Predatory behaviour of *Fictor composticola* Khan *et al.* and its potential for the management of nematode pests of button mushroom

By
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CERTIFICATE – I

This is to certify that this thesis entitled, "Predatory behaviour of *Fictor composticola* Khan *et al.* and its potential for the management of nematode pests of button mushroom" submitted for the degree of **Doctor of philosophy** in the subject of **Nematology** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar** is a bonafide research work carried out by **Mrs. Nishi Keshari,** Admission No. **2012A32D** under my guidance and supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of the investigation have been fully acknowledged.

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CERTIFICATE – II

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Hisar *Nishi Keshari*

Dated

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CHAPTER-I

INTRODUCTION

Button mushroom, *Agaricus bisporus* (Lange) Singer contributes more than 80 % of total mushroom production in India (NRCM 2007). Mushroom growing is a young progressive industry all over the world today and is one of the fastest growing small scale industries especially in rural areas. In India, its commercial cultivation is picking up in states like Himachal Pradesh, Haryana etc. The successful growing of this delicacy needs attention and hygienic conditions which is rarely possible in farmers' field. The mycophagous nematodes are noxious pests which once introduced into the beds, are very difficult to eliminate. The mycophagous nematodes like *Aphelenchus avenae, Aphelenchoides* spp., *Ditylenchus* sp., are common in mushroom beds (Bajaj and Kanwar 2011). They feed on the mushroom mycelia by piercing the mycelial wall with their hollow stylet and suck the contents of the pierced cells. They may attack the mycelium at any time from spawning onwards. Due to their greater initial numbers, they may cause a steady decline in mushroom yield and production may suffer a loss. They may cause patchy to no growth of mycelium, sinking and foul smell of spawn run in mushroom bed leading to severe reduction in the mushroom yield (Kumar *et al.* 2008).

To get good productivity, this crop needs to be protected from nematodes. Mushroom cropping often continues for 6-8 weeks, and the mushrooms are harvested and consumed soon after they appear. Therefore, applying any nematicide during cropping, is not safe for health because of toxicity and residual problems. Also mushroom is very sensitive to many chemicals and the sporophores on the surface are sometimes more sensitive than the mycelia. Clearly, there are many real and potential difficulties in treating large volumes of compost with nematicides. Thus, the role of biocontrol agents become important in the management of these mycophagous nematodes. Presence of naturally occurring parasites and predators in the mushroom ecosystem can be exploited for the management of these nematodes.

The bio-control agents are the cheaper, non-toxic and provide pollution free control of pests. The bioagents may be preventive as well as curative because they can help in evading the pest or disease but, if the disease is already set, it can be corrected by reducing the population densities of the pest or pathogen. Amongst these biocontrol agents, predaceous nematodes can play a vital role in nematode management if given equal importance and opportunity. Biocontrol potential of predatory nematodes was known since Cobb (1917) discovered their possible role in management of plant parasitic nematodes. Cassidy (1931) and Christie (1960) suggested that the predatory nematodes might be useful as biocontrol

agents against plant parasitic nematodes. Further studies on this aspect were done by Mulvey (1961), Esser (1963), Esser and Sobers (1964), Ritter and Laumond (1975).

Mononchids have been known to feed on a variety of soil organisms including nematodes (Banage 1963). Small (1979) reported significant reductions in the population densities of potato cyst nematode, *Globodera rostochiensis* and root-knot nematode, *Meloidogyne incognita* in presence of a predatory nematode, *Prionchulus punctatus*, in pot experiments. Biocontrol may be effective without disturbing the eco-system, and may fetch economic and effective control measures (Sikora 1992) and may turn out to be an important component for integrated nematode management system. Cohn and Mordechai (1974) reported density dependent predation by *Mylonchulus sigmaturus* upon citrus nematode, *Tylenchulus semipenetrans.* Predatory nematodes reduce populations of plant parasitic nematodes in virtually all soils because of their constant association with plant parasitic nematodes in the rhizosphere.

The majority of predatory nematodes belong to four major taxonomic groups of nematodes - Mononchida, Dorylaimida, Diplogasterida and Aphelenchida. Each group has its own type of feeding apparatus, feeding mechanisms and food preferences. Mononchids have strong and well developed buccal cavity and buccal musculature besides teeth and denticles. Their feeding apparatus is cutting, sucking and engulfing type. Dorylaimids have piercing and sucking type buccal cavity. They have dagger shaped odontostyle with which they puncture the body wall of the prey and suck its body contents. The aphelenchids possess a small narrow spear with a lumen without basal knobs and their spear is piercing and sucking type.

The diplogasterids are the excellent example of predators. They have small buccal cavity but have teeth of different sizes located at different positions. Their feeding apparatus is cutting and sucking type. The mouth of these predators is circular with 6 pairs of ‘rugae’ and 10 labial papillae. They have a claw like tooth which is movable and hollow from inside. Opposite to the dorsal tooth, they bear small, rose thorn shaped teeth, and inside the bucal cavity, a small tooth at base. Some species also possess denticles which help in grinding the food particles. Diplogasterids are generally found abundantly in decomposing organic manure. Their life cycle is short and they can be easily cultured and maintained on simple nutrient media containing bacteria (Yeates 1969). Thus, they may prove as promising biocontrol agents. The main advantage of using diplogasterid predators are their short life cycle, high rate of predation, easy culturing, high fecundity (Siddiqi *et al*. 2004, Bilgrami *et al.* 2005). This group of predators remained neglected until Yeates (1969) evaluated the predatory abilities of *Mononchus potohikus.*

Diplogasterid predators appear to be more prey selective than other groups. *Odontopharynx longicaudata* attacked and killed six out of 17 prey species and 100 % individuals of *Anguina pacificae* were killed (Chitamber and Noffsinger 1989). A strong

degree of prey preference was shown by *Mononchoides fortidens, M. longicaudatus, M. gaugleri* and *M. composticola.* They preferred juveniles of endoparasitic over ectoparasitic nematodes and predation rate was higher on the small and slow moving species than on larger and more motile nematode species (Bilgrami and Jairajpuri 1989; Bilgrami *et al.* 2005; Steel *et al.* 2011). Bilgrami and Jairajpuri (1988 and 1989) and Bilgrami (1990 and 1997) provided detailed accounts on prey searching, preference, strike rate etc.

