]: Sánchez Monge

severely stunted growth, and root development anomalies are all common signs of RKN attack, leading to huge crop losses (Philbrick et al., 2020; Arshad et al., 2021). *M. incognita* and *M. javanica* are two dormant RKN species in Pakistan since they are common in vegetable-growing areas, severely limiting growth and yield (Mukhtar, 2018). Root-knot nematodes are a danger to economic crop farming around the world. Nematode inoculum development and annual production of the same cultivars on the same land are the primary causes of their yield losses (Mukhtar and Hussain, 2019; Mukhtar and Kayani, 2020). Because nematodes can increase susceptibility to other parasites, the severity of this damage can be substantially great (Mabbott, 2018). Crop loss caused by nematodes is estimated to cost between \$80 and 118 billion dollars per year (Roopa and Gadag, 2020). It is estimated that these worms cause 18–20.7% of tomato production losses, accounting for one-third of the losses normally attributed to pests and diseases (Hajihassani et al., 2020). When nematode populations are low, the foliar symptoms may or may not be present. Furthermore, RKN infestation can make the host plant more vulnerable to other diseases, such as root rot and *Fusarium* crown, in areas where these pathogens are present (Cola Ateş et al., 2018; Abd-Elgawad, 2019). RKNs are difficult to identify and control because they live in infected host plants below the soil surface. *Meloidogyne* sp. has always been difficult to control owing to its high reproductive potential and extensive host specificity, which restricts crop rotation's effectiveness. (Bridge and Starr, 2019; Philbrick et al., 2020). Plant mortality, lower production, decreased chlorophyll content, and a variety of other negative physiology are all additional symptoms and damages of root-knot nematode infestation (El-Sagheer, 2019; Guerrero Abad et al., 2021).

Comment [G10]: ÇolaC Ateş

Biological control of root-knot nematodes (RKN)

To ensure food quality in agricultural production, a variety of plant diseases must be handled and managed well (Sidhu et al., 2019). Several approaches and treatment options are used around the world to manage, relieve, and inhibit disease in plants (O'Brien 2017; Singh et al., 2019b). The need for synthetic chemicals in the control of diseases in plants is becoming less popular around the world. Today, many types of research are being done to develop safe, environmentally acceptable, and efficient options to synthesize pesticides for reducing decomposition damage in cultivated crops and managing plant diseases in the field, both of which result in significant economic losses (Droby et al., 2016; Nabi et al., 2017). Biocontrol is a term commonly used in

Comment [G11]: Did not appear in the reference list.

plant pathology and entomology. Biocontrol is used in the field of plant pathology to suppress the buildup of pathogens in the microbial population, whereas biocontrol in entomology is used to suppress the multiplication of parasitic insects against pathogenic microbes, entomophagous nematodes, or predation parasites (Hajek and Eilenberg, 2018; Singh et al., 2020). Biocontrol is also defined as "the employment of microbes or their metabolites to eliminate or reduce pest-related damages or losses" (Barratt et al., 2018b; Van Lenteren, 2021). Bioagents, which occupy the same rhizospheric zone as pathogens and absorb the same nutrients, are often used to manage diseased plants (Thakur and Singh, 2018; Hussain et al., 2020a). Biocontrol could be accomplished in a variety of ways, including partial, significant, and entire control. Biological control agents have shown promise as a cost-effective and ecologically friendly pest control approach (Subedi et al., 2020; Karimi et al., 2021). Several antagonistic organisms, including soil fungi from the genera *Trichoderma* (*Hypocreaceae*), *Verticillium*, *Pochonia*, and *Paecilomyces*, have been tested against *Meloidogyne* sp. and have been commercialized (Anwer 2017; Kiriga 2018). In diverse crops and experimental situations, a variety of fungi, including *Pochonia chlamydosporia* isolates, were tested as RKN bioagents (Escudero et al., 2017; Peiris et al., 2020; Tazi et al., 2021). Pathogen growth is suppressed while plant growth and development are promoted by *P. chlamydosporia* colonization of the root (Kumar et al., 2018; Zhuang et al., 2021). *Pochonia chlamydosporia* has been proven to be a bioagent for RKNs and cyst nematodes. This fungus parasitizes RKN eggs within 24 hours, preventing them from hatching by more than 55% (Nagachandrabose, 2018). *Trichoderma* sp enables the development of biocontrol strategies for economically significant plant infections (Guler et al., 2016). *Trichoderma* sp. has an antagonistic effect on *Pythium ultimum* and *Rhizoctonia solani* due to the production of secondary metabolites (Khan et al., 2020). *Purpureocillium lilacinum*, formerly *Paecilomyces lilacinus* (Juyal et al., 2018; Raghavan et al., 2018), is a saprophyte that parasitizes nematode sedentary stages, particularly their eggs, which are generally deposited in a gelatinous matrix, as well as female nematodes (Kiriga, 2018; Walia et al., 2021). Because of its strong potential for biological nematode control, it has been successfully used on tomatoes against *M. javanica* and *M. incognita* (Kiriga et al., 2018; Dahlin et al., 2019). *Bacillus subtilis*, *Bacillus sphaericus*, and *Pseudomonas fluorescens* are the antagonistic rhizobacteria that affect RKN (Ahmad et al., 2020b; Migunova and Sasanelli, 2021). *Agrobacterium*, *Enterobacter*, *Aureobacterium*, *Chryseobacterium*, *Alcaligenes*, *Corynebacterium*, *Klebsiella*, *Paenibacillus*,

Phyllobacillus, *Xanthomonas*, *Telluria*, and *Rhizobium*, are among the other genera mentioned (Rubio et al., 2019). Fungi from the *Trichoderma* and *Purpureocillium* genera (Baron et al., 2020), endospores of *Pasteuria penetrans*, and commercially available rhizobacteria (e.g., *Bacillus firmus*) hold the most promise for biological control of RKNs (*Meloidogyne* sp.) (Engelbrecht, 2019; Abd-Elgawad, 2020). Biological management approaches appear to be less expensive, making them more accessible to farmers and contributing to the agricultural sector's long-term viability. Bioagents are mostly developed to reduce pest populations economically (Bielza et al., 2020; Gehlot et al., 2021). The activity and performance of biological control agents are influenced by their surroundings.

Bioagents used in controlling root-knot nematodes (RKNs)

A biological control agent (BCA) is an organism that inhibits a pest or disease. They are microbial antagonists that reduce plant disease and phytopathogens in several ways (Verma et al., 2019b; Maurya, 2020). Much information on the variety of methods of BCA in the control of plant diseases has been published over the last few decades (O'Brien, 2017; Rashad and Moussa, 2020). For pest and disease management, BCAs offer an alternative to chemical fertilizers and pesticides. Biotechnological applications, such as gene modification, enable us to enhance the characteristics of such bioagents, allowing them to survive in stressful and nutrient-limited environments, producing more antimicrobial phytochemicals under different temperatures and pH conditions than the existing isolates. Once a BCA has established itself in the rhizosphere, it should be able to colonize and compete for space and nutrients with grown roots (Odelade et al., 2019; Poveda et al., 2020). BCA will be unable to compete for food and space if it is unable to develop itself in the rhizosphere and grow along with the treated plant's root system (Khan et al., 2011). BCAs for the management of phytopathogens are often fungal or bacterial isolates obtained from the phyllosphere, endosphere, or rhizosphere, and they serve a vital role in pathogen management. Plant-parasitic nematodes are parasites, predators, or antagonists of fungi, bacteria, protozoans, viruses, turbellarians, enchytraeids, mites, predatory nematodes, collembolans, and tardigrades. The above microbes are being utilized to regulate PPN in some agricultural and horticultural crops as biocontrol agents (Hussain et al., 2020b; Tóthné Bogdányi et al., 2021). Plant diseases can be combated using microbial biological control agents (MBCAs) such as mycoviruses and bacteriophages. In 2017, 101 MBCAs were certified for disease control

Comment [G12]: Odelade and Babalola

in Australia, Brazil, Canada, Europe, Japan, New Zealand, and the United States (Köhl et al., 2019; Ji et al., 2020; Zehra et al., 2021). Bioagents or antagonistic microbes hinder pathogen invasion or pathogen establishment in the host plant. The production of extracellular enzymes by the antagonist, competition for food and habitat among pathogens, and pathogenicity detoxification are all related to the biological management of the disease (Odoh, 2017; Sharma et al., 2019). In a variety of ways, microbial biocontrol agents (MBCAs) prevent plants from disease damage. In the absence of direct antagonistic interaction with the parasites, they may develop or activate enhanced resistance to pathogen infections in plant tissues (Köhl et al., 2019). Competition for nutrients and space is another way to come into contact with viruses (Miller et al., 2019). MBCAs can interact with pathogens actively via hyperparasitism or antibiosis. Hyperparasites attack and destroy fungal pathogen hyphae, spores, and resting structures, as well as bacterial pathogen cells (Adejumo et al., 2021). MBCAs protect agricultural commodities from disease damage in a variety of ways. They compete with pathogens for available space and nutrients in an indirect way (Ons et al., 2020). They interact with pathogen species directly via an antibiosis or hyperparasitism mechanism. The production of antimicrobial compounds that suppress bacteria is another direct-mode strategy (Palyzová et al., 2019; Los et al., 2020; Dann and McLeod, 2021). The compounds emerge as potential plant disease control options. Most BCAs that suppress fungal or bacterial plant diseases and pathogens employ one or more pathways. The production of antibiotics, enzymes, or specific active compounds is referred to as antibiosis, whereas competitive displacement is referred to as competition for food or space (Singh et al., 2020a). Microbial pathogen-associated molecular patterns (MAMPs) are resistance-inducing stimuli produced by microorganisms that are identified by pattern recognition receptors (PRRs) (De Lorenzo et al., 2018; Mélida et al., 2020; Zehra et al., 2021). The fact that BCAs are pathogen-specific and unlikely to harm non-target species is the major advantage of using them. Weeds, worms, insects, micro-pathogens, mites, and even vertebrates are among the target species controlled by biocontrol agents. Some phytopathogens are so toxic that they kill the organisms they infect (Singh et al., 2020a; Zhang et al., 2020).

