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Influence of nematodes infesting mushrooms (*Agaricus bisporus*)

Devashree Ningombi and Pooja Kapoor

Abstract
Mushroom nematodes are parasitic roundworms that can infect and damage the roots of mushroom crops. These nematodes are a major threat to mushroom growers and can cause significant economic losses. There are several species of mushroom nematodes, including *Aphelenchoides composticola* and *Aphelenchus avenae*, which are commonly found in mushroom compost and casing soil. Infected mushrooms may exhibit symptoms such as stunted growth, abnormal morphology, and reduced yields. Management strategies for mushroom nematodes include cultural, physical, chemical and biological methods. Early detection and effective management are essential to minimize the impact of mushroom nematodes on mushroom production. Furthermore, to manage nematode populations, the use of chemical pesticides can have negative environmental and health impacts. Researchers and growers are investigating different control strategies, such as the use of biocontrol agents including predatory nematodes, fungal organisms, and bacteria, to solve this issue. These agents can help reduce nematode populations in soil and protect mushroom crops without the negative impacts associated with chemical pesticides. Although the present generation of mushroom producers continues to face challenges from the nematodes, continued research and development activities offer hope for more long-lasting and efficient control methods in the future.

Keywords: *Agaricus bisporus,* nematodes, mushroom, mycophagous, saprophagous

Introduction

A mushroom is the fruiting body of a fungus that is fleshy, spore-bearing (Basidiomycota, Agaricomycetes), and edible that grows on dead and decaying organic matter (Manoharachary, 2022) [39]. Although numerous species have been discovered, they can be divided into three main categories: medicinal mushrooms, edible mushrooms and poisonous mushrooms. Mushroom contains high protein and low calorific value so adding them to our daily diet is beneficial (Nongthombam *et al.*, 2021) [49]. It has a high vitamin B, copper, and selenium concentration, is low in salt, and contains over 90% water and relative to 1% fat. (Kratika 2018) [37]. In addition to their unique flavour, mushrooms are a meal that people adore because of the health benefits they provide. It is sold in various forms namely as fresh body, preserved/dried form, as pickles or even as canned foods which can be later made into soups, sauces, etc. The growing popularity of mushroom cultivation and processing is due in part to its high income and low-cost input, as well as its rich nutritional content and other positive health effects. (Gupta *et al.*, 2018) [23]. Mushrooms contain bioactive substances that can have a positive impact on one's health, including phenolic compounds, steroids, terpenes, polysaccharides, and vitamins. Mushrooms also contain macronutrients, micronutrients, and a few bioactive substances that have medical use. Due to their immunological properties, the chemicals extracted from mushrooms are highly significant in pharmaceutical, cosmetic, neurological and therapeutic purposes in preventing and treating diseases (table 1) (Sen *et al.* 2021) [59]. However, mushroom cultivation is affected by many diseases (bacterial, viral and fungal), pests and nematodes (Okigbo and Anuagasi 2021) [50]. In this review paper, nematode infestation in button mushrooms is being highlighted.

Table 1: Some properties and contents of mushroom

Sl.no.	Properties and contents	References
1.	substances with bioactive properties such as polysaccharides, steroids, terpenes, and phenolic compounds	Kim *et al.* 2015 [35]; Royse 2014 [57]; Shang *et al.* 2015 [61]; Sheu *et al.* 2007 [63]; Mariga *et al.* 2014 [40]
2.	Vitamin B, vitamin C and vitamin D	Panjikkaran and Mathew 2013 [51]
3.	20-35% dry-weight protein and 9 essential amino acids	Kalac 2009 [27]
4.	Antigenotoxic	Wang *et al.* 2005 [71]
5.	Antioxidative	Roupas *et al.* 2012 [56]
6.	Antiproliferative	Zhou *et al.* 2013 [75]
7.	Tumorigenic	Kim *et al.* 2015 [35]
8.	Antihypertensive	Vaz *et al.* 2011 [69]
9.	Hypocholesterolaemic	Han *et al.* 2011 [24]
10.	Stress-reducing properties	Akata *et al.* 2012 [2]
11	Appetite suppressant	Kim *et al.* 2011 [34]