Diplogasterid predators certainly deserve the attention of nematologists to explore their potential as biocontrol agents. Steel *et al.* (2010) found the high abundance of *M. composticola* during the composting process which indicates its natural microhabitat in compost, involving a diversity of bacteria and nematodes, and a particular temperature regime with temperatures up to 30 °C or more for several days. Predatory nematodes present a small amount of the available biomass in the soil, but their presence across so many trophic levels such as plant, fungal and bacterial feeders is vitally important in soil ecosystem process.

The prey catching and feeding mechanism of the majority of predators belonging to different groups of nematodes involve five steps - encounter with prey, attack response, attack, salivation/extra corporeal digestion and ingestion/feeding (Bilgrami and Jairajpuri 1990). Most of the information on predatory nematodes are based on agar plate experiments. Successful biocontrol could be achieved if prey nematodes are susceptible to predation. Prey specificity is an important factor in biocontrol. Mononchids generally lack prey specificity and they feed on all types of nematodes (Bilgrami *et al.* 1986) whereas diplogasterids are highly prey specific (Chitamber and Noffsinger 1989). Short life cycle and high reproductive potential are important traits of predatory nematodes which are commonly found in diplogasterid predators. (Tahseen *et al.* 1990, Siddiqi *et al.* 2004 and Chitamber & Noffsinger 1989).

Fictor composticola, a diplogasterid predatory nematode was described from mushroom compost (Khan *et al.* 2008) and was commonly found in the mushroom compost (Kanwar *et al.* 2009), holds promise as bio-control of mushroom feeding nematodes. It was found prevalent in compost used for cultivating button mushroom (*Agaricus bisporus* (Lange) Singer) in Haryana and Bihar states of India (Khan *et al.* 2008). Kanwar *et al.* (2009) and Bajaj and Kanwar (2015) conducted preliminary studies on this nematode. The present investigation was planned to study predatory behaviour and survival of *F. composticola,* and to explore its potential as bio control agent of nematode pests of mushroom with following objectives :

1. To explore the prey range and prey preference of *Fictor composticola*
2. To study predation behaviour of *F. composticola*
3. To study the survival of *F. composticola*
4. To explore the potential of *F. composticola* for the management of mycophagous nematode in button mushroom, *Agaricus bisporus.*

CHAPTER-II

REVIEW OF LITERATURE

The present investigation was carried out to study the prey range, prey preference, predatory behaviour, survival of *Fictor composticola* and management of mycophagous nematodes in button mushroom cultivation.

Prey range of the predatory nematodes

The knowledge of predator-prey relationship and range of prey has great significance in formulating biological control programmes and in proper utilization of different kinds of predators. The predatory nematodes of different groups are having a wide range of hosts.

The first report of the host of predatory nematode was done by Cobb (1917, 1920) and Steiner and Henley (1922) when a mononchid predatory nematode, *Clarkus papillatus* was found feeding on a plant parasitic nematodes, *Meloidogyne* sp. Cohn and Mordechai (1974) found the host of *Mylonchulus sigmaturus* on *Tylenchulus semipenetrans*. Similarly, the plant parasitic nematodes, *Trichodorus* sp. and *Hemicycliophora* sp. were found hosts of *Parahadronchus shakili* (Ahmad and Jairajpuri 1982). Rama and Dasgupta (1998) reported *T. semipenetrans* and *Helicotylenchus dihystera* as the hosts of *Iotonchus tenuicaudatus*. Table 2.1 represents hosts of some important predatory nematodes.

Table 2.1. Prey range of predatory nematodes

Predators	Prey	Reference
A. Mononchids		
Clarkus papillatus	*Aphelenchoides* sp., *Hemicriconemoides* sp., *Heterodera schachtii, M. hapla, Tylenchus, T. semipenetrans, Subanguina radicicola*	Cobb (1917), Menzel (1920), Steiner and Henley (1922), Thorne (1927)
Iotonchus kheri	*Helicotylenchus multicinctus, Hirschmaniella oryzae, M. incognita, Rotylenchulus reniformis, Scutellonema curvata, Tylenchorhynchus nudus, Xiphinema elongatum*	Mohandas and Prabhoo (1980)
I. monhystera	*H. multicinctus, H. dihystera, H. oryzae, Hoplolaimus, M. incognita, Pratylenchus* sp., *T. nudus, R. reniformis*	Bilgrami *et al.*(1986), Mohandas and Prabhoo (1980), Azmi (1983)
I. tenuicaudatus	*T. semipenetrans, H. dihystera*	Rama and Dasgupta (1998)
Mononchus aquaticus	*A. parvus, A. tritici, G. rostochiensis, H. oryzae, H. indicus, H. mothi, Longidorus,*	Grootaert and Maertens (1976), Grootaert *et al.*