Mechanism of antagonistic fungi

Fungal antagonists are now recognized as a rapidly expanding natural phenomenon with a wide range of agricultural applications, including food production and yield. Biological control agents such as antagonistic fungi are used in agriculture. Fungi have a high rate of sexual and asexual reproduction, are target-specific, and have a short generation period, which has increased the potential for biological control agents to combat plant diseases. Most fungal species have defense systems that enable them to effectively defend plants against plant pathogenic fungi-caused diseases. Regardless of the process of fungi seizing or parasitizing, the association of both host-pathogen and fungi or prey entails the infiltration of the outermost body shell. This infiltration subsequently leads to the pathogen's colonizing the body's interior tissues via digestion, enabling it to satisfy its nutrient requirement (Branine et al., 2019; Tawidian et al., 2019). Despite being saprophytes, these fungi can trap nematodes in the soil during their larval or free adult stages. Hydrolytic enzymes found in the cuticle, such as lipases and chitinase, are thought to be responsible for fungi's ability to kill insects and pests (Amobonye et al., 2020; Lin et al., 2021; Litwin et al., 2020). Extracellular proteases hydrolyzing the cuticle of worms have been shown to produce peptides that can result in trap formation (Ahmad et al., 2021b; Liang et al., 2019; Shalaby et al., 2020). RKNs (*M. javanica*, and *M. incognita*) have all been demonstrated to be suppressed by *Paecilomyces lilacinus* and *P. lilacinum* (Iqbal et al., 2018; Tariq et al., 2020; Xu et al., 2021), with good results against *Meloidogyne* spp. (He et al., 2020). The production of proteases and chitinases by the fungus is linked to the infection process (Xu et al., 2021). The enzymes pierce the eggshell's vitelline layer, allowing mycelium to infiltrate, proliferate, and harm early embryonic developmental stages. The hyphae breach the eggshell and multiply when the egg contents are depleted, parasitizing other eggs in the egg mass (Islam et al., 2021). Chemical compounds and extracts generated by a variety of fungi are important in plant-pathogen biocontrol activities as well (Latz et al., 2018; De Silva et al., 2019; Keswani et al., 2020). *Trichoderma*, *Paecilomyces* (Al-Hazmia et al., 2019), *Pochonia*, and *Arthrobotrys* (Kassam et al., 2021) are well-known *Meloidogyne* sp. inhibitors. *Pochonia chlamydosporae* have been demonstrated to parasitize *Meloidogyne* sp. eggs, and females (Silva et al., 2017; Ghahremani et al., 2019). *Pochonia chlamydosporae* are among the most extensively researched biocontrol agents (BCA) against PPNs in the world today (Lubian et al., 2017). *Arthrobotrys* sp. produces hyphae with sticky features that catch and feed on nematodes as a nematophagous fungus (Cao et al., 2018; Karakaya 2020). When used before planting tomato seedlings,

Comment [G13]: Did not appear in the reference list.

Comment [G14]: Karakaş

Arthrobotrys dactyloides reduced the quantity of *M. incognita* (Peiris et al., 2020; Soliman et al., 2021). *Meloidogyne* sp. is also known to be antagonized by fungi from the genera *Trichoderma* and *Fusarium*. It has been demonstrated that *Trichoderma* sp. can invade plant root surfaces. This has been linked to its ability to minimize root-knot disease (Mukhtar et al., 2021; Wang et al., 2021b) as well as competition with nematodes. *Trichoderma* sp. successfully decreased *Meloidogyne* sp., second-stage juvenile (J2) densities, and egg production in tomato roots (Dahlin et al., 2019; Kiriga et al., 2018; Tazi et al., 2021). *Trichoderma* is rhizosphere dwellers that colonize the surface of plant roots. Their antagonism effect is primarily directed at fungi, yet has an impact on the life cycle of the RKN (Rawal, 2020; Sarker et al., 2021). *Trichoderma* sp. aids plant development by inhibiting nematode penetration. *Trichoderma* conidia attach to the cuticle or eggshell of worms and parasitize them (Du et al., 2019; Zhang et al., 2020; Ahmad et al., 2021a). Mycoparasitism and entomopathogenicity are the two primary mechanisms by which fungal biological control agents kill agricultural pests and insects. Mycoparasitism is the interaction of a fungus parasite and a fungus host. In contrast, entomopathogenic fungi are parasitic fungi that can kill pathogens. Fungi that control fungal infections in plants via mycoparasitism are known as *Gliocladium* and *Trichoderma* (Vinale et al., 2014; Gomes et al., 2015). Toxic chemicals generated by fungi can affect the pathogens of the host organism (Ramesh and Radhakrishnan, 2020). *Trichoderma* species are known to produce toxins and antibiotics such as viridian, fusaric acid, lilacin, oxalic acid, trichoderin, trichodermol A, harzianolide, and penicillic acid, which suppress the development of RKNs (Devi et al., 2018). *Trichoderma* sp. is also being proposed to combat plant diseases and phytopathogens through mycoparasitism, competition, antibiosis, hydrolysis of enzymes, and induced host resistance, among other methods (Silva et al., 2019; Deb and Das, 2020). *Trichoderma* also produces chemicals that harm nematode cuticles, such as volatile organic compounds, 6-pentyl-pyrone, and metabolites (Basit et al., 2021). In addition to direct antagonism, *Trichoderma* sp. manages *Meloidogyne* through a range of methods, including the generation of fungal metabolites (e.g., AAL toxins 3–10, helvolic acid) and induced resistance (Abdelrahman and Jogaiah, 2019; Al-Ani, 2018). Direct antagonism, indirect antagonism, and mixed path antagonism are the three types of intraspecific antagonistic processes related to biocontrol (Ramesh and Radhakrishnan, 2020). Hyperparasitism is a type of predation that underpins direct antagonism. Predation, toxic metabolite formation, and competition for space and nutrients are all examples of direct

Comment [G15]: Devi and Bora

antagonism. Mixed path antagonism is induced by metabolic enzymes, physical, chemical inference, antibiotics, and uncontrolled byproducts. Indirect antagonism, on the other hand, refers to activities that have no direct effect on the pathogens under attack. Indirect antagonism is characterized by two basic processes: competition and host resistance enhancement. Nutrient scavenging via siderophores, leachate consumption, and niche competition are the main mechanisms at work in the competition. The method includes host resistance induction at the molecular level, as well as phytohormone-associated direct pathogen contact (Solairaj et al., 2021). ISR has been linked to phytoalexins, pathogenesis-related proteins, phenolic compounds, reactive oxygen species, and other compounds. These also contribute to the development of numerous physiological obstacles, such as the cuticle and cell plant changes, mostly caused by induced plant action (Aragon et al., 2017; Ziv et al., 2018). These mechanisms are energy-dependent, allowing plants to maintain their defense systems. Defensive priming, in contrast to direct-induced resistance, allows for a powerful and quick response at a minimal energy cost (Chen et al., 2019; Mageroy et al., 2020). Mechanisms of plant defense or reactions are activated by MBCAs depending on plant genotype (Maheshwari et al., 2020; Pandey et al., 2021). Siderophores, biosurfactants, volatile organic compounds (VOCs), antibiotics, pyocyanin, and DAP are all used to induce systemic resistance. The production of signal components by MBCAs triggers defensive mechanisms to respond to infections, which is how they work. The biocontrol mechanism, in other words, is reliant on MBCAs' capacity to adapt to and thrive on the plant (Walia et al., 2021; Zehra et al., 2021).

