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The Anti-Nemic Potential of Mushroom against Plant-Parasitic Nematodes

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Abstract

Plant-parasitic nematodes are responsible for huge annual economic loss that is estimated to be more than 215 billion US$ worldwide due to plants damages caused by nematodes. The root-knot nematode (*Meloidogyne* spp.) is ranked first in the global list of top ten plant-parasitic nematodes, with wide host range of more than 3000 host plant species and posing a major threat in the cultivation of agricultural, vegetables, and horticultural crops. Such pathogens are commonly controlled using chemical nematicides. However, the risk of using such chemicals on human, animals, and surrounding environment has forced researchers to search for natural, less harmful, and effective nematicidal agents. In this review, we discuss the biological control of nematodes by different microorganisms, stressing on the promising capabilities of some mushrooms such as some species of *Pleurotus, Beauveria, Ganoderma lucidum,* and *Lentinus edodes*.

Keywords: Biocontrol; Mushroom; *Pleurotus Ostreatus*; Plant-Parasitic Nematodes; Anti-Nemic Potential

Introduction

Sustainable agriculture has become one of the fundamental needs to ensure food security for Humans worldwide. Yet, as a result of population increase, the balance between human and their food supply is not safe. One traditional solution was to increase food via pest control [1,2]. Plant-parasitic nematodes have been present for nearly a billion years [3]. More than 4100 species belonging to different genera of plant-parasitic nematodes have been identified [4]. Such nematodes cause serious annual economic loss worldwide that exceed 215 billion US dollars [5]. Root-knot nematodes (Meloidogyne spp.) are soil-borne, sedentary endoparasite and came in the first position in the top ten list of plant-parasitic nematodes across the world. This genus has widespread, a host range of more than 3000 host plant species and posing a major threat in the cultivation of agricultural, vegetables, and horticultural crops [6-9]. The infection by Root-knot nematodes starts with the penetration of juveniles (J2) plant roots and modifies the vascular cylinder. The migration is aided by a combination of specialized glands secretion of cell-wall-degrading enzymes together with stylet protrusion (mechanical force) at the same time [10]. The J2s do not kill parasitized cells but it induces giant cells generation [11].

There are more than 100 species of *Meloidogyne* spp. dispersed around the world and they parasitize different plants genera [12]. *Meloidogyne incognita*, *Meloidogyne javanica*, *Meloidogyne arenaria*, and *Meloidogyne hapla* are the most important species that cause about 95% of economic losses in cultivated lands [13]. Controlling root-knot nematodes can be performed by applying various strategies such as regulatory, cultural, physical, chemical, and biological strategies. However, some limitations and risks appear associated with these strategies [14,15]. The cause of the problematic hardness in controlling nematodes is due to the difficulty in distinguishing the plant infections caused by nematodes with those caused by other pathogens or abiotic factors.They have a wide host range, short periods of high reproductive rate and generation [16]. Although nematicides are the commonest approach for the management of root-knot nematodes but due to the risk to humans and environments presented by using synthetic nematicides hazardous are incited scientists for working on the alternatives to nematicides less harmful control [17].

Biological Control of Nematodes

Biological control is recently developed approach to controlling nematodes using microorganisms such as fungi and bacteria and their natural product [18-21]. Several biocontrol agents have shown to be able to produce secondary metabolites as antibiotics, toxins, and lytic enzymes. Hydrolytic enzymes such as collagenases, chitinases, proteases and lipase have been related to the nematicides effect in microbial, and were verified as important factor in the degradation process of different chemical components of nematodes during different developmental stages [22]. The clear reason behind their use is that the nematodes biochemical composition during their mobile stages includes collagens and lipids, as well as chitin, and protein in the sedentary stages for tylenchoid nematodes such as *Meloidogyne* spp.

Generally, the eggshell of the root-knot nematode consists of three main layers:
(a) The outer vitelline layer that gives the structural uniformity of eggs [23];
(b) The middle chitinous layer of the eggshell which contains chitin fibrils embedded in a protein matrix [24] and
(c) The internal lipid layer which preserve the impermeability of the shell [25].
Chitin was detected in found in gelatinous matrix of *Meloidogyne javanica* [26]. The role of microbial lytic enzymes and their effect on nematode hatching and morphological changes in juveniles, eggs, and eggshells under laboratory condition and efficiency on plant parasitic nematodes biocontrol Figure 1.