Taxonomy of Button Mushroom *(Agaricus bisporus)*

In India, two types of button mushrooms are cultivated i.e., white button mushroom (commonly grown) and brown button mushroom (Amin *et al.* 2021) [4]. *Agaricus bisporus*, the most commonly cultivated mushroom species, accounts for around 40% of global production. (Banik 2010) [6]. In contrast to seasonal growers who only grow them in the winter, commercial units grow button mushroom crops throughout the year. The most cultivated states are Maharashtra, Punjab, Haryana, Gujarat, Goa, Uttarakhand, and Himachal Pradesh. (Nihal 2022) [48]. *Agaricus bisporus* is a common edible mushroom that belongs to the kingdom Fungi, phylum Basidiomycota, class Agaricomycetes, order Agaricales, and family Agaricaceae (El-Sebaaly *et al.*,2021) [12] (Table 2)

Table 2: Taxonomic classification

Kingdom	Fungi
Division	Basidiomycota
Class	Agaricomyctes
Order	Agaricales
Family	Agaricaceae
Genus	Agaricus
Species	bisporous

Mushroom-Nematodes interaction

Mushroom cultivation, one of the employment-generating sources, is famous or popular mainly amongst marginal farmers, young entrepreneurs and housewives (Borah *et al.* 2019) [10]. Mushroom cultivation and processing require a hygienic place to carry out and large industries have pasteurization units to sanitize. But these marginal farmers, young entrepreneurs and housewives do not have this pasteurization unit. Numerous pests, such as nematodes, fungi, bacteria, insects, as well as biotic and abiotic factors, are attracted to this unsanitary situation, which lowers the quality and yield of the mushroom. As a result of this improper sanitization, nematode infestation is a popular biotic stress which affects mushroom cultivation and causes crop losses (Keshari, and Kranti 2020) [29].

Mushroom nematodes are parasitic roundworms that attack mushroom crops. They are considered harmful to the mushroom crop and affect the quality of mushroom production (Zhang *et al.* 2020) [74]. They are mostly found in raw compost such as poultry manure, wheat straw, horse manure, etc. They developed mainly because of unhygienic, improper pasteurization and not properly prepared compost and casing material (Keshari, and Kranti 2020) [29]. In mushroom cultivation, unhygienic conditions provide a favourable environment for many pests, diseases and nematode infestation. Nematodes carry the greatest threat of all because once a crop has been infested by nematodes, there is no coming back meaning that the crop has to be fully eradicated (Phani *et al.* 2021) [52]. So, nematode infestation causes the greatest yield loss or total crop failure in mushroom cultivation as the crop could not be saved. In this context, a study conducted by Seth in 1984 [76] at Solan revealed that there was extremely less harvest in the beginning, resulting in total crop failures due to 84.4% nematode infestation. The reason behind the fast infestation of nematodes is that they reproduce very quickly by adapting themselves to the biological requirements of the crops and thus causing crop losses of up to 100% (Nagesh and Reddy. 2000) [45]. Bhardwaj *et al.* (1972) [8] published the first report about nematode damage mushrooms in India from Himachal Pradesh. With the growth in the mushroom industry for the last two decades, there have been numerous reports of nematode-caused crop failure. (Thapa *et al.* 1977; Chhabra & Kaul 1982; Seth 1984) [68, 12, 76]

Nematodes are of 2 types:

1. Myceliophagus or mycophagous nematodes
2. Saprophagous nematodes.

Myceliophagus or mycophagous

Myceliophagus or mycophagous nematodes feed on the mycelium of the mushroom fungus. This type of nematode uses a bear-shaped stylet to penetrate the mycelium and drain out its contents, thus leaving the mycelium dead and non-functioning for further growth of the mushroom body (Reddy and Reddy 2021) [54]. In some cases, even if the mycelium grows into a mushroom body, these Mycophagous nematodes go up the pinhead or pilus of the mushroom and attack (Godfrey 2003) [20]. The mushroom body shows stunted growth, the colour changes and eventually it dies. Mycophagous nematode infestation is hazardous as once this nematode enters the mushroom unit, it is very hard to eradicate. Also, they serve as carriers of several bacterial (eg. *Pseudomonas tolaasii*), viral, and fungal diseases (Maurya *et al.* 2020) [42]. Mycophagous nematodes have short lifespans, high fecundity, are highly pathogenic and are a destructive pest of mushrooms but they are found rarely due to proper sanitization in modern cultivation (Sattar *et al.* 2021) [58].

Table 3: Some Myceliophagus or mycophagous nematodes

Myceliophagus or mycophagous nematodes	**References**
Aphelenchus avenae	Hesling 1979 [25]
Aphelenchoides composticola	Bajaj and Walia (1999) [5], Khanna and Sharma (1988a, b) [30, 31], Gitanjali and Nandal (2001a, b) [18, 19]
Aphelenchoides agarici	Seth and Sharma (1986) [60], Bajaj and Walia (1999) [5], Seth (1984) [76]
Aphelenchoides neocomposticola	Seth and Sharma (1986) [60]
Ditylenchus Myceliophagus	Sharma *et al.* (1981) [62], Thapa *et al.* (1981) [67]

Saprophagous nematodes

Unlike mycophagous nematodes, Saprophagous nematodes have a tubular mouthpart with which they penetrate and withdraw the nutrient content of the mycelium (Marjanović 2022) [41]. While the mycophagous nematodes leave the mycelium to die, the saprophagous nematodes only injure the mycelium with their toxins and do not cause any direct damage (Keshari, and Kranti 2020) [29]. They usually affect the mushroom only after the infestation of the mycophagous nematodes. They reduce the quality of the compost beds making it unfavourable for the growth of mushrooms and also impacting the spawn run. They multiply very fast and are found in large numbers. Their population number depends on the quality of pasteurization of the compost beds (Sattar *et al.* 2021) [58]. Some symptoms usually seen are distortion, kidney-shaped mushrooms, gills colour changed into violet and sometimes sporophores turning brown in colour. These signs and symptoms are seen as a result of the nematode infestation in the mushroom beds. They carry the live bacteria in their gut and release them in the compost beds thereby inhibiting the growth of the fungal mycelium. (Keshari and Kranti 2020) [29].

Some species of saprophagous nematodes are *Rhabditis spp., Diplogaster spp., Caenorhabditis elegans, Panagrolaimus spp. Like Panagrolaimus fuchsia* (Nagesh and Reddy 2000) [45].

Source of Nematode infestation

During the entire cultivation process, the button mushroom is extremely vulnerable to nematode attack. Damp wheat straw, poultry manures, casing soil, farm yard manure (FYM), garden soil, spent compost, platform soil, irrigation water, composting with contaminated water, and contaminated utensils are the major sources of nematode infestation (Bellettini *et al.* 2018) [7]. Nematodes can be moved across beds by flies, especially sciarids (Navarro *et al.*2021) [47]. Sometimes nematodes are contaminated through diseased compost and soil. It is also spread from infected to non-infected areas via equipment, clothing, and employees' hands. Once the roof is infested, the crop is affected by nematode larvae droppings or eggs in the water droplets condensing on the roof. Another main reason for the nematode infestation is the lack of awareness. As mushroom cultivation is practiced mainly by marginal farmers, housewives and young entrepreneurs, they are not fully aware of the need for sterilization and pasteurization and thus, the higher rate of nematode infestation. A study conducted by Fletcher and Gaze (2007) [14] states that nematodes feed on fungi and in this particular study, they found that the presence of a particular fungus species, *Arthrobotrys spp.* shows the high nematode contamination in the mushroom bed. The presence of this fungus can be seen in the brown fungal colonies in the compost bed or casing soil.