Comment [G16]: Aragón

Table 1: Fungi species used as bioagents and their mechanisms against RKN

Fungi Strain	Mechanism	Target Pathogen and Host Plant	Reference
<i>Trichoderma spp</i> (eg, <i>T. harzianum</i> , <i>T. viride</i> , <i>T. virens</i> , <i>T. atroviride</i>)	Parasitism, Antibiotic production (eg. trichodermin, trichoviridin, dermadin), ISR and SAR, Secretes lytic enzymes (chitinase, glucanases, and protease), toxic metabolites	<i>M. incognita</i> . (Tomato), <i>M. javanica</i> , (Tomato), <i>M. graminicola</i> , (Rice), <i>M. arenaria</i> , (Maize).	(Abd-El-Kareem et al., 2019; Javeed et al., 2016; Singh et al., 2017)

<i>Pochonia chlamydosporia</i>	Parasitism, Toxin secretion	<i>M. incognita</i> , (Tomato), <i>M. javanica</i> , (Lettuce), <i>M. hapla</i> , (Lettuce)	(Kumar, 2020; Saxena, 2018; Tian et al., 2014)
<i>Paecilomyces lilacinus</i>	Parasitism, Antibiotics (leucinostatin, lilacin), Enzymes (chitinase and protease).	<i>M. javanica</i> , (Pigeonpea), <i>M. incognita</i> , (Tomato) <i>M. arenaria</i> , (Brinjal)	(Moosavi and Zare, 2020; Najafi et al., 2016)
<i>Aspergillus niger</i>	Parasitism, Induces systemic resistance (ISR)	<i>M. incognita</i> , (Mung bean), <i>M. javanica</i> , (Pigeonpea), <i>M. arenaria</i> , (Tomato).	(Al-Ani, 2018; Jin et al., 2019; Khanna et al., 2021)
<i>Verticillium chlamydosporium</i>	parasitism	<i>M. incognita</i> , <i>M. javanica</i> and <i>M. arenaria</i> (maize, kale and Phaseolus).	(Giné et al., 2016; Tranier et al., 2014)
<i>Arbuscular mycorrhizal fungi (AMF)</i>	Parasitism	<i>M. incognita</i> (sweet, pepper, tomato)	(Herrera-Parra et al., 2021)
<i>Syncephalastrum racemosum</i>	Secondary metabolites, production of toxins, enzymes, ISR, and parasitism	<i>M. incognita</i> (Cucumber)	(Huang et al., 2014)

Mechanism of antagonistic bacteria

Several bacterial strains have been shown to have the potential to become biocontrol agents. *Bacillus*, *Pseudomonas*, and *Azotobacter* isolates from plant roots displayed antagonistic activity against the plant pathogen and acted as disease control agents (Verma et al., 2019a; Migunova and Sasanelli, 2021). The bacterial group which colonizes and supports the development of plants' roots is known as plant growth-promoting rhizobacteria (PGPR) (Noumavo et al., 2016; Qiao et al., 2017). The above (PGPR) are among the most efficient and sustainable BCAs for controlling plant pathogens and disease (Shaikh and Sayyed 2015; Vejan et al., 2016). Because PGPR is non-toxic, naturally occurring microorganisms with long-term use, they have many advantages over chemical biocontrol agents. *Pseudomonas* sp. and *Bacillus* sp. have been regarded as significant bioagents in the fight against root and soil-borne diseases in a variety of crops, including wheat, tomato, potato, and chickpea (Nguvo et al., 2019; Hussain et al., 2020b).

Antimicrobial metabolites generated by bacteria bioagents of the genera *Agrobacterium*, *Bacillus*, *Pantoea*, *Pseudomonas*, *Serratia*, *Stenotrophomonas*, *Streptomyces*, and others have been identified, with a majority of them having broad-spectrum action. *Bacillus* has been studied for lipopeptides like iturin, surfactin, and fengycin, whereas *Pseudomonas* has been studied for antibiotic metabolites like DAPG, pyrrolnitrin, and phenazine (Kenawy et al., 2019; Tariq et al., 2020). Many antibiotics are only made after a bacteria reaches a certain level of resistance. In phenazine-producing *Pseudomonas*, this quorum-sensing mechanism is well understood. Plant growth secreted toxin surface chemicals (bio-surfactants) and volatiles, chitinase cell wall-degrading enzymes, and -1,3-glucanase enhancing rhizobacteria to reduce soil-borne pathogens (Youssef et al., 2018; Sayyed et al., 2019; Wang et al., 2021a). The release of siderophore ligands, which efficiently grab iron and inhibit pathogen development, was previously identified as a biocontrol mechanism (Parry et al., 2019; Avelar, 2021).

Comment [G17]: Did not appear in the reference list.

Table 2: Mechanism of Bacteria Bio-control agents in controlling Root-knot nematodes

Bacteria Strain	Mechanism	Target Nematode	Reference
<i>Pasteuria penetrans</i> ¹	Predation	<i>Meloidogyne spp.</i>	(Subedi et al., 2020)
<i>Pseudomonas spp.</i> (<i>P. aeruginosa</i> , <i>P. stutzeri</i> , <i>P. fluorescens</i> , <i>P. putida</i>)	Hydrogen cyanide (HCN), Diacetylphloroglucinol (DAPG), ISR and SAR, Pyoluteorin, Extracellular protease	<i>M. incognita</i> , <i>M. javanica</i>	(Avelar, 2021; Khanna et al., 2021)
<i>Serratia marcescens</i>	Volatile metabolites, Prodigiosin	<i>M. incognita</i> , <i>M. javanica</i> ,	(El-Ashry et al., 2020; Zhao et al., 2021)
<i>Bacillus spp.</i> (e.g <i>B. cereus</i> , <i>B. coagulans</i> , <i>B. megaterium</i> , <i>B. licheniformis</i> , <i>B. firmus</i>)	Antibiotic production, Hydrolytic enzymes (Chitinase, Protease, Sphingosine), ISR, Secondary metabolites,	<i>M. incognita</i> , <i>M. javanica</i> , <i>M. graminicola</i> , <i>M. arenaria</i>	(Ahmad et al., 2021a; Subedi et al., 2020)
<i>Corynebacterium paurometabolum</i>	Hydrogen sulfide, Chitinase	<i>M. incognita</i>	(Márquez et al., 2019; Subedi et al., 2020)
<i>Rhizobium etli</i>	ISR	<i>M. javanica</i>	(Xia et al., 2019)

		(Tomato)	
--	--	----------	--

Future direction / prospects

Man has worked since ancient times to improve agricultural productivity and reduce disease susceptibility in crops by adopting agricultural methods that minimize both diseases and pathogens (Thurstun, 2019; Thambugala et al., 2020). Food security is a top priority for all governments, but it is especially important in developing countries with rapidly growing populations (Emami et al., 2018). Food crop production must be expanded to satisfy the nutritional demands of a growing population. Overuse of synthetic pesticides, on the other hand, is an unsustainable practice that comes at a high cost in terms of environmental harm and organism health. Commercial uses and implementations of plant disease biocontrol have been delayed due to the variable effectiveness of BCAs in different climatic environmental conditions as well as host specificity. Recent advancements in science have enabled us to learn more about molecular action mechanisms like the production of nemato-toxins, signaling pathways that activate the host-plant defense mechanisms, and the infestation process. This knowledge must lead to the development of new approaches to enhance the effectiveness of BCAs for biocontrol implementations against RKN, increasing the microbial secretion of toxic compounds or metabolites, and developing commercial nematocidal agents. To overcome this challenge, new biotechnological techniques must be developed to generate BCA formulations with greater stability, efficiency, and survival to overcome this challenge (Legrand et al., 2017; Adeniji and Babalola, 2018). BACs are expensive to commercialize because they require several steps, including microorganism isolation in pure culture or enhancement, identification, and characterization, formulation development, mass production, product efficacy testing, storage durability inspection, finding a manufacturing partner, licensing and marketing, health, and ecological safety considerations (Backer et al., 2018; Bubici et al., 2019; Soumare et al., 2020). Agriculture's biodiversity is essential for its long-term existence. Effective biocontrol agents produce economic advantages, and their contribution to the management of preexisting pest species, predators, and pathogens has been investigated (Barratt et al., 2018; Lacey et al., 2015). There is a majority of research in this sector being done in the lab, and there has been minimal focus on generating practical bioagents in the field. Furthermore, because of a lack of understanding about their application, cost-effective products are not widely explored by

Comment [G18]: a or b ??

growers. Therefore, efforts must be made to popularise biological control. When deployed in the field, BCAs that appear promising in the lab frequently fail. Biotechnology and other molecular approaches have recently gained attention as prospective solutions to the problem of improving BCA selection and characterization. To improve the efficacy of BCA for viable marketability, complete knowledge of BCA mechanisms, and environmental evaluation, various strategies such as mutation or protoplast fusion should be applied. The bulk of bioagents does poorly in field testing yet excel in the laboratory. However, there are various reasons for this, the majority of which can be linked to environmental and physical obstacles that hinder metabolic efficiency. Compounds synthesized by bioagents are important to today's agricultural production environment. However, their utilization must be fully studied. The majority of research in this area is currently done in the lab, with minimal emphasis on generating profitable bioagent formulations. To maximize the efficiency of these agents, new application procedures must be developed. Furthermore, due to a lack of awareness of how to use cost-effective items, farmers have found it difficult to do so. As a result, a more fundamental study in this field is needed to develop the concept of biological control extension.

Conclusion

Considerably, much research has been conducted over the last two decades to probe the use of microbes as biocontrol agents antagonistic to nematode pests. Many BCAs have been recognized as plant-parasitic nematode pathogens and have been shown to suppress nematode pest infestations. However, just a few economically viable biological control products derived from BCAs with nematocidal potential have been established and used in agriculture. Researchers have reported on a variety of bio-agents for root-knot nematode treatment, including fungi and bacteria. The efficacy of the bioagent differed depending on whether it was evaluated in vitro or in the field. This could be due to inconsistencies between the in vitro and field conditions. In vitro and the field, bioagents such as *Verticillium*, *Pochonia*, *Paecilomyces*, *Trichoderma* sp., *Pseudomonas* sp., *Agrobacterium*, and *Bacillus* sp. showed considerable suppression of root-knot nematode infestation. These bioagents must be used in a wider range of applications. In addition, emerging bioagents with broader applications must be thoroughly explored to better understand and apply them. Antibiotics, siderophores, cell wall disintegrating enzymes, volatile organic compounds, mycoparasitism, competition for space, and nutrients are all documented processes

of bioagents in the reduction of root-knot nematodes, as is resistance induction. To achieve optimum biocontrol effects in practice, regardless of how friendly and economic nematode antagonist is to a specific host in a lab experiment, an intensive investigation of the antagonist's mechanisms against nematode populations, as well as a deep understanding of the relationships between biological control strains, nematode targets, microbial biomass, plants, and the ecosystems, should be conducted. Finding new and biocontrol microorganisms that are highly effective against phytopathogens is also very significant. Finally, bioagents should be used for specific diseases and pathogens, as well as in the fields where they have the most promises.