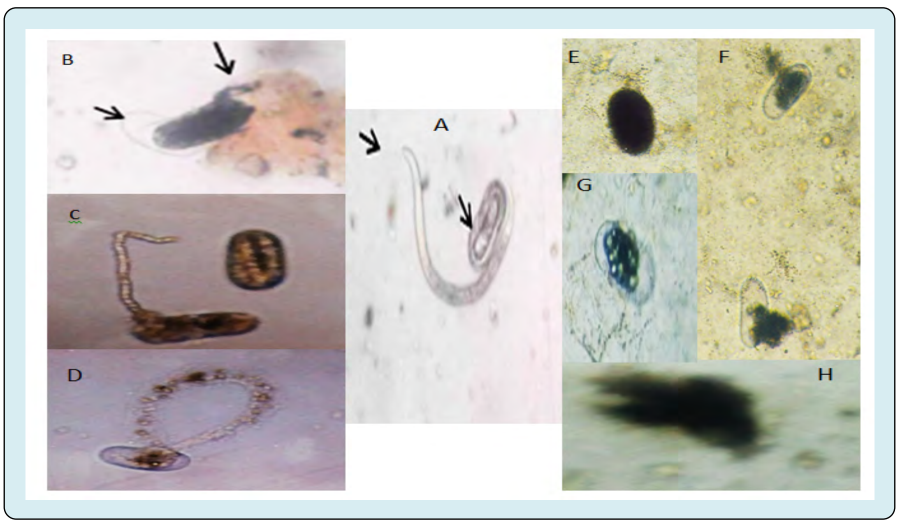

Figure 1 Hatching is observed in the water control; normal juvenile and normal egg-containing J2 (A, arrows). Abnormal juveniles appeared (B and C), Spherical egg (E); eggshells appeared to be destroyed (F and G), abnormal hatching and eggs are decomposed (D, H) by microbial enzymes. A photo was taken by Dr. Gaziea at Plant Pathology Department, Nematology Unit, at National Research Centre.

Consequently, fungal biological control is an interesting and rapidly developing research area and there is increasing attention in the nematodes biocontrol using fungi [27-29]. Fungi are known to possess a huge diversity of metabolic pathways and they have provided several large classes of commercial compounds, including many antibiotics used in medicine. Consequently, secondary metabolites in fungi could have much potential in their novel structures and nematicidal activities [30-32].

Role of Mushrooms as Eco-Friendly and Less Harmful Nematicides

Owing to the current focused on eco-friendly approaches for plant disease management caused by nematodes, the present study emphasis on mushroom fungi can serve as a promising source as alternative tools for biocontrol of plant-parasitic nematodes. Basidiomycetous macrofungi possess many biological activities as antimicrobial, antiviral, mosquito larvicidal, and nematicidal agents [33]. As an example, omphalotin which is a new peptide secreted by the mushroom *Omphalotus olearius*. Omphalotin has nematicidal activity that is as potent as that obtained by the commercial nematicide ivermectin. Many researches have been made to find potent nematicidal substances that can replace traditional man-made chemical nematicides, few have been developed for wide use [34]. Till now, no fungal-based nematicidal commercial product has been developed [35].

Macromycete Mushrooms as Anti-nematodes Promising Tool

Macromycete mushrooms are filamentous organisms, lacking chlorophyll, saprobes, which can be seen by the naked eye. They obtain their nutrients from the organic matter in their surrounding environment. They reproduce by the two ways asexually or sexually by spores. These fungi cell wall is composed of cellulose or chitin, and their growth is apical. Macromycetes mushrooms develop fruiting bodies, depend on organic matter in decay and can be parasitic, saprobic, or mutualistic. Such mushrooms can be categorized into edible mushrooms (such as *Pleurotus ostreatus*) and poisonous ones (such as *Amanita abrupta*) [36,37]. Mushrooms especially edible mushrooms have many importance concerning their nutritional composition. Edible mushrooms rich source of essential amino acids, vitamins, fibres and others. Mushrooms are a source for many pharmaceutical drugs. Edible mushrooms polysaccharides have antimicrobial and antioxidant activity [38,39]. Mushrooms belong to a toxin-producing group of nematophagous fungi. These fungi secrete specific toxins that are capable of paralyzing and/or killing nematodes [40]. Moreover, enzymes are important key factors in the nematode infection and digestion processes by nematophagous mushrooms [41]. Degenkolb and Vilcinskas [42] reported that nematophagous basidiomycetes secrete different toxic nematicidal secondary metabolites.