	M. incognita, M. naasi, Paralongidorus citri, Paratrichodorus sp., *Rotylenchus fallorobustus, Trichodorus* sp., *X. americanum, Tylenchorhynchus mashhoodi*	(1977), Grootaert and Wyss (1979), Small and Grootaert (1983), Bilgrami (1992)
Mylonchulus dentatus	*A. tritici, Basiria* sp., *Helicotylenchus indicus, H. oryzae, Hoplolaimus indicus, Longidorus* sp., *M. incognita, P. citri, T. mashhoodi, T. semipenetrans*	Jairajpuri and Azmi (1978), Bilgrami and Kulshreshtha (1993)
M. minor	*A. tritici, M. incognita, T. semipenetrans, X. americanum, R. reniformis*	Kulshreshtha *et al*. (1993), Choudhary and Shivkumar (2000)
M. sigmaturus	*H. schachtii* (eggs), *M. javanica, R. similis, S. radicicola, T. semipenetrans*	Thorne (1927), Cassidy (1931), Cohn and Mordechai (1973, 1974)
Prionchulus punctatus	*A. tritici, G. rostochiensis, H. dihystera, M. naasi, R. fallorobustus*	Nelmes (1974), Grootaert *et al*. (1977), Small and Evans (1981),
B. Dorylaimids		
Aporcelaimus nivalis	*A. tritici, Aphelenchoides* sp., *Basiria* sp., *H. indicus, H. mangiferae, H. dhirendri, H. mothi, H. oryzae, H. indicus, Longidorus* sp., *M. incognita, P. citri, Scutellonema* sp., *T. mashhoodi, T. semipenetrans, Trichodorus* sp., *X. americanum, X. insigne*	Khan *et al.* (1991), Bilgrami (1993)
Aquatides thornei	*A. tritici, H. indicus, H. mothi, H. oryzae, Longidorus* sp., *M. incognita, P. citri, T. mashhoodi, Paratrichodorus* sp., *X. americanum*	Bilgrami *et al.* (1985), Bilgrami (1992)
Labronema vulvapapillatus	*A. tritici, G. rostochiensis, M. naasi, X. index*	Wyss and Grootaert (1977), Grootaert and Small (1982), Small and Grootaert (1983)
C. Diplogasterids		
Butlerius degrissei	*A. fragariae, Pratylenchus* sp., *G. rostochiensis, M. naasi, R. robustus*	Grootaert *et al.* (1977), Small and Grootaert (1983)
Mononchoides fortidens and *M. longicaudatus*	*A. tritici, H. indicus, H. oryzae, Longidorus* sp., *M. incognita, Trichodorus* sp., *T. mashhoodi, X. americanum*	Bilgrami and Jairajpuri (1988, 1989)

M. gaugleri	*A. tritici, H. indicus, H. mangiferae, H. oryzae, L. attenuates, M. incognita, P. christiei, T. mashhoodi, X. americanum*	Bilgrami *et al.* (2005)
Odontopharynx longicaudata	*M. incognita, M. hapla, M. javanica, P. vulnus, Trichodorus* sp., *T. semipenetrans, X. index, Criconemella xenoplex, A. fragariae, A. pacificae*,	Chitamber and Noffsinger (1989)

Cabos *et.al.*(2013) reported after DNA detection of the gut contents of predator and omnivorous nematodes through PCR based approach that when the predatory nematodes, *Mononchoides* sp., *Mononchus* sp., *Neoactinolaimus* sp., *Mesodorylaimus* sp., *Aporcelaimellus* sp. were assayed, the plant parasitic nematodes, *Rotylenchulus reniformis, M. incognita* and *Radopholus similis* were found.

Fictor composticola, a diplogasterid predator, found mostly in compost, is a voracious feeder. It feeds on the nematodes belonging to different categories like plant parasitic, mycophagous, saprophagous nematodes etc. The prey range of this predator includes *Aphelenchoides swarupi, A. asterocaudatus, Aphelenchus avenae, A. radicicolus*, second stage juveniles of *Heterodera avenae, H. cajani, H. sorghi, H. zeae, M. incognita, T. semipenetrans, T. mashhoodi, Mesorhabditis* sp., *Bursilla* sp. and *Panagrolaimus* sp. It did not feed upon *Helicotylenchus dihystera, Hemicriconemoides cocophilus, Hoplolaimus indicus*, young females of *R. reniformis*, *Zeldia* sp. and *Diplogastrellus gracilis* (Bajaj and Kanwar 2015).

Prey preference of predatory nematodes

Though no predator is really prey specific but, the range of prey is rather limited and differs from species to species. Esser (1963) observed that the predatory dorylaims and mononchs prefer *Meloidodera floridensis, Pratylenchus penetrans, P. vulnus, Paratylenchus curvitatus* and *Meloidogyne* spp. Yeates (1969) studied prey selectivity of the nematode, *Mononchoides potohikus* and found that in pure populations, the number of each species removed do not differ significantly from those for any other species. In mixed populations, none of the three combinations, *Mesorhabditis littoralis + Acrobeloides systisus, M. littoralis + Panagrolaimus australis* and *A. systisus + P. australis*, there was a significant difference between the number of each species, *M. littoralis, A. systisus* and *P. australis*. Thus, *M. potohikus* was not found selective in its predation behaviour.

Prionchulus punctatus preferred *A. tritici* and *A. avenae* but not *Helicotylenchus* sp. (Nelmes 1974). *Mylonchulus dentatus, Dorylaimus stagnalis, Mononchoides longicaudatus* and *M. fortidens* also killed fewer *Helicotylenchus indicus* (Jairajpuri and Azmi 1978, Shafqat *et al.* 1987).

The dorylaim predator, *Labronema vulvapapillatum* preferred *A. avenae, Panagrellus redivivus,* and *A. tritici* in place of *P. penetrans* and *Xiphinema index* (Wyss and Grootaert 1977).

Prey preference has also been observed in diplogasterid predators. *Butlerius* sp. preferred soil stages of endoparasitic nematodes in place of ectoparasitic ones (Grootaert *et al.* 1977). While observing the predation abilities of *M. longicaudatus* and *M. fortidens* (Bilgrami and Jairajpuri 1989) found that these predators prefer *Acrobeloides* sp., *Cephalobus* sp., *P. redivivus, Hirschmaniella oryzae* and the second stage juveniles of *M. incognita* and *A. tritici,* but did not feed upon *Hoplolaimus indicus* and *Hemicriconemoides mangiferae*. Other prey nematodes, *viz*., *Rhabditis* sp., *Longidorus* sp., *X. americanum, T. mashhoodi* and *Helicotylenchus indicus* were moderately preferred.