Reference

Abd-Elgawad, M. M. (2020). Plant-parasitic nematodes and their biocontrol agents: current status and future vistas. In *Management of phytonematodes: recent advances and future challenges* (pp. 171-203). Springer, Singapore.

Abd-Elgawad, Mahfouz. M. (2019). Plant-parasitic nematodes of strawberry in Egypt: a review. *Bulletin of the National Research Centre*, 43(1), 1-13.

Abd-El-Kareem, F., Elshahawy, I. E., & Abd-Elgawad, M. M. (2019). Local *Trichoderma* strains as a control strategy of complex black root rot disease of strawberry in Egypt. *Bulletin of the National Research Centre*, 43(1), 1-7.

Abdelrahman, M., & Jogaiah, S. (2019). Defense mechanism and diverse actions of fungal biological control agents against plant biotic stresses. In *Plant Biotechnology: Progress in Genomic Era* (pp. 461-478). Springer, Singapore.

Adejumo TO, Voegelé RT, Agriculture Mfl, and Health H. 2021. Effective Biological Control Strategies of Plant Diseases Using Microorganisms. *Biopesticides: Botanicals*:135.

Adeniji, A. A., and Babalola, O. O. (2018). Tackling maize fusariosis: In search of *Fusarium graminearum* biosuppressors. *Archives of microbiology*, 200(8), 1239-1255.

Ahmad, G., Haris, M., Shakeel, A., Khan, A. A., & Ali, A. (2020). Plant-Parasitic Nematode Management by Phytobiomes and Application of Fly Ash. In *Phytobiomes: Current Insights and Future Vistas* (pp. 357-379). Springer, Singapore.

Comment [G19]: Did not appear in the text.

a or b ??

- Ahmad, G., Khan, A., Khan, A. A., Ali, A., & Mohhammad, H. I. (2021a). Biological control: a novel strategy for the control of the plant parasitic nematodes. *Antonie van Leeuwenhoek*, 1-28.
- Ahmad, G., Khan, A., Khan, A. A., Ali, A., & Mohhammad, H. I. (2021b). Biological control: a novel strategy for the control of the plant parasitic nematodes. *Antonie van Leeuwenhoek*, 1-28.
- Al-Ani, L. K. T. (2018). *Trichoderma*: beneficial role in sustainable agriculture by plant disease management. In *Plant microbiome: Stress response* (pp. 105-126). Springer, Singapore.
- Al-Hazmia, A. S., Al-Yahya, F. A., AbdelRafaab, O. A., & Lafia, A. H. (2019). Effects of humic acid, *Trichoderma harzianum* and *Paecilomyces lilacinus* on *Meloidogyne javanica*. *Int J Agric Environ Biores*, 4(1), 61-74.
- Amobonye, A., Bhagwat, P., Pandey, A., Singh, S., & Pillai, S. (2020). Biotechnological potential of *Beauveria bassiana* as a source of novel biocatalysts and metabolites. *Critical Reviews in Biotechnology*, 40(7), 1019-1034.
- Anwer, M. A. (Ed.). (2017). *Biopesticides and bioagents: novel tools for pest management*. CRC Press.
- Aragón, W., Reina-Pinto, J. J., & Serrano, M. (2017). The intimate talk between plants and microorganisms at the leaf surface. *Journal of Experimental Botany*, 68(19), 5339-5350.
- Arshad, U., Butt, H., Ali, M. A., Jabran, M., Zahid, M. S., & Sarfraz, S. (2021). Exploring the nematicidal activity of plant extracts for management of *Meloidogyne incognita* in local cultivars of eggplant (*Solanum melongena* L.) in Pakistan. *Archives of Phytopathology and Plant Protection*, 1-12.
- Avelar, I. C. (2021). *Actinobacteria for the control of phytopathogenic and/or mycotoxinogenic fungi of cereals* (Doctoral dissertation, Université Montpellier).
- Aydinli, G., & Mennan, S. (2016). Identification of root-knot nematodes (*Meloidogyne* spp.) from greenhouses in the Middle Black Sea Region of Turkey. *Turkish Journal of Zoology*, 40(5), 675-685.
- Backer, R., Rokem, J. S., Ilangumaran, G., Lamont, J., Praslickova, D., Ricci, E., Subramanian S, and Smith, D. L. (2018). Plant growth-promoting rhizobacteria: context, mechanisms of

action, and roadmap to commercialization of biostimulants for sustainable agriculture. *Frontiers in plant science*, 9, 1473.

Baron, N. C., de Souza Pollo, A., & Rigobelo, E. C. (2020). *Purpureocillium lilacinum* and *Metarhizium marquandii* as plant growth-promoting fungi. *PeerJ*, 8, e9005.

Barratt, B. I. P., Moran, V. C., Bigler, F., & Van Lenteren, J. C. (2018a). The status of biological control and recommendations for improving uptake for the future. *BioControl*, 63(1), 155-167.

Barratt, B. I. P., Moran, V. C., Bigler, F., & Van Lenteren, J. C. (2018b). The status of biological control and recommendations for improving uptake for the future. *BioControl*, 63(1), 155-167.

Basit, A., Shah, S. T., Ullah, I., Ullah, I., & Mohamed, H. I. (2021). Microbial Bioactive Compounds Produced by Endophytes (Bacteria and Fungi) and Their Uses in Plant Health. *Plant Growth-Promoting Microbes for Sustainable Biotic and Abiotic Stress Management*, 285-318.

Bielza, P., Balanza, V., Cifuentes, D., & Mendoza, J. E. (2020). Challenges facing arthropod biological control: identifying traits for genetic improvement of predators in protected crops. *Pest management science*, 76(11), 3517-3526.

Branine, M., Bazzicalupo, A., & Branco, S. (2019). Biology and applications of endophytic insect-pathogenic fungi. *PLoS Pathogens*, 15(7), e1007831.

Bridge, John, & Starr, J. (2019). *Plant nematodes of agricultural importance: a colour handbook*. CRC Press.

Bubici, G., Kaushal, M., Prigigallo, M. I., Gómez-Lama Cabanás, C., & Mercado-Blanco, J. (2019). Biological control agents against *Fusarium* wilt of banana. *Frontiers in microbiology*, 10, 616.

Cao, X., Xu, Q., Wan, X.M., Yang, X.C., Jia, X.Y., Xue, X.J., Du, J.L. and Cai, K.Z. (2018). Isolation, identification, and in vitro predatory activity of nematophagous fungus *Arthrobotrys musiformis* and its interaction with nematodes using scanning electron microscopy. *Biocontrol Science and Technology*, 28(1), pp.94-104.

Chen, D., Shao, M., Sun, S., Liu, T., Zhang, H., Qin, N., Zeng, R. and Song, Y., 2019. Enhancement of jasmonate-mediated antiherbivore defense responses in tomato by acetic acid, a potent inducer for plant protection. *Frontiers in plant science*, 10, p.764.

ÇolaC Ateş, A., Dincer, D., & Ata, A. (2018). Determination of The Interaction Between *Fusarium* Crown-Root Rot Disease and Root-Knot Nematode on Tomato Genotypes. *Journal Fresen. Environ. Bull*, 27, 6785-6791.

Dahlin, P., Eder, R., Consoli, E., Krauss, J., & Kiewnick, S. (2019). Integrated control of *Meloidogyne incognita* in tomatoes using fluopyram and *Purpureocillium lilacinum* strain 251. *Crop Protection*, 124, 104874.

Dann, E., & McLeod, A. (2021). Phosphonic acid: a long-standing and versatile crop protectant. *Pest Management Science*, 77(5), 2197-2208.

De Lorenzo, G., Ferrari, S., Cervone, F., & Okun, E. (2018). Extracellular DAMPs in plants and mammals: immunity, tissue damage and repair. *Trends in immunology*, 39(11), 937-950.

De Silva, N. I., Brooks, S., Lumyong, S., & Hyde, K. D. (2019). Use of endophytes as biocontrol agents. *Fungal Biology Reviews*, 33(2), 133-148.

Deb, A., & Das, K. (2020). *Trichoderma*: An Antagonist With Multifaceted Mode Of Action. *TTPP*, 409.

Devi, G., & Bora, L. C. (2018). Effect of some biocontrol agents against root-knot nematode (*Meloidogyne incognita* race2). *International Journal of Environment, Agriculture and Biotechnology*, 3(5), 265260.

DiLegge, M. J., Manter, D. K., & Vivanco, J. M. (2019). A novel approach to determine generalist nematophagous microbes reveals *Mortierella globalpina* as a new biocontrol agent against *Meloidogyne* spp. nematodes. *Scientific reports*, 9(1), 1-9.

Droby, S., Wisniewski, M., Teixidó, N., Spadaro, D., & Jijakli, M. H. (2016). The science, development, and commercialization of postharvest biocontrol products. *Postharvest Biology and Technology*, 122, 22-29.

Comment [G20]: Did not appear in the text.

Du, B., Xu, Y., Dong, H., Yan, L., & Wang, J. (2019). *Phanerochaete chrysosporium* strain B-22, a parasitic fungus infecting *Meloidogyne incognita*. bioRxiv, 622472.