Symptoms of nematodes infestation on *Agaricus bisporus* mushroom

Nematodes are microscopic worm-like organisms that can infect the mycelium of *Agaricus bisporus* mushrooms and cause damage to the crop (Zhang *et al.* 2020) [74]. If nematode infestation is suspected, it is important to take appropriate measures to prevent the spread of the infestation to other crops (Khanna *et al.* 2004) [33]. This may involve removing infected mushrooms and using nematode-resistant strains of *Agaricus bisporus* in future crops. Nematode infestations on *Agaricus bisporus* mushrooms can cause a variety of symptoms, including:

1. **Stunted growth**: Nematodes can cause the mycelium of the mushrooms to grow more slowly than usual, resulting in stunted growth and smaller mushroom caps.
2. **Reduced yields**: As a result of the slower growth, nematode-infected mushroom crops may produce lower yields than healthy crops and sometimes 100% crop failure.
3. **Poor quality**: Nematode-infected mushrooms may have a lower average weight, a higher proportion of malformed mushrooms, and other quality issues that make them less desirable for sale or consumption.
4. **Yellowing of mycelium**: In some cases, nematode infestations can cause the mycelium of the mushrooms to turn yellow or brown, indicating that the nematodes are feeding on the mycelium.
5. **Distorted mushroom caps**: Nematodes can also cause the caps of the mushrooms to become distorted or misshapen, which can affect their appearance and marketability.
6. **Reduced shelf life**: Nematode-infected mushrooms may have a shorter shelf life than healthy mushrooms, due to their lower quality and increased susceptibility to decay.

It is significant to remember that additional causes might potentially contribute to these symptoms, such as poor growing conditions or other pests and diseases, so growers should conduct a proper diagnosis to confirm nematode infestation. Growers can seek assistance from plant pathologists or nematologists to conduct tests and recommend appropriate control measures (Fletcher and Gaze 2007) [14].

Negative interaction of nematodes on mushroom

Nematodes can have a negative interaction with mushrooms and are often considered a pest in mushroom cultivation (Zhang *et al.* 2020) [74]. Nematodes may attack and feed on the mushroom's mycelium, which may delay any development of the mycelium and lower the crop's overall yield (Rinker 2017) [55]. In some cases, nematodes can also feed on the developing mushroom caps, causing them to become distorted or misshapen. In addition to direct damage, nematodes can also transmit other pathogens to the mushroom culture, such as bacteria or fungi, which can further damage the mycelium and decrease the crop's quality and yield (Ahmad *et al.* 2021) [2]. Nematodes can create entry points for other pests and pathogens by causing wounds in the mycelium or weakening the overall health of the mushroom culture. They can enter mushroom cultures through contaminated substrates or other materials used in the cultivation process. They can also be introduced through contaminated water or equipment (Bellettini *et al.* 2018) [7]. Once they enter the culture, they can move through the soil or growing media, seeking out the mycelium of the mushrooms to feed on. To prevent nematode attacks on mushrooms, growers should take several measures, including using nematode-free substrates and materials, sterilizing growing media before use, maintaining good hygiene practices in the cultivation environment, and monitoring the growing environment for signs of nematode activity. In addition, some growers may choose to use nematicides or other control measures to treat nematode infestations (Tapia-Vázquez *et al.* 2022) [66].