Hoplolaimus indicus was not preferred by *Mylonchulus dentatus* (Jairajpuri and Azmi 1978) and *D. stagnalis* (Shafqat *et al* 1987). *Diplenteron colobocercus,* however did not show preference for any particular type of prey and killed *Mesorhabditis littoralis, Panagrolaimus australis, Acrobeloides syrtisus* and *Zeldia punua* in equal numbers. Cohn and Mordechai (1974) reported that the feeding by *Mylonchulus sigmaturus* was more on *T. semipenetrans* or *M. javanica* juveniles than on *Helicotylenchus multicinctus* or *Longidorus africanus.*

The selection of prey depends on the activity, size and the behaviour of prey nematodes like *Cephalobus* sp., *Aglenchus parvus* as compared to more active *Prismatolaimus* sp. (Bilgrami *et al.* 1983) and hence the prey selection may differ from species to species of predators. Thorne (1932) found remnants of *Rotylenchus robustus* and *Trichodorus sparsus* in *Iotonchus acutus* which were not killed by *Butlerius* sp.

Bilgrami *et al.* (1986) analysed the intestinal contents of over 1000 specimens of 33 species of nine genera of Mononchida to assess their choice of prey. They found that the choice differed widely and there was no clear-cut pattern. Bilgrami and Jairajpuri (1989) reported that *Mononchoides fortidens* and *M. longicaudatus* showed maximum predation on *Acrobeloides* sp., *Cephalobus* sp., *Panagrellus redivivus* and the second stage juveniles of *M. incognita* and *A. tritici* when subjected singly. *M. incognita* and *A. tritici* were most preferred by both predators in all the combinations in which they were tested. When tested together in one combination, *M. incognita* and *A. tritici* juveniles were killed in equal numbers by both predators. It did not prefer *Hoplolaimus indicus* or *H. mangiferae*.

Bilgrami and Kulshreshtha (1993) found that *M. dentatus,* exhibited preference on endo-parasitic nematodes, *M. incognita, T. semipenetrans, H. mothi* and *A. tritici* most in comparison to other species of prey when placed with different species of prey nematodes. Females were most active predators than the juveniles. Other species of prey, i. e., *Hoplolaimus indicus, Helicotylenchus indicus, T. mashhoodi, Hirschmanniella oryzae, Basiria* sp., *H. mangiferae, X. basiri* and *Longidorus* sp., were killed in moderate numbers.

Khan and Jairajpuri (1997) reported that *Paractinolaimus elongatus* preferred second stage juveniles of *M. incognita* to a maximum extent. *A. tritici* were also preferred and killed in large numbers when placed in combination with the other species of the prey. The adults of *T. mashoodi* and *H. oryzae* were killed and consumed but in moderate numbers, while those of *Hoplolaimus indicus, X. basiri* and *Longidorus* sp. were preferred the least.

Moens *et al.* (2000) demonstrated that the predatory nematode, *Adoncholaimus fuscus* showed no preference for any prey tested (*Diplolaimelloides meyli or Monhystera* sp.) but *Enoploides. longispiculosus* exhibited a distinct preference for *Monhystera* sp.

M. gaugleri also preferred some prey species (*M. incognita, H. mothi, A. tritici, H. oryzae, T. mashhoodi, X. americanum, Paratrichodorus christiei, Longidorus attenuatus* and *Helicotylenchus indicus*) over others (*H. mangiferae* and *Hoplolaimus indicus*) reflected its discriminatory behaviour which is a desirable trait of a biocontrol agent (Bilgrami *et al.* 2005).

Predation behaviour of predatory nematodes

A predator may be considered as an efficient agent of bio-control if it possesses high strike rate (ability to attack and wounding prey) against a particular type of prey depending upon the degree of resistance/susceptibility of prey against predation. The most effective and suitable combination of predator and prey could be the most efficient predator (in terms of highest strike rate) and most susceptible prey (i.e., most vulnerable to wounding). Bilgrami and Jairajpuri (1989) first modeled the strike rate of *Mononchoides longicaudatus* and *M. fortidens* devising by assessing the number of encounters of the predatory nematode on prey, and the number of encounters resulting in attack (EA).

Bilgrami (1993) studied the strike rate of the predator, *Aporcelaimellus nivalis*. He established the relationships between strike rate of predators, prey susceptibility, wounding, feeding etc. on five different prey trophic categories: (1) Bacterial feeders (saprophagous nematodes), (2) Migratory juveniles (Sedentary endoparasitic nematodes) (3) Epidermal feeders (Ectoparasitic nematodes), (4) Cortical feeders (Ectoparasitic nematodes) and (5) Predatory nematodes. A significant correlation between EA and AW (total number of encounters resulting wounding) was observed for all the prey trophic categories. Similar correlations were obtained between AW and FW (Feeding after wounding prey) for bacterial feeders, endoparasites and epidermal feeders but for cortical feeders and predators the relationships were insignificant.

Bilgrami (1992) studied the strike rate of three predators, *Mononchus aquaticus, Dorylaimus stagnalis* and *Aquatides thornei* on the prey species, *Acrobeloides* sp., *Cephalobus* sp., *Rhabditis* sp., *Panagrellus redivivus, T. mashhoodi, Hoplolaimus indicus, Helicotylenchus indicus, Scutellonema* sp., *Hemicycliophora* sp., *H. mangiferae, H. oryzae, Longidorus* sp., *Paralongidorus citri, Paratrichodorus* sp., *X. americanum* and the second

stage juveniles of *M. incognita, H. mothi* and *A. tritici.* The predation rate was measured and quantified. *M. aquaticus* was the most successful predator with maximum strike rate (SR = upto 100%) on various species of nematodes. All saprophagous nematodes were highly susceptible to predation (PS > 90%) except *Rhabditis* sp. which showed some degree of behavioural resistance in the form of active body undulations. *Helicotylenchus indicus* resisted predation by chemical means, i.e., toxic/unfavourable secretions. *X. americanum, P. citri, Longidorus* sp. and *Paratrichodorus* sp. are provided with physical characteristics (eg. cuticle) which provided partial resistance against predation. *Hoplolaimus indicus, Scutellonema* sp., *Hemicycliophora* sp. and *H. mangiferae* were totally resistant to predation by *D. stagnalis* and *A. thornei* as their individuals were neither injured nor killed by the two predators.