El-Ashry, R. M., Ali, A. A., & Awad, S. E. (2020). Enhancing Application Efficiency of *Pseudomonas* SPP. and *Serratia marcescens* Isolates against *Meloidogyne incognita* in Tomato Plants. Egyptian Academic Journal of Biological Sciences, F. Toxicology & Pest Control, 12(2), 127-145.

El-Sagheer, A. M. (2019). Plant responses to phytonematodes infestations. In Plant health under biotic stress (pp. 161-175). Springer, Singapore.

Emami, M., Almassi, M., & Bakhoda, H. (2018). Agricultural mechanization, a key to food security in developing countries: strategy formulating for Iran. Agriculture & Food Security, 7(1), 1-12.

Engelbrecht, G. (2019). Metabolite profiling of *Bacillus* species with nematicidal activity (Doctoral dissertation, North-West University (South Africa). Potchefstroom Campus).

Escudero, N., Lopez-Moya, F., Ghahremani, Z., Zavala-Gonzalez, E.A., Alaguero-Cordovilla, A., Ros-Ibañez, C., Lacasa, A., Sorribas, F.J. and Lopez-Llorca, L.V., 2017. Chitosan increases tomato root colonization by *Pochonia chlamydosporia* and their combination reduces root-knot nematode damage. Frontiers in plant science, 8, p.1415.

Gehlot, P., Pareek, N., & Vivekanand, V. (2021). Development of Biofertilizers and Microbial Consortium an Approach to Sustainable Agriculture Practices. In Plant, Soil and Microbes in Tropical Ecosystems (pp. 315-348). Springer, Singapore.

Ghahremani, Z., Escudero, N., Saus, E., Gabaldón, T., & Sorribas, F. J. (2019). *Pochonia chlamydosporia* induces plant-dependent systemic resistance to *Meloidogyne incognita*. Frontiers in plant science, 10, 945.

Giné, A., Carrasquilla, M., Martínez-Alonso, M., Gaju, N., & Sorribas, F. J. (2016). Characterization of soil suppressiveness to root-knot nematodes in organic horticulture in plastic greenhouse. Frontiers in plant science, 7, 164.

Gomes, E. V., Costa, M., de Paula, R. G., de Azevedo, R. R., da Silva, F. L., Noronha, E. F., Ulhoa, C. J., Monteiro, V. N., Cardoza, R. E., Gutiérrez, S., & Silva, R. N. (2015). The Cerato-

Platanin protein Epl-1 from *Trichoderma harzianum* is involved in mycoparasitism, plant resistance induction and self cell wall protection. Scientific reports, 5, 17998. <https://doi.org/10.1038/srep17998>

Guerrero Abad, J.C., Padilla Domínguez, A., Torres Flores, E., López Rodríguez, C., Guerrero Abad, R.A., Coyne, D., Oehl, F. and Corazón Guivín, M.A., 2021. A pathogen complex between the root knot nematode *Meloidogyne incognita* and *Fusarium verticillioides* results in extreme mortality of the inka nut (*Plukenetia volubilis*). Journal of Applied Botany and Food Quality 94, 162-168 (2021).

Guler, N. S., Pehlivan, N., Karaoglu, S. A., Guzel, S., & Bozdeveci, A. (2016). *Trichoderma atroviride* ID20G inoculation ameliorates drought stress-induced damages by improving antioxidant defence in maize seedlings. *Acta Physiologiae Plantarum*, 38(6), 132.

Hajek, A. E., & Eilenberg, J. (2018). Natural enemies: an introduction to biological control. Cambridge University Press.

Hajihassani, A., Rutter, W. B., Schwarz, T., Woldemeskel, M., Ali, M. E., & Hamidi, N. (2020). Characterization of resistance to major tropical root-knot nematodes (*Meloidogyne* spp.) in *Solanum sisymbriifolium*. *Phytopathology*, 110(3), 666-673.

He, Q., Wang, D., Li, B., Maqsood, A., & Wu, H. (2020). Nematicidal evaluation and active compounds isolation of *Aspergillus japonicus* ZW1 against root-knot nematodes *Meloidogyne incognita*. *Agronomy*, 10(9), 1222.

Herrera-Parra, E., Ramos-Zapata, J., Basto-Pool, C., & Cristóbal-Alejo, J. (2021). Sweet pepper (*Capsicum annuum*) response to the inoculation of native *arbuscular mycorrhizal* fungi and the parasitism of root-knot *Meloidogyne incognita*. *Revista bio ciencias*, 8.

Holajjer, P., Jadon, K. S., Chandrawat, B. S., & Gawade, B. (2020). Seed-Borne and Seed-Associated Nematodes: An Overview. *Seed-Borne Diseases of Agricultural Crops: Detection, Diagnosis & Management*, 355-368.

Huang, W.K., Sun, J.H., Cui, J.K., Wang, G.F., Kong, L.A., Peng, H., Chen, S.L. and Peng, D.L., 2014. Efficacy evaluation of fungus *Syncephalastrum racemosum* and nematicide

avermectin against the root-knot nematode *Meloidogyne incognita* on cucumber. PLoS one, 9(2), p.e89717.

Hussain, M. A., & Mukhtar, T. (2019). Root-knot nematodes infecting okra in major vegetable growing districts of Punjab, Pakistan. Pakistan Journal of Zoology, 51(3), 1137.

Hussain, T., Akthar, N., Aminedi, R., Danish, M., Nishat, Y., & Patel, S. (2020). Role of the potent microbial based bioagents and their emerging strategies for the ecofriendly management of agricultural phytopathogens. In Natural Bioactive Products in Sustainable Agriculture Springer, Singapore, pp. 45-66.

Comment [G21]: a or b ???

Hussain, T., Singh, S., Danish, M., Pervez, R., Hussain, K., & Husain, R. (2020). Natural Metabolites: An Eco-friendly Approach to Manage Plant Diseases and. Natural Bioactive Products in Sustainable Agriculture, 1.

Comment [G22]: a or b ???

Iqbal, M., Dubey, M., McEwan, K., Menzel, U., Franko, M.A., Viketoft, M., Jensen, D.F. and Karlsson, M., 2018. Evaluation of *Clonostachys rosea* for control of plant-parasitic nematodes in soil and in roots of carrot and wheat. Phytopathology, 108(1), pp.52-59.

Islam, W., Adnan, M., Shabbir, A., Naveed, H., Abubakar, Y.S., Qasim, M., Tayyab, M., Noman, A., Nisar, M.S., Khan, K.A. and Ali, H., 2021. Insect-fungal-interactions: A detailed review on entomopathogenic fungi pathogenicity to combat insect pests. Microbial Pathogenesis, 159, p.105122.

Javeed, M. T., Al-Hazmi, A. S., & Molan, Y. Y. (2016). Antagonistic effects of some indigenous isolates of *Trichoderma* spp. against *Meloidogyne javanica*. Pak J Nematol, 34(2), 183-191.

Ji, Z. L., Peng, S., Zhu, W., Dong, J. P., & Zhu, F. (2020). Induced resistance in nectarine fruit by *Bacillus licheniformis* W10 for the control of brown rot caused by *Monilinia fructicola*. Food Microbiology, 92, 103558.

Jin, N., Liu, S.M., Peng, H., Huang, W.K., Kong, L.A., Wu, Y.H., Chen, Y.P., Ge, F.Y., Jian, H. and Peng, D.L., 2019. Isolation and characterization of *Aspergillus niger* NBC001 underlying suppression against *Heterodera glycines*. Scientific reports, 9(1), pp.1-13.

Jones, J. G. (2016). Examination of chemical, biological, and cultural control measures of root-knot nematodes in lima beans. University of Delaware.

Juyal, D., Pal, S., Sharma, M., Negi, V., Adekhandi, S., & Tyagi, M. (2018). *Keratomycosis* due to *Purpureocillium lilacinum*: A case report from Sub-Himalayan region of Uttarakhand. *Indian Journal of Pathology and Microbiology*, 61(4), 607.

Karakas, M. (2020). Nematode-Destroying Fungi: Infection Structures, Interaction Mechanisms And Biocontrol. *Communications Faculty Of Sciences University Of Ankara Series C Biology*, 29(1), 176-201.

Karimi, J., Kamali, S., Madadi, H., Goldansaz, S. H., Ghasemi, S., Saadi, H., & Attaran, M. (2021). Analytical Approach to Opportunities and Obstacles of Iranian Biological Pest Control. In *Biological Control of Insect and Mite Pests in Iran* (pp. 601-621). Springer, Cham.

Karuri, H. W., Olago, D., Neilson, R., Mararo, E., & Villinger, J. (2017). A survey of root knot nematodes and resistance to *Meloidogyne incognita* in sweet potato varieties from Kenyan fields. *Crop protection*, 92, 114-121.

Kassam, R., Kamil, D., & Rao, U. (2021). *Caenorhabditis elegans* as bait for isolating promising biocontrol fungi against *Meloidogyne incognita* from soils across India. *Indian Phytopathology*, 1-14.

Kenawy, A., Dailin, D.J., Abo-Zaid, G.A., Abd Malek, R., Ambehabeti, K.K., Zakaria, K.H.N., Sayyed, R.Z. and El Enshasy, H.A., 2019. Biosynthesis of antibiotics by PGPR and their roles in biocontrol of plant diseases. In *Plant Growth Promoting Rhizobacteria for Sustainable Stress Management* (pp. 1-35). Springer, Singapore.