Positive interaction of nematodes on mushroom

While nematodes are often considered a pest in mushroom cultivation, there are some instances where they can have a positive interaction with mushrooms. Mushroom nematodes are parasites that infect and damage mushroom crops, and as such, they are generally considered to have negative effects. However, there are many beneficial uses of mushrooms themselves, such as providing food, medicine, and ecological services. For example, some types of mushrooms are known to have immune-boosting, anti-inflammatory, and anti-cancer qualities. Some nematodes form mutually beneficial associations with mycorrhizal fungi, which are fungi that form symbiotic relationships with the roots of most plants, including mushrooms (Yuvaraj and Ramasamy 2020) [73]. The nematodes help the mycorrhizal fungi by breaking down organic matter and releasing nutrients that the fungi can use to grow and spread, while the fungi provide the nematodes with a source of food in the form of sugars and other nutrients. This mutualistic relationship benefits both the nematodes and the mushrooms, as it enhances nutrient cycling and can contribute to their overall health and growth (Carrasco and Preston 2020) [11]. Some species of nematodes can act as decomposers, breaking down organic matter in the soil or growing media and releasing nutrients that can be taken up by the mushrooms and used for growth (Adegbeye *et al.* 2020) [1]. This helps in recycling nutrients and making them available for mushroom growth, thereby positively influencing mushroom growth and productivity. This can improve the overall health and growth of the mushroom culture (Naik. *et al.* 2019) [46]. Additionally, there is potential for using certain species of nematodes as biocontrol agents against other pests and diseases that can affect mushroom cultivation, which may negatively impact mushroom growth. Some nematodes are known to feed on bacteria or other fungi that compete with mushrooms for resources, helping to reduce competition and promote the growth of mushrooms. Certain species of nematodes can act as biocontrol agents against pests that can attack mushrooms. Some nematodes are known to parasitize and kill insect pests, such as mushroom flies or mites, that can damage mushrooms (Rinker 2017) [55]. By reducing the population of pests, nematodes can help protect mushrooms from damage and promote healthy mushroom growth. Using these nematodes as a natural control measure could reduce the need for chemical pesticides and improve the sustainability of mushroom cultivation (Soliman *et al.*2022). Furthermore, nematodes can also stimulate mycelial growth, which is the vegetative part of mushrooms, by feeding on certain substances or by physically breaking up mycelial mats (Kamalakannan *et al.*2020) [28]. This can result in increased mycelial growth and branching, which in turn can lead to enhanced mushroom fruiting. Overall, nematodes can have positive interactions with mushrooms by forming mutualistic associations, preying on competing organisms, contributing to nutrient recycling, acting as biocontrol agents, and stimulating mycelial growth, all of which can promote healthy mushroom growth and productivity (Zhang *et al.* 2020) [74]. However, it's important to note that the effects of nematodes on mushrooms can vary depending on the specific species of nematodes, mushrooms, and environmental conditions, and more research is needed to better understand these interactions (Koppenhöfer *et al.* 2020) [36].

Integrated Management of Mushroom Nematodes

Nematodes can get controlled by using various methods like cultural, physical, biological and chemical methods (WA *et al.* 2021) [70]. Although nematicides are commonly used for the prevention of nematodes as they affect the environment and human health, scientists are researching more for alternatives to control nematodes that are not harmful (Gamalero and Glick 2020) [16]. Nematode entry into the beds should be prevented rather than controlled because of the crop's nature, the shortage of nematicides that are both safe and effective, residue issues, and other nematicide dangers (Reddy and Reddy 2021) [54]. There is currently no curative measure that can be used during the cropping stage. As a result, an integrated approach is used as the sole control measure.

1. Cultural measures

In mushroom cultivation, cropping should be done in specially constructed mushroom chambers with enough ventilation, using properly pasteurized compost produced through the short method because sometimes in the long method of composting, the level of contamination is higher (Fletcher and Gaze 2007) [14]. Rigorous sanitary and sanitation measures must be implemented throughout the cropping season. Everything has to be sterilized with 2% formalin 24 hours before composting. Also, treatment with 4% formalin is required for all equipments, floors, walls, and galleries. (Kamalakannan *et al.* 2020) [28]. Disinfectants (5% formalin concentration) should be used by both employees and guests before entering and after leaving the mushroom chamber (Keshari and Kranti 2020) [29]. Ingredients for composting should always be kept in clean surroundings. Mushroom farms should be kept clean both inside and outside. Good sanitation practices such as removing and destroying infested mushroom substrates, cleaning and disinfecting equipment, and keeping the growing area clean can help to reduce nematode populations (Okigbo and Anuagasi 2021) [50]. The casing combination should be adequately pasteurized. Manures intended for composting should be properly decomposed and given adequate time to decompose. The growth rooms should have sufficient ventilation and doors and windows enclosed with wire mesh measuring 14 to 16 cm per layer to avoid the entry of insect pests. (Singh and Sharma 2016) [64] The mushroom growers can also practice crop rotation, a cultural control measure that involves alternating mushroom cultivation with non-host crops. This helps to break the life cycle of the nematodes, thereby reducing their population (Wesemael *et al.* 2011) [72]. Another technique is Soil solarization which involves covering the mushroom bed with a clear plastic sheet and exposing it to sunlight for several weeks. This technique helps to kill nematodes, bacteria, and other soil-borne pathogens that can affect mushroom growth (Munshi *et al.* 2010) [44]. And finally, maintaining the Soil pH is as important as the other practices in the cultural control of mushroom nematodes. Mushroom nematodes thrive in acidic soils. Maintaining a neutral to slightly alkaline soil pH of 7-7.2 can help to reduce nematode populations (Keshari and Kranti 2020) [29].