Bilgrami (1993) studied the numerical analysis of the predatory behaviour of *Aporcelaimellus nivalis* including strike rate with the five different prey trophic categories of nematodes like bacterial feeders, migratory juveniles of sedentary endoparasites, epidermal feeders, cortical feeders and predatory nematodes. The endoparasitic nematodes were highly susceptible (Prey susceptibility = 77%) but predators resisted predation well (Prey resistance = 78%). Characteristics such as thick body cuticle, body annulations and thick longitudinal cuticular folds provided physical resistance to *Hoplolaimus indicus, Scutellonema* sp., *H. mangiferae, Hemicycliophora dhirendri* and *Mononchoides fortidens* (PF = 100%). *Mononchoides aquaticus* and *Rhabditis* sp. exhibited behavioural resistance in the form of rapid undulatory movements and took evasive action when attacked. No individuals of *Helicotylenchus indicus* were consumed by the predators. This was attributed to toxic prey contents. Duration of feeding on an individual prey depended on the size of the prey and other physical and chemical factors.

Bilgrami (1995) analysed the predatory abilities of the predator, *Mesodorylaimus bastiani* on the prey nematodes belonging to five trophic groups *viz*., bacteriophagous, endoparasitic, ectoparasitic-epidermal feeders, ectoparasitic-cortical feeders and predaceous nematodes. Predaceous nematodes were most successful on endoparasitic nematodes. Predaceous nematodes as prey exhibited high degree of resistance against predation by *M. bastiani*. Only 11% attacks resulted in wounding out of 31% encounters that resulted in attacks. Physical characteristics like thick body cuticle, body annulations, thick longitudinal cuticular folds are hypothesized as the cause of 100% resistance of *Hoplolaimus indicus, Hemicriconemoides mangiferae, Hemicycliophora dhirendri* and *Dorylaimus stagnalis.*

Bilgrami *et al.* (2005) described the feeding behaviour of the diplogasterid predator, *Mononchoides gaugleri* on 11 phytoparasitic species as prey. *M. gaugleri* attacked *H. mothi* and *A. tritici* (maximum strike rate, SR = 92-94%), which has resulted in maximal prey wounding

(encounters resulted in wounding (EW = 46-47%). *Longidorus attenuatus* was attacked minimally (SR= 42%) with fewest casualties (EW = 21%). *Hirschmaniella oryzae, H. mothi* and *M. incognita* were most susceptible (Prey susceptibility, PS = 87.5-93.5%), whereas *X. americanum* and *P. christiei* were highly resistant prey species (Prey resistance, PR = 66.7-74.2%). The shortest and longest feeding durations of *M. gaugleri* were for *M. incognita* and *L. attenuatus*, respectively.

Effect of prey density on the predation efficiency of nematodes

The effect of different prey densities affect the predatory behaviour of the predatory nematodes. Yeates (1969) found that the predation rate of predatory nematode, *Mononchoides potohikus* increased with the increase in prey density when *Mesorhabditis littoralis* used as prey. It was found that the predation rate was proportional to the prey density. He concluded that predation is due to chance encounter and that the prey is detected largely by tactile stimuli. The predator was found to be facultative preying on a wide range of nematode species.

Bilgrami and Jairajpuri (1989) studied the effect of the number of prey nematodes on the predatory abilities of predatory nematodes, *Mononchoides longicaudatus* and *M. fortidens*. Maximum predation took place at 200 prey individuals per plate. There was a positive correlation between the number of preys killed by *M. fortidens* and *M. longicaudatus* and numbers of prey increased. Maximum predation was recorded in a population of 25 prey individuals of both preys, *M. incognita* and *H. oryzae* juveniles.

Bilgrami and Kulshreshtha (1993) studied the predation abilities of the predaceous nematode, *Mylonchulus dentatus* on the different population levels (25, 50, 75, 100, 125, 150, 175 and 200) of the prey, *M. incognita.* The prey density affected predation by *M. dentatus.* More preys were killed when their number was increased from 25 to 200 individuals. Maximum predation occurred in a population of 200 prey individuals and minimum on 25 individuals.

Bilgrami *et al.* (1994) studied the effect of prey density on the predation behaviour of *Mononchus aquaticus* with 25, 50, 100 and 150 specimens of *C. symmetricus* and *Cephalobus* sp. in 1 % water agar, separately. It was observed after 24 h that the abundance of prey did not influence predation as there was no significant difference ($P > 0.05$) in the rate of predation when 25, 50, 100 or 150 specimens of *Cephalobus* sp. or *C. symmetricus* were used as prey.

Prey densities of 200-250 individuals were found the most suitable for predators, *Mesodorylaimus bastiani* and *Aquatides thornei* (Bilgrami and Liang 2004).

Bilgrami *et al.* (2005) while studying the effect of prey density on the feeding behaviour of the diplogasterid predator, *Mononchoides gaugleri* at prey densities from 25 to 250 individuals, found that the prey search duration was dependent on prey density. Search

duration increased at a prey density of less than 100 individuals. Predation rate by *M. gaugleri* on *M. incognita* was also prey density dependent. Most of *M. incognita* were killed when 175-225 prey individuals were exposed to *M. gaugleri.* Duration of post feeding aggregation was negatively correlated with prey density. Feeding duration also depended on prey density. It was shortest at densities of 25-50 and longest at densities of 225-250.