Oyster mushroom compost is one of the potent compost that is famous for producing nematicidal toxic metabolites. Gray oyster (*Pleurotus ostreatus*) is one of the commercially produced oyster mushrooms that is known to produce trans-2-decenedioic acid which is a toxin secreted by hyphae [43], this toxin paralyzes the nematodes on contact, which allows the hyphae to move into position to colonize and digest the nematode. Till now, only *in vitro* studies were performed to evaluate the effects of oyster mushroom on nematodes. Mushroom compost of *Pleurotus sajor-caju* provides promising results in suppressing root-knot nematodes *Meloidogyne incognita* and has been given a lot of attention by researchers due to their environmentally safe and economically acceptable solution [44]. Xiang and Feng [45], reported the positive effects of *Pleurotus ostreatus* on the control of the peanut root-knot nematode *Meloidogyne arenaria* in the greenhouse, and the results of the experiments showed that *Pleurotus ostreatus* could markedly reduce the infecting number of nematode. *Pleurotus ostreatus* produces tiny droplets of toxin from minute spathulate secretory cells. When nematodes touching produced *Pleurotus ostreatus* droplets show a sudden and dramatic response. The head region shrinks significantly. In as little as 30 s, and usually within several minutes, the nematode becomes more or less immobilized but is not killed. *Pleurotus strigosus, Pleurotus subareolatus, and Pleurotus cornucopiae* behave in a similar way against nematodes [46].

Recently many researchers reported that most edible mushrooms species have nematocidal activity belong to the genus *Pleurotus*. The anthelmintic activity has been reported form extracts and its fractions obtained from *Pleurotus* fruiting bodies, mycelium, and degraded substrate. Among the nematicidal biologically active compounds originated from mushroom extracts pentadecanoic acid, octadecadienoic acid, octadecanoic acid, and the terpene β-sitosterol [47-50]. The capabilities of oyster mushrooms to infect and kill sugar beet cyst nematode *Heterodera schachtii* was investigated by Palizi, et al. [51], and the potency of *Pleurotus ostreatus, P. sajor-caju, P. florida, P. flabellatus, P. ostreatus*, *P. eryngii* and *Hypsizygus ulmarius* to prey on the cyst nematode was confirmed.

Zhao, et al. [52], mentioned that the culture filtrate of different isolates of *Beauveria bassiana* and its associated fungus had different levels of nematicidal activities, and the same culture filtrate had selective toxicity against different nematodes. This can be due to the ability of the different species belonging to the genus *Beauveria* to secrete different potent secondary metabolites as beauvericin, bassianin, bassianolide, beauverolides, bassiacridin, tenellin and oosporein [53,54]. Junxianke is a fermentation product produced by *Beauveria bassiana*, Junxianke is lethal to *Ditylenchus destructor*, *Heterodera glycines* and *Meloidogyne incognita* [55-57], thus *Beauveria* genus especially *Beauveria bassiana* have the potentially to applied in prevention of plant parasitic pests and nematodes. However, currently there are insufficient studies on the application of *Beauveria* in the control of nematode diseases.

Recently some experimental results revealed that the highest hatching inhibition and the juvenile deaths were observed after treatment with the *Ganoderma* lucidum ethyl acetate fraction followed by that of *Lentinus edodes*. The maximum inhibition of egg hatching (92.6%) and juvenile mortality (93.2%) of *Meloidogyne incognita* was achieved using 1000 ppm concentration of *Ganoderma lucidum* bio-active molecules after 72 hours of incubation [58-60]. Nematophagous activities of five mushrooms were evaluated by Ishizaki, et al. [61], and resulted that five species of saprophytic mushroom including *Cyptotrama asprata, Panellus stipticus, Hohenbuehelia reniformes, Resupinatus applicatus,* and *Pleurotus salmoneostramineus* can successfully immobilize and consume the pinewood nematode, *Bursaphelenchus xylophilus*.

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