2. Chemical control

Since mushrooms are grown indoors, the use of pesticides is limited (Reddy and Reddy 2021) [54]. Also, it is usually eaten fresh so the use of pesticides will be hazardous to human health. But when using a long composting technique, some of the chemicals that can be used can help control nematode populations. (Keshari and Kranti 2020) [29]. Organochlorine insecticides were the first class of chemicals utilized to eradicate pests that affect mushrooms (Read 1968) [53]. Additionally utilized as nematicides are organophosphates. When mixed with the compost and applied as sprays during the spawn run, thionazin at 80 ppm (0.008%) effectively controlled *D. Myceliophagus* and *A. composticola* without leaving any hazardous residue. (Singh and Sharma 2016) [64]. The most effective method for controlling *A. composticola* and *Rhabditis sp.* was Dichlorvos at 0.04% administered for 3–4 days under polythene cover. (Keshari and Kranti 2020) [29] (table 4). Lack of awareness about the use of nematicides or pesticides in mushroom cultivation and processing is one of the main causes of decline in yield, insect resistance, self-harm to the mushroom growers, contaminated mushrooms and serious health issues (Reddy and Reddy 2021) [54]. In this modern world, where sustainable agriculture and natural farming are being encouraged, the most effective way to eliminate mushroom nematodes is farm hygiene and sanitization.

Table 4: Some nematicides/ pesticides used for mushroom nematodes

Sl. No.	Nematicides/ pesticides	Nematode species	References
1.	Thionazin at 80 ppm	*D. myceliophagus and A. composticola*	Singh and Sharma 2016) [64].
2.	Dichlorvos (0.04%)	*A. composticola and Rhabditis sp.*	Keshari and Kranti 2020 [29]
3.	Phenamiphos (EC) at a dose of 20 mg/kg	*Aphelenchoides composticola*	Mcleod and Khair 2008 [43]
4.	diflubenzuron	*Aphelenchoides spp.*	Gahukar 2014 [15]
5.	benomyl and thiabendiazole	*Aphelenchoides spp.*	Mcleod and Khair 1978 [43]
6.	Carbofuran	*Myceliophagus and saprophagous nematodes*	Sharma *et al.* 1981 [62]

3. Physical Control

Physical control measures for mushroom nematodes involve the use of physical barriers or traps to prevent or reduce the spread of nematodes (Georgis *et al.* 2006) [17]. Soil steaming is a physical control measure that involves using steam to heat the mushroom bed and soil to high temperatures. This helps to kill nematodes and other soil-borne pests (Fletcher and Gaze 2007) [14]. In order to control nematodes in the mushroom industry, heat is the most effective method. In order to eradicate compost nematodes, the pasteurization room's air and bed temperatures must be maintained for at least two hours at 60°C, and the incubation temperature must be maintained for five to six hours at 70°C or for thirty to sixty minutes at 80°C (Thapa *et al.* 1981) [68]. Disinfecting used equipments such as trays and utensils with 5% formalin or cresylic acid or by using boiling water for 1-2 minutes is ideal (Nagesh and Reddy 2000) [12]. Soil solarization, which was mentioned in the cultural control section, is also a physical control measure that involves covering the mushroom bed with a clear plastic sheet and exposing it to sunlight for several weeks. This technique helps to kill nematodes and other soil-borne pathogens that can affect mushroom growth (Munshi *et al.* 2010) [44]. Traps can also be used to reduce the population of mushroom nematodes. For example, sticky traps can be placed around the mushroom bed to trap and kill nematodes (Grewal 2000) [22]. Physical barriers such as mesh screens can be used to prevent nematodes from entering the mushroom bed or transfer nematodes from one bed to the other.