Keswani, C., Singh, H.B., García-Estrada, C., Caradus, J., He, Y.W., Mezaache-Aichour, S., Glare, T.R., Borriss, R. and Sansinenea, E., 2020. Antimicrobial secondary metabolites from agriculturally important bacteria as next-generation pesticides. *Applied microbiology and biotechnology*, 104(3), pp.1013-1034.

Khan, M. R., Majid, S., Mohidin, F. A., & Khan, N. (2011). A new bioprocess to produce low cost powder formulations of biocontrol bacteria and fungi to control fusarial wilt and root-knot nematode of pulses. *Biological control*, 59(2), 130-140.

Khan, R. A. A., Najeeb, S., Mao, Z., Ling, J., Yang, Y., Li, Y., & Xie, B. (2020b). Bioactive secondary metabolites from *Trichoderma* spp. against phytopathogenic bacteria and Root-knot nematode. *Microorganisms*, 8(3), 401.

Comment [G23]: b ???

Khanna, K., Kohli, S.K., Sharma, P., Kour, J., Singh, A.D., Sharma, N., Ohri, P. and Bhardwaj, R., 2021. Antioxidant Potential of Plant Growth-Promoting Rhizobacteria (PGPR) in Agricultural Crops Infected with Root-Knot Nematodes. In *Antioxidants in Plant-Microbe Interaction* (pp. 339-379). Springer, Singapore.

Kiriga, A. W. (2018). Occurrence of Plant Parasitic Nematodes in Commercial Pineapple Fields and Effect of Biocontrol agents on *Meloidogyne* species in Kenya (Doctoral dissertation, Kenyatta University).

Kiriga, A. W., Haukeland, S., Kariuki, G. M., Coyne, D. L., & Beek, N. V. (2018). Effect of *Trichoderma* spp. and *Purpureocillium lilacinum* on *Meloidogyne javanica* in commercial pineapple production in Kenya. *Biological Control*, 119, 27-32.

Köhl, J., Kolnaar, R., & Ravensberg, W. J. (2019). Mode of action of microbial biological control agents against plant diseases: relevance beyond efficacy. *Frontiers in plant science*, 10, 845.

Kumar, C. S., Jacob, T. K., Devasahayam, S., Thomas, S., & Geethu, C. (2018). Multifarious plant growth promotion by an entomopathogenic fungus *Lecanicillium psalliotae*. *Microbiological research*, 207, 153-160.

Kumar, K. K. (2020). Fungi: A Bio-resource for the Control of Plant Parasitic Nematodes. In *Agriculturally Important Fungi for Sustainable Agriculture* (pp. 285-311). Springer, Cham.

Lacey, L. A., Grzywacz, D., Shapiro-Ilan, D. I., Frutos, R., Brownbridge, M., & Goettel, M. S. (2015). Insect pathogens as biological control agents: back to the future. *Journal of invertebrate pathology*, 132, 1-41.

Latz, M. A., Jensen, B., Collinge, D. B., & Jørgensen, H. J. (2018). Endophytic fungi as biocontrol agents: elucidating mechanisms in disease suppression. *Plant Ecology & Diversity*, 11(5-6), 555-567.

Legrand, F., Picot, A., Cobo-Díaz, J. F., Chen, W., & Le Floch, G. (2017). Challenges facing the biological control strategies for the management of *Fusarium* Head Blight of cereals caused by *F. graminearum*. *Biological Control*, 113, 26-38.

Leong, S. S., Leong, S. C. T., Pau, C. G., & Beattie, G. A. C. (2021). In Vitro Bioassay of *Purpureocillium lilacinum* and *Bacillus thuringiensis* for Control of *Meloidogyne incognita* on Black Pepper (*Piper nigrum* L.) in Sarawak, Malaysia, Northern Borneo. *Journal of the Entomological Research Society*, 23(1), 41-59.

Liang, L. M., Zou, C. G., Xu, J., & Zhang, K. Q. (2019). Signal pathways involved in microbe–nematode interactions provide new insights into the biocontrol of plant-parasitic nematodes. *Philosophical Transactions of the Royal Society B*, 374(1767), 20180317.

Lima, F. S., Correa, V. R., Nogueira, S. R., & Santos, P. R. (2017). Nematodes affecting soybean and sustainable practices for their management. *Soybean–basis of yield, biomass and productivity*, 95-110.

Lin, W. J., Chiu, M. C., Lin, C. C., Chung, Y. K., & Chou, J. Y. (2021). Efficacy of Entomopathogenic fungus *Aspergillus nomius* against *Dolichoderus thoracicus*. *BioControl*, 1-11.

Litwin, A., Nowak, M., & Różalska, S. (2020). Entomopathogenic fungi: unconventional applications. *Reviews in Environmental Science and Bio/Technology*, 19(1), 23-42.

Los, A., Ziuzina, D., Boehm, D., & Bourke, P. (2020). Effects of cold plasma on wheat grain microbiome and antimicrobial efficacy against challenge pathogens and their resistance. *International Journal of Food Microbiology*, 335, 108889.

Lubian, C., Martinha, D.D., Portz, R.L., Missio, V.C., Rinaldi, L.K., Chiapetti, T.P., Hendges, C., Rocha, M.E.L. and Abade, M.T.R., 2017. *Hirsutella thompsonii* and *Pochonia chlamydosporia* (Syn. *Verticillium chlamydosporium*) mycelia growth and predation on *Panagrellus redivivus*. *Journal of Agricultural Science (Toronto)*, 9(11), pp.137-143.

Mabbott, N. A. (2018). The influence of parasite infections on host immunity to co-infection with other pathogens. *Frontiers in immunology*, 9, 2579.

Mageroy, M.H., Wilkinson, S.W., Tengs, T., Cross, H., Almvik, M., Pétriacq, P., Vivian-Smith, A., Zhao, T., Fossdal, C.G. and Krokene, P., 2020. Molecular underpinnings of methyl jasmonate-induced resistance in Norway spruce. *Plant, cell & environment*, 43(8), pp.1827-1843.

Maheshwari, H.S., Agnihotri, R., Bharti, A., Chourasiya, D., Laad, P., Dukare, A., Prabina, B.J., Sharma, M.P. and Sharma, S.K., 2020. Signaling in the Rhizosphere for Better Plant and Soil Health. In *Rhizosphere Microbes* (pp. 149-173). Springer, Singapore.

Maurya, S. (2020). Biological control a sustainable approach for plant diseases management: A review. *J. Pharmacogn. Phytochem*, 9, 1514-1523.

Mélida, H., Bacete, L., Ruprecht, C., Rebaque, D., Del Hierro, I., López, G., Brunner, F., Pfrengle, F. and Molina, A., 2020. Arabinoxylan-oligosaccharides act as damage associated molecular patterns in plants regulating disease resistance. *Frontiers in plant science*, 11, p.1210.

Migunova, V. D., & Sasanelli, N. (2021). Bacteria as biocontrol tool against phytoparasitic nematodes. *Plants*, 10(2), 389.

Miller, D. P., Fitzsimonds, Z. R., & Lamont, R. J. (2019). Metabolic signaling and spatial interactions in the oral polymicrobial community. *Journal of dental research*, 98(12), 1308-1314.

Misgana Mitiku (2018). Plant-parasitic nematodes and their management: A review. 16.

Moosavi, M. R., & Zare, R. (2012). Fungi as biological control agents of plant-parasitic nematodes. In *Plant defence: biological control* (pp. 67-107). Springer, Dordrecht.

Comment [G24]: 2020

Mukhtar, T. (2018). Management of root-knot nematode, *Meloidogyne incognita*, in tomato with two *Trichoderma* species. *Pakistan Journal of Zoology*, 50(4).

Mukhtar, T., & Hussain, M. A. (2019). Pathogenic Potential of *Javanese* Root-knot Nematode on Susceptible and Resistant Okra Cultivars. *Pakistan Journal of Zoology*, 51(5).

Mukhtar, T., & Kayani, M. Z. (2020). Comparison of the damaging effects of *Meloidogyne incognita* on a resistant and susceptible cultivar of cucumber. *Bragantia*, (AHEAD).

Mukhtar, T., Hussain, M. A., & Kayani, M. Z. (2017). Yield responses of 12 okra cultivars to southern root-knot nematode (*Meloidogyne incognita*). *Bragantia*, 76, 108-112.