Survival of predatory nematodes

Nematodes are a highly diverse group of organisms that show a variety of adaptations to extremes in soil and plant environments. A moisture film is necessary for normal nematode activity (Wallace 1973), and therefore soil moisture, relative humidity, and related environmental factors directly affect nematode survival. Developmental dormancy and diapause are important for seasonal survival and long-term longevity of eggs in some species, whereas changing sex ratios may improve survival chances of the next generation in some instances.

Temperature is an important factor for the survival of nematodes. The survival duration in nematodes without food is also influenced by temperature because consumption of the reserved energy depends on the level of activity which is influenced by temperature. Since no/little information is available on the survival of predatory nematodes, the relevant literature on plant parasitic and free living nematodes is reviewed.

Womersley (1981) studied the effect of dehydration on salt loss in the second-stage larvae of *A. tritici.* Salt concentrations decreased with each dehydration-rehydration cycle. The greatest loss occurred on revival from the first desiccation period. He found that *A. tritici* was incapable of regulating its internal sodium content during revival, but had a limited ability to control potassium, magnesium and calcium loss. Salt loss through the nematode cuticle was restricted to potassium and calcium during desiccation.

Womersley and Ching (1989) studied the induction of anhydrobiosis in *Rotylenchulus reniformis* (Linford and Oliviera 1938) using direct exposure to elevated relative humidities and conditions resembling natural dehydration regimes. All larvae and preadults were unable to survive direct short-term exposure to 97 % relative humidity. However, dehydration of larvae on model substrates (0.5 % agar : 1.0 % agarose) that mimic the natural rate of soil moisture loss, induced coiling and successful entry into anhydrobiosis.

Coiling was maximized at 10–12 days and only coiled larvae survived dehydration, emerging as the preadult form. Larvae could withstand severe dehydration at 80 and 40 % relative humidity after the induction of coiling, but were unable to withstand direct exposure to 0 % relative humidity.

When investigating the role of glycerol, myo-inositol and trehalose during desiccation of nematodes, *A. tritici*, *Ditylenchus dipsaci*, *Pangrellus redivivus, D. myceliophagus* and *Turbatrix aceti,* (Womersley and Smith 1981) reported significant differences in free and bound sugar levels

were found between the two good anhydrobiotes *A. tritici* and *D. dipsaci* and the three poor survivors *P. redivivus, D. myceliophagus* and *T. aceti.* Highest trehalose contents were found in desiccated *A.tritici* and *D. dipsaci*, but glycerol levels were low. *P. redivivus* and *T. aceti* contained high concentrations of free glycerol. Desiccated *A. tritici* larvae contained more free and bound inositol than all other species studied, but desiccated *D. dipsaci* larvae had higher levels of bound inositol than *P. redivivus, D. myceliophagus* and *T. aceti.*

Womersley and Higa (1989) reported that adults and larvae of *Ditylenchus myceliophagus* were able to survive anhydrobiotically if dried slowly enough. The nematode exhibited behavioural (swarming) and morphological (coiling) adaptations under dehydration stress. Nematodes reared on *Rhizoctonia cerealis* and allowed to dehydrate naturally in culture for 6 weeks post-swarm showed an unexpected increase in lipid during swarming (28 % to 42 % dry weight), glycogen levels declined and trehalose levels increased from 2.0 % to 4.0 % dry weight. None of these changes were associated with dehydration stress. After 3 weeks nematodes began to coil and had lipid and trehalose contents of about 32 % and 16.65 % dry weight, respectively. At the end of the six week period lipid contents declined to 26 % dry weight and trehalose contents remained stable.

Wharton (1996) studied the water loss and morphological changes during desiccation in *Ditylenchus dipsaci,* an anhydrobiotic nematode, which can withstand direct exposure to extreme desiccation. Water loss in the nematode occurred in two distinct phases, with a permeability slump two minutes after the onset of desiccation. The permeability slump remained after treatment with sodium azide or carbon dioxide but disappeared after heat treatment. There was a marked decrease in body length during the first two minutes of desiccation but diameter decreased throughout the desiccation period, mainly as a result of a decrease in the thickness of the hyaline layer. These observations suggested that one mechanism for controlling water loss during desiccation was by narrowing the grooves between annulations.

Perry (1977) reported that survival of *Ditylenchus dipsaci* and *D. myceliophagus* was enhanced when they were dried at high humidities and, for D. *myceliophagus*, by the lower temperature. The survival of all stages of D. *myceliophagus* was poor. Although the 4th-stage larva of D. *dipsaci* was overwhelmingly superior to all other stages, the 3rd stage, and to a lesser extent, the adult of this species also showed remarkable ability of survival to desiccation.

Hominick (1986) while studying the photoperiod and diapause in the potato cyst-nematode, *Globodera rostochiensis,* found that the juveniles in cysts which had been reared outdoors showed a marked diapause. There was a slow hatching response in October,

December and February and a markedly faster one in the following April, June and October. The juveniles emerged slowly even a year after harvest. The amount and/or intensity of light during growth of the host (potato) affected hatching. In all tests, in both potato root diffusate and tap water, emergence from cysts grown on plants in constant light was much more rapid than from cysts grown in the other conditions. Photoperiod, acting on the potato, affected developing females and influenced the hatching mechanism of the developing juveniles.

Studies of Glazer and Orion (1983) on anhydrobiosis of *Pratylenchus thornei* indicated that large populations of *P. thornei*, a winter pest of cereals, legumes, and potatoes in the northern Negev region of Israel, survived 7-8 months of summer drought and returned to full activity at the beginning of the rainy season. All developmental stages of *P. thornei* were exposed to gradually reduced relative humidity (RH) using glycerin water solutions. At 97.7 % RH the nematodes were coiled and able to survive exposure to 0 % RH. About 40 % of artificially desiccated nematodes could be reactivated by gradually increasing the humidity to the final water environment. Desiccated nematodes could withstand temperatures up to 40 °C. Reactivated individuals showed intestines apparently devoid of reserve materials. Only 3 % survived three cycles of desiccation and reactivation. *P. thornei* reactivated after anhydrobiosis multiplied twice as much within *Vicia sativa* roots as did fresh nematodes.

Forge and MacGuidwin (1992) reported that the survival of *Meloidogyne hapla* second-stage juveniles was greater in soil at water potentials of -1910 to -520 kPa than in soil at higher water potentials. Saturating the soil immediately before freezing reduced survivorship, but it was still greater for juveniles exposed to low water potentials before saturation. Thus, low water potentials increased survivorship directly by reducing the pore space filled with ice and indirectly by causing physiological changes that increased the ability of juveniles to survive frozen conditions. Exposure to low water potentials in polyethylene glycol solutions at 24 °C also caused an increase in the percentage of juveniles that survived frozen conditions.

In a study on desiccation survival in *H. rostochiensis* and *D. dipsaci*, Ellenby (1968) found that the free second-stage larva of the potato-root eelworm, *H. rostochiensis*, took up water at the same rate as one still enclosed inside the egg-shell. The fourth-stage larva of the narcissus strain of *D. dipsaci*, both in the 'eelworm wool' aggregations and in the isolated individual larva also survived. In the aggregations, nematodes on the outside of the mass died first.

Bird and Soeffky (1972) studied the changes in the ultrastructure of the gelatinous matrix of *M. javanica* during dehydration. The fine structure of the gelatinous matrix of *M. javanica* consisted of an irregular meshwork when hydrated and a uniform granular mass of much greater density when dehydrated. The spaces in the hydrated meshwork are presumed to contain water. The change from a hydrated to a dehydrated state was accompanied by an

overall shrinkage and hardening of the egg mass with a change in colour from yellow to reddish-orange.

Bird and Buttrose (1972) studied the ultrastructural changes in the nematode *Anguina tritici* associated with anhydrobiosis. They detected morphological differences between anhydrobiotic and active second-stage larvae of *A. tritici*. The nematodes, which contain less water than other genera examined, could maintain viability in the anhydrobiotic state over the range -190 °C to 105 °C for short periods of time. In this state they assumed a characteristic coiled posture with the outermost parts of their cuticles touching. The morphological redistribution of lipid, both in the cuticle and in the droplets, was considered to be an important factor in the ability of these nematodes to survive in the dry state.

Barrett (1982) reported that fourth stage juveniles of the stem nematode, *D. dipsaci* lost almost all body water and survived in an anabiotic state for long periods of time. Desiccation of the juveniles did not result in any appreciable denaturation of the metabolic enzymes.

Pickup and Rothery (1991) studied the water-loss and anhydrobiotic survival in nematodes of antarctic fellfields, *Teratocephalus tilbrooki* and *Ditylenchus* sp. *T. tilbrooki* exhibited seasonal variation in the length of time it can survive anhydrobiotically. The ability of *Ditylenchus* sp. to resist water loss and to survive anhydrobiotically was greater than *T. tilbrooki*. Both species possessed extremely well developed anhydrobiotic capabilities and were capable of surviving the levels of water stress recorded in their respective habitats within the maritime antarctic.

Daulton and Nusbaum (1961) studied the effect of soil temperature on the survival of the root-knot nematodes *M. javanica* and *M. hapla*. *M. hapla* could survive for a longer period than those of *M. javanica*. At a soil temperature of -2 °C, eggs of *M. hapla* survived for a longer period than those of *M. javanica*. A longer period was required to kill eggs of all populations in dry soil than in damp soil. However, at 36 °C and 40 °C, eggs were killed more rapidly in dry soil. The response of *M. javanica* and *M. hapla* to these high temperatures was the reverse of that found at -2 °C.

Steel *et al.* (2013) studied the survival and colonization of nematodes in a composting process. Juveniles and dauer stages of *Aphelenchoides* sp., *Panagrolaimus* sp., and rhabditids survived an experimentally induced temperature peak, while members of Tylenchidae did not. Their results indicated that the rapidly changing nematode community in compost is the result of both differential survival and colonization capacities.

Effect of neem products on nematodes

No work is available on the effect of neem on predatory nematodes but good deal of work has been done on plant parasitic nematodes, some of which has been reviewed here. Egunjobi and Afolami (1976) reported that four water extracts of neem (*Azadirachta indica*)

leaves each in three concentrations of 1.5, 1.0, and 0.5 kg fresh leaves / 3 litre water was directly toxic to *P. brachyurus* under laboratory conditions. Grain yield, plant heights and root weights were significantly increased in plots receiving the extract. Strong correlation existed between root populations of *P. brachyurus* and extract concentrations.

Akhtar (1998) reported that the soil-amendments with various products prepared from neem (*A. indica*) such as leaf powder, sawdust and oilseed cake, and urea caused significant decrease of plant-parasitic nematodes (*Hoplolaimus indicus*, *Helicotylenchus indicus*, *R. reniformis* and *M. incognita* juveniles). In contrast, populations of predatory and free-living nematodes increased.

Soil applications of powdered neem seed or neem cake at 100 g/plant at planting and, subsequently, at 3-months intervals, reduced the populations of *Pratylenchus goodeyi* (Musabyimana and Saxena 1999). Various products (oils, cakes, extracts, etc.) prepared from the leaves and seeds of the neem plant (*A. indica* A. Juss) have been reported as effective protectants against nematode pests when used as root-dips and seed treatments (Akhtar 2000).

Javed *et al.* (2007) reported that the neem (*A. indica*) leaves, neem cake and a commercially refined product Aza (azadirachtin) extracted from seed significantly reduced the number of females and egg masses in roots whereas the one did not. All the neem formulations significantly reduced the number of eggs per egg mass on the un-treated root portion. Even after 16 weeks all the treatments significantly reduced the galling index and number of egg masses but their effectiveness declined over time.

The aqueous extracts of neem (*A. indica*) crude formulations (leaves and cake) at 10 %, 5 %, and 2.5 % w/v caused immobility and mortality, in root-knot nematode (*Meloidogyne javanica*) whereas a refined product, Aza at 0.1% w/v caused neither immobility or mortality of juveniles. When egg masses were placed in extracts of these formulations, hatching did not occur in any of the concentrations (10 %, 5 %, 2.5 % and 1.25 % w/v) of the crude formulations (Javed *et al.* 2008).

Lynn *et al.*, (2010) reported that the isolated soil nematodes (*M. incognita*) when exposed to various concentrations of azadirachtin, Neema, and Neema-plus, the immobility of juvenile nematodes showed no change at 2 h after treatment, whereas a reduction of 36.3 % was observed at day 1 with 10 ppm of azadirachtin. Nevertheless, the effects of neem formulations were faster and much higher than those of azadirachtin. At a cucumber greenhouse, soil treatments with neem formulations significantly reduced the numbers of soil nematodes and plant root-knots; the reduction with Neema was 12.1 and 9.0 %, and with Neema-plus 26.4 and 24.6 % of the control, respectively. Furthermore, soil treatment with Neema-plus greatly improved the growth of cucumber plants in nematode-infested pots.

Management of prey nematodes

In terms of work on biocontrol of plant parasitic nematodes using predatory nematodes, it is critical to match the population dynamics of predator and prey. Many studies have shown that the predatory nematodes are effective in reducing the population of plant parasitic nematodes. Much of the information on predatory nematodes is based on agar plate experiments, limited data are available on predation in soil. However, considerable studies have demonstrated that predatory nematodes substantially reduced the population of plant parasitic nematodes.

The possibility of using predatory nematodes for checking populations of plant parasitic nematodes in soil was first proposed by Cobb (1917). Later Cobb (1920) and Steiner and Heinely (1922) observed feeding by *Clarkus papillatus* on *Meloidogyne* sp. and suggested the use of *C. papillatus* for controlling plant parasitic nematodes in sugar beet fields. Cassidy (1931) and Christie (1960) suggested that predatory nematodes might be useful as biocontrol agents against plant parasitic nematodes. Mononchids have been known to feed on a variety of soil microorganisms including nematodes (Banage, 1963).

Dorylaim and nygolaim predators also possess predatory potential and their role is more promising in the biological control of plant parasitic nematodes. The wide spread and abundant presence of these predators indicate their biological control activities. Detection of *Eudorylaimus obtusicaudatus* feeding on eggs inside cysts of *H. schachtii* and an increase in pot trials (Boosalis and Mankau 1965) indicates its biocontrol potential.

According to Webster (1972) and Jones (1974), non-specific predators like mononchids exert only partial control of plant parasitic nematodes. However, in pot trials, Cohn and Mordechai (1974) found a constant correlation between a high population level of *Mylonchulus sigmaturus* and a low population level of citrus nematode, *T. semipenetrans.*

Small (1979) reported significant reductions in the population densities of potato cyst nematode, *Globodera rostochiensis* and root-knot nematode, *M. incognita* in the presence of a predatory nematode, *Prionchulus punctatus*, in pot experiments.

Ahmad and Jairajpuri (1982) found a significant negative correlation between populations of a predatory nematode, *Parahadronchus shakili* and plant parasitic nematodes, *Trichodorus* sp. and *Hemicycliophora* sp., under field conditions. Similarly, Azmi (1983) found an increase in the abundance of *Iotonchus monhystera* and a reduction in that of *Helicotylenchus dihystera*, in mandarin orange orchards.

The diplogasterid predators remained largely neglected until Yeates (1969) evaluated the predatory abilities of *Diplenteron colobocercus* (*Mononchoides potohikus*). Fauzia *et al.* (1998) demonstrated the ability of *Mononchoides longicaudatus* to reduce root galling by root-knot nematodes in pot tests, resulting in improved vegetative growth and increased root mass.

Mohandas and Prabhoo (1980) analysed the intestinal contents of mononchid nematodes and found that the most favoured food items were the plant parasitic forms, including *R. reniformis* and *M. incognita,* and free living forms, including *Rhabditis* sp. and *Monhystrella* sp., which were fed upon by all predators.

Osman (1988) tested the efficacy of *Diplogaster* sp. and found that it killed large numbers of prey of *M. incognita* and *T. semipenetrans* larvae. *M. incognita* and *T. semipenetrans* populations in the roots of tomato and sour orange, respectively, were significantly reduced by the addition of *Diplogaster* sp., in the pot experiment.

Akhtar (1995) conducted experiments on the biocontrol of root-knot nematode, *M. incognita* in tomato by the predatory nematode, *Mononchus aquaticus*. The root-knot development caused by *M. incognita* was significantly inhibited in the presence of *M. aquaticus*. There was further suppression in the development of root-knot symptoms when neem leaves (*A. indica*) and castor leaves (*Ricinus cummunis*) were incorporated into the soil. Addition of these leaves to the soil increased the population of *M. aquaticus.*

Fauzia *et al.* (1998) studied the biocontrol potential of predatory nematode, *Mononchoides longicaudatus* on *M. incognita* on tomato plants. The population of *M. incognita* was significantly decreased in all levels (100, 200 and 400) of inoculums of predatory nematodes after 45 days. Fewer root galls were found on roots of treated plants than those inoculated with *M. incognita* alone. It also improved the vegetative growth of plants and increased root-mass production. They found that with the increase in inoculum level of predatory nematodes, there was a corresponding increase in overall plant growth and decrease in population of the parasite and root-gall development.

Rama and Dasgupta (1998) studied the biocontrol efficacy of predatory nematode, *Iotonchus tenucaudatus* on the nematodes associated with Mandarin orange. It preyed upon the juveniles of *T. semipenetrans* and *Helicotylenchus dihystera*. The juveniles of *T. semipenetrans* and *H. dihystera