4. Biological control

Natural enemies or other species, such as fungi and bacteria and their byproducts, are used in biological management to reduce mushroom nematodes as mushrooms are typically consumed fresh and the use of nematodes or pesticides is not advised (Keshari and Kranti 2020) [29]. Because of their extreme sensitivity to chemicals, fresh mushrooms shouldn't be consumed after being sprayed with a nematicide. Consequently, the importance of biocontrol agents has increased. Two nematophagous fungi, *Arthrobotrys irregularis* and *Candelalretta musiformis*, were shown to be very effective in suppressing nematode multiplication on mushroom mycelium, according to a study conducted in Solan (Himachal Pradesh). (Khanna and Sharma 1990; Grewal and Sohi 1988) [32, 21]. A wide range of plants has been found to have nematicidal properties. Another fungus known as Royal 300, Arthrobotrys *robusta*, is effective against mycophagous nematodes. It has been found that *Candelalretta musiformis* extracted from used compost is extremely good at preventing nematode multiplication (Keshari and Kranti 2020) [29]. Another fungus known as *A. irregularis* is incredibly successful at eliminating *A. composticola*, claim Grewal and Sohi (1988) [21] and Khanna and Sharma (1988a, b) [30, 31]. However, when growing mushrooms, one should only utilize biocontrol agents found in compost, such as predatory nematodes and nematophagous fungi, which are easy to grow and multiply since they are facultative parasites and they can consume both saprophytic bacteria and nematodes (Kumar *et al.* 2020) [28]. In order to manage plant infections, such as mushroom nematodes, biocontrol agents are increasingly being employed as a sustainable and environmentally friendly substitute to chemical pesticides (Soliman *et al.* 2022) [65]. Predatory nematodes, fungus, and bacteria are some of the biocontrol agents that have been identified to control mushroom nematodes. In general, the use of biocontrol agents in the control of mushroom nematodes shows promise as a sustainable and effective approach to reducing nematode populations and protecting mushroom crops (Bilgrami 2008) [9]. Further study is required regarding integrated pest management strategies that combine biocontrol with other control techniques and to optimise the use of these agents.

Conclusion

In India, mushroom growing is a relatively young and expanding industry. The demand for producing mushrooms is increasing as people become more aware of their taste and high food value. Because mushrooms are a short-term crop, using insecticides to kill nematodes is not recommended owing to health hazards. There is a need to investigate the utilization of some plant materials that exhibit nematicidal qualities while still being safe for mushroom mycelium. Nematode issues in mushrooms are distinct in that the nematodes have fully adapted to the crop's ecological needs and also reproduce incredibly quickly, leading to crop losses of up to 100%. An integrated approach is used to control nematodes. In conclusion, mushroom nematodes pose a significant threat to mushroom growers, causing damage to mushroom crops and leading to economic losses. Chemical pesticides have traditionally been used to control nematode populations, but these can have negative environmental and health impacts. Alternative methods of managing mushroom nematodes, like the use of biocontrol agents, are more environmentally responsible and sustainable. Further study is required regarding integrated pest management strategies that combine biocontrol with other control techniques and to optimise the use of these agents. Overall, it is important for mushroom growers to remain vigilant in monitoring for nematode infestations and to implement effective control measures to minimize the impact of nematodes on mushroom production. By doing so, growers can protect their crops and ensure a more sustainable and profitable mushroom industry.

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