- Mukhtar, T., Tariq-Khan, M., & Aslam, M. N. (2021). Bioefficacy of *Trichoderma* species against *javanese* root-knot nematode, *meloidogyne javanica*, in green gram. *Gesunde Pflanzen*, 1-8.
- Murata, G., Uesugi, K., Uehara, T., Kumaishi, K., Ichihashi, Y., Saito, T., & Shinmura, Y. (2020). *Solanum palinacanthum*: broad-spectrum resistance to root-knot nematodes (*Meloidogyne* spp.). *Pest Management Science*, 76(12), 3945-3953.
- Nabi, S. U., Raja, W. H., Kumawat, K. L., Mir, J. I., Sharma, O. C., Singh, D. B., & Sheikh, M. A. (2017). Post harvest diseases of temperate fruits and their management strategies-a review.
- Nagachandrabose, S. (2018). Liquid bioformulations for the management of root-knot nematode, *Meloidogyne hapla* that infects carrot. *Crop Protection*, 114, 155-161.
- Najafi, F., Naddaf, S. R., Rezaie, S., Kia, E. B., & Mowlavi, G. (2016). In Vitro Ovicidal Activity of Nematophagous Fungus *Paecilomyces lilacinus* on the Eggs of Parasitic Helminths. *Journal of Medical Microbiology and Infectious Diseases*, 4(3), 52-56.
- Nguvo, K. J., & Gao, X. (2019). Weapons hidden underneath: bio-control agents and their potentials to activate plant induced systemic resistance in controlling crop *Fusarium* diseases. *Journal of Plant Diseases and Protection*, 126(3), 177-190.
- Noumavo, P. A., Agbodjato, N. A., Baba-Moussa, F., Adjanohoun, A., & Baba-Moussa, L. (2016). Plant growth promoting rhizobacteria: Beneficial effects for healthy and sustainable agriculture. *African Journal of Biotechnology*, 15(27), 1452-1463.
- O'Brien, P.A. (2017) Biological control of plant diseases. *Australasian Plant Pathology*, 46 (4). pp. 293-304.
- Odelade, K. A., & Babalola, O. O. (2019). Bacteria, fungi and archaea domains in rhizospheric soil and their effects in enhancing agricultural productivity. *International journal of environmental research and public health*, 16(20), 3873.
- Odoh, C. K. (2017). Plant growth promoting rhizobacteria (PGPR): a bioprotectant bioinoculant for sustainable agrobiolgy. A review. *International Journal of Advanced Research in Biological Sciences*, 4(5), 123-142.

Ons, L., Bylemans, D., Thevissen, K., & Cammue, B. (2020). Combining biocontrol agents with chemical fungicides for integrated plant fungal disease control. *Microorganisms*, 8(12), 1930.

Palyzová, A., Svobodová, K., Sokolová, L., Novák, J., & Novotný, Č. (2019). Metabolic profiling of *Fusarium oxysporum* f. sp. *conglutinans* race 2 in dual cultures with biocontrol agents *Bacillus amyloliquefaciens*, *Pseudomonas aeruginosa*, and *Trichoderma harzianum*. *Folia microbiologica*, 64(6), 779-787.

Pandey, A. K., Savani, A. K., & Singh, P. (2021). The Early Blight of Tomato: Omics Interventions Toward Controlling Disease Spread and Development. In *Omics Technologies for Sustainable Agriculture and Global Food Security Volume 1* (pp. 85-108). Springer, Singapore.

Parray JA, Mir MY, and Shameem N. 2019. Rhizosphere engineering and agricultural productivity. *Sustainable Agriculture: Biotechniques in Plant Biology*: Springer, 71-154.

Peiris, P. U. S., Li, Y., Brown, P., & Xu, C. (2020). Fungal biocontrol against *Meloidogyne* spp. in agricultural crops: A systematic review and meta-analysis. *Biological Control*, 144, 104235.

Perpétuo, L. S., da Cunha, M. J., Batista, M. T., & Conceição, I. L. (2021). *Solanum linnaeanum* and *Solanum sisymbriifolium* as a sustainable strategy for the management of *Meloidogyne chitwoodi*. *Scientific reports*, 11(1), 1-8.

Philbrick, A. N., Adhikari, T. B., Louws, F. J., & Gorny, A. M. (2020). *Meloidogyne enterolobii*, a major threat to tomato production: current status and future prospects for its management. *Frontiers in plant science*, 11.

Postnikova, O. A., Hult, M., Shao, J., Skantar, A., & Nemchinov, L. G. (2015). Transcriptome analysis of resistant and susceptible alfalfa cultivars infected with root-knot nematode *Meloidogyne incognita*. *PLoS One*, 10(2), e0118269.

Poveda, J., Abril-Urias, P., & Escobar, C. (2020). Biological control of plant-parasitic nematodes by filamentous fungi inducers of resistance: *Trichoderma*, *mycorrhizal* and endophytic fungi. *Frontiers in Microbiology*, 11, 992.

Pretorius, M. (2018). The abundance, identity and population dynamics of *Meloidogyne* spp. associated with maize in South Africa (Doctoral dissertation, North-West University (South Africa), Potchefstroom Campus).

Qiao, J., Yu, X., Liang, X., Liu, Y., Borriss, R., & Liu, Y. (2017). Addition of plant-growth-promoting *Bacillus subtilis* PTS-394 on tomato rhizosphere has no durable impact on composition of root microbiome. *BMC microbiology*, 17(1), 1-12.

Raghavan, R., Chithra, G., Fernandez, S., Suryanarayana, B. S., & Singh, R. (2018). An unusual case of *hyalohyphomycosis* due to *Purpureocillium lilacinum* in a patient with myasthenia gravis. *Current medical mycology*, 4(2), 36.

Ramesh, S., & Radhakrishnan, P. (2020). 10 Natural Products as Eco-Friendly Bactericides for Plant Growth and Development. *Natural Bioactive Products in Sustainable Agriculture*, 221.

Rashad, Y. M., & Moussa, T. A. (2020). Biocontrol agents for fungal plant diseases management. In *Cottage industry of biocontrol agents and their applications* (pp. 337-363). Springer, Cham.

Rawal, S. (2020). A Review On Root-Knot Nematode Infestation And Its Management Practices Through Different Approaches In Tomato. *Tropical Agroecosystems (TAEC)*, 1(2), 92-96.

Ribeiro Costa, C., Silva Costa, A., dos Santos, A., Lima Pereira, J., e Carvalho, R., & Carvalho Filho, J. L. (2019). Current Status of the Occurrence and Reaction Root-knot Nematodes in the Main Botanical Families of Medicinal Plants. *Journal of Experimental Agriculture International*, 32(2), 1-21. <https://doi.org/10.9734/jeai/2019/v32i230096>

Rocha, I., Ma, Y., Souza-Alonso, P., Vosátka, M., Freitas, H., & Oliveira, R. S. (2019). Seed coating: a tool for delivering beneficial microbes to agricultural crops. *Frontiers in Plant Science*, 10, 1357.

Roopa, K. P., & Gadag, A. S. (2020). Importance of Biopesticides in the Sustainable Management of Plant-Parasitic Nematodes. In *Management of Phytonematodes: Recent Advances and Future Challenges* (pp. 205-227). Springer, Singapore.

Rubio, M. B., de Medeiros, H. A., Morán-Diez, M. E., Castillo, P., Hermosa, R., & Monte, E. (2019). A split-root method to study systemic and heritable traits induced by *Trichoderma* in tomato plants. In *Methods in Rhizosphere Biology Research* (pp. 151-166). Springer, Singapore.

Sánchez Monge, G. A., Flores, L., Salazar, L., Hocland, S., & Bert, W. (2015). An updated list of the plants associated with plant-parasitic *Aphelenchoides* (Nematoda: *Aphelenchoididae*) and its implications for plant-parasitism within this genus.

Sarker M, Ali M, Islam M, Huda M, Pun I, Podder R, Tomczak A, and Hossain A. (2021). Use of different eco-friendly management approaches for controlling root-knot nematode (*Meloidogyne incognita* L.) in tomato (*Solanum lycopersicum* L.). 54:89– 103-189– 103.

Sato, K., Kadota, Y., & Shirasu, K. (2019). Plant immune responses to parasitic nematodes. *Frontiers in plant science*, 10, 1165.

Saxena, G. (2018). Biological control of root-knot and cyst nematodes using nematophagous fungi. In *Root Biology* (pp. 221-237). Springer, Cham.

Sayyed, R. Z., Ilyas, N., Tabassum, B., Hashem, A., Abd_Allah, E. F., & Jadhav, H. P. (2019). Plausible role of plant growth-promoting rhizobacteria in future climatic scenario. *Environmental biotechnology: for sustainable future*, 175-197.

Seong, J., Shin, J., Kim, K., & Cho, B. K. (2021). Microbial production of nematocidal agents for controlling plant-parasitic nematodes. *Process Biochemistry*.

Shaikh, S. S., & Sayyed, R. Z. (2015). Role of plant growth-promoting rhizobacteria and their formulation in biocontrol of plant diseases. In *Plant microbes symbiosis: Applied facets* (pp. 337-351). Springer, New Delhi.

Shalaby, H., Ashry, H., Moataza, S. A. A. D., & Farag, T. (2020). In Vitro Effects of *Streptomyces tyrosinase* on the Egg and Adult Worm of *Toxocara vitulorum*. *Iranian Journal of Parasitology*, 15(1), 67.

Sharma, S., Kour, D., Rana, K.L., Dhiman, A., Thakur, S., Thakur, P., Thakur, S., Thakur, N., Sudheer, S., Yadav, N. and Yadav, A.N., 2019. Trichoderma: biodiversity, ecological significances, and industrial applications. In *Recent advancement in white biotechnology through fungi* (pp. 85-120). Springer, Cham.

Silva, J.C., Nunes, T., Guimarães, R.A., Pylro, V.S., Costa, L.S., Zaia, R., Campos, V.P. and Medeiros, F.H., 2021. Organic practices intensify the microbiome assembly and suppress root-knot nematodes. *Journal of Pest Science*, pp.1-13.

Silva, S. D., Carneiro, R. M., Faria, M., Souza, D. A., Monnerat, R. G., & Lopes, R. B. (2017). Evaluation of *Pochonia chlamydosporia* and *Purpureocillium lilacinum* for suppression of *Meloidogyne enterolobii* on tomato and banana. *Journal of nematology*, 49(1), 77.

Singh, A., Sharma, P., Kumari, A., Kumar, R., & Pathak, D. V. (2019a). Management of root-knot nematode in different crops using microorganisms. In *Plant Biotic Interactions* (pp. 85-99). Springer, Cham.

Singh, D., Ghosh, P., Kumar, J., & Kumar, A. (2019b). Plant growth-promoting rhizobacteria (PGPRs): functions and benefits. In *Microbial interventions in agriculture and environment* (pp. 205-227). Springer, Singapore.

Singh, J., Rajput, R. S., Bisen, K., Singh, S., & Singh, H. B. (2017). Role of *Trichoderma* secondary metabolites in plant growth promotion and biological control. *Advances in PGPR research*. CABI, Oxfordshire, 411-426.

Singh, S., Kumar, V., Dhanjal, D. S., & Singh, J. (2020). Biological control agents: diversity, ecological significances, and biotechnological applications. In *Natural Bioactive Products in Sustainable Agriculture* (pp. 31-44). Springer, Singapore.

Comment [G25]: a or b ???

Sivasubramaniam, N., Hariharan, G., & Zakeel, M. C. M. (2020). Sustainable Management of Plant-Parasitic Nematodes: An Overview from Conventional Practices to Modern Techniques. *Management of Phytonematodes: Recent Advances and Future Challenges*, 353-399.

Soliman, M. S., El-Deriny, M. M., Ibrahim, D. S., Zakaria, H., & Ahmed, Y. (2021). Suppression of root-knot nematode *Meloidogyne incognita* on tomato plants using the nematode trapping fungus *Arthrobotrys oligospora* Fresenius. *Journal of Applied Microbiology*.

Soumare, A., Boubekri, K., Lyamlouli, K., Hafidi, M., Ouhdouch, Y., & Kouisni, L. (2020). From isolation of phosphate solubilizing microbes to their formulation and use as biofertilizers: status and needs. *Frontiers in bioengineering and biotechnology*, 7, 425.

Subedi, P., Gattoni, K., Liu, W., Lawrence, K. S., & Park, S. W. (2020). Current utility of plant growth-promoting rhizobacteria as biological control agents towards plant-parasitic nematodes. *Plants*, 9(9), 1167.

Tawidian, P., Rhodes, V. L., & Michel, K. (2019). Mosquito-fungus interactions and antifungal immunity. *Insect biochemistry and molecular biology*, 111, 103182.

Tazi, H., Hamza, M.A., Hallouti, A., Benjlil, H., Idhmida, A., Furze, J.N., Paulitz, T.C., Mayad, E.H., Boubaker, H. and El Mousadik, A., 2021. Biocontrol potential of nematophagous fungi against *Meloidogyne* spp. infecting tomato. *Organic Agriculture*, 11(1), pp.63-71.

Thakur, P., & Singh, I. (2018). Biocontrol of soilborne root pathogens: An Overview. *Root Biology*, 181-220.

Thambugala, K. M., Daranagama, D. A., Phillips, A. J., Kannangara, S. D., & Promputtha, I. (2020). Fungi vs. fungi in biocontrol: an overview of fungal antagonists applied against fungal plant pathogens. *Frontiers in cellular and infection microbiology*, 10.

Thurston, H. D. (2019). Sustainable practices for plant disease management in traditional farming systems. CRC Press.

Tian, X., Yao, Y., Chen, G., Mao, Z., Wang, X., & Xie, B. (2014). Suppression of *Meloidogyne incognita* by the endophytic fungus *Acremonium implicatum* from tomato root galls. *International Journal of Pest Management*, 60(4), 239-245.

Tóthné Bogdányi, F., Boziné Pullai, K., Doshi, P., Erdős, E., Gilián, L.D., Lajos, K., Leonetti, P., Nagy, P.I., Pantaleo, V., Petrikovszki, R. and Sera, B., 2021. Composted Municipal Green Waste Infused with Biocontrol Agents to Control Plant Parasitic Nematodes—A Review. *Microorganisms*, 9(10), p.2130.

Tranier, M. S., Pognant-Gros, J., Quiroz, R. D. L. C., González, C. N. A., Mateille, T., & Roussos, S. (2014). Commercial biological control agents targeted against plant-parasitic root-knot nematodes. *Brazilian Archives of Biology and Technology*, 57, 831-841.

Van Lenteren, J. C. (2021). Will the “Nagoya Protocol on Access and Benefit Sharing” Put an End to Biological Control?. In *Area-Wide Integrated Pest Management* (pp. 655-667). CRC Press.

Vejan, P., Abdullah, R., Khadiran, T., Ismail, S., & Nasrullah Boyce, A. (2016). Role of plant growth promoting rhizobacteria in agricultural sustainability—a review. *Molecules*, 21(5), 573.

Verma, M., Mishra, J., & Arora, N. K. (2019a). Plant growth-promoting rhizobacteria: diversity and applications. In *Environmental biotechnology: for sustainable future* (pp. 129-173). Springer, Singapore.

Verma, P. P., Shelake, R. M., Das, S., Sharma, P., & Kim, J. Y. (2019b). Plant growth-promoting rhizobacteria (PGPR) and fungi (PGPF): potential biological control agents of diseases and pests. In *Microbial Interventions in Agriculture and Environment* (pp. 281-311). Springer, Singapore.

Vinale, F., Sivasithamparam, K., Ghisalberti, E.L., Woo, S.L., Nigro, M., Marra, R., Lombardi, N., Pascale, A., Ruocco, M., Lanzuise, S. and Manganiello, G., 2014. *Trichoderma* secondary metabolites active on plants and fungal pathogens. *The Open Mycology Journal*, 8(1).

Walia, A., Putatunda, C., Sharma, R., Sharma, S., & Thakur, A. (2021). Biocontrol: A Sustainable Agricultural Solution for Management of Plant Diseases. In *Microbial Biotechnology in Crop Protection* (pp. 1-54). Springer, Singapore.

Wang, H., Liu, R., You, M. P., Barbetti, M. J., & Chen, Y. (2021a). Pathogen Biocontrol Using Plant Growth-Promoting Bacteria (PGPR): Role of Bacterial Diversity. *Microorganisms*, 9(9), 1988.

Wang, J.Y., Guo, C., Zhao, P., Yu, F.Y., Su, Y., Qu, J.P., Wang, J.L., Lin, R.S., Wang, B., Gao, Z. and Yang, Z.Y., (2021b). Biocontrol potential of *Bacillus altitudinis* AMCC1040 against root-knot nematode disease of ginger and its impact on rhizosphere microbial community. *Biological Control*, 158, p.104598.

Xia, Y., Li, S., Liu, X., Zhang, C., Xu, J., & Chen, Y. (2019). *Bacillus halotolerans* strain LYSX1-induced systemic resistance against the root-knot nematode *Meloidogyne javanica* in tomato. *Annals of Microbiology*, 69(12), 1227-1233.

Xu, W. F., Yang, J. L., Meng, X. K., Gu, Z. G., Zhang, Q. L., & Lin, L. B. (2021). Understanding the Transcriptional Changes During Infection of *Meloidogyne incognita* Eggs by the Egg-Parasitic Fungus *Purpureocillium lilacinum*. *Frontiers in microbiology*, 12, 786.

Ye, W., Robbins, R. T., & Kirkpatrick, T. (2019). Molecular characterization of root-knot nematodes (*Meloidogyne* spp.) from Arkansas, USA. *Scientific reports*, 9(1), 1-21.

Yergaliyev, T. M., Alexander-Shani, R., Dimerets, H., Pivonia, S., Bird, D. M., Rachmilevitch, S., & Szitenberg, A. (2020). Bacterial community structure dynamics in *Meloidogyne incognita*-infected roots and its role in worm-microbiome interactions. *Msphere*, 5(4), e00306-20.

Youssef, S. A., Tartoura, K. A., & Greash, A. G. (2018). *Serratia proteamaculans* mediated alteration of tomato defense system and growth parameters in response to early blight pathogen *Alternaria solani* infection. *Physiological and Molecular Plant Pathology*, 103, 16-22.

Zehra, A., Raytekar, N. A., Meena, M., & Swapnil, P. (2021). Efficiency of microbial bio-agents as elicitors in plant defense mechanism under biotic stress: A review. *Current Research in Microbial Sciences*, 2, 100054.

Zhang, Y., Li, S., Li, H., Wang, R., Zhang, K. Q., & Xu, J. (2020). Fungi–nematode interactions: Diversity, ecology, and biocontrol prospects in agriculture. *Journal of Fungi*, 6(4), 206.

Zhao, J., Wang, S., Zhu, X., Wang, Y., Liu, X., Duan, Y., Fan, H. and Chen, L., 2021. Isolation and characterization of nodules endophytic bacteria *Pseudomonas protegens* Sneb1997 and *Serratia plymuthica* Sneb2001 for the biological control of root-knot nematode. *Applied Soil Ecology*, 164, p.103924.

Zhuang, X., Zhao, J.L., Bai, M., Ping, X.X., Li, Y.L., Yang, Y.H., Mao, Z.C., Yang, G.S. and Xie, B.Y., 2021. *Pochonia chlamydosporia* Isolate PC-170-Induced Expression of Marker Genes for Defense Pathways in Tomatoes Challenged by Different Pathogens. *Microorganisms*, 9(9), p.1882.

Ziv, C., Zhao, Z., Gao, Y. G., & Xia, Y. (2018). Multifunctional roles of plant cuticle during plant-pathogen interactions. *Frontiers in plant science*, 9, 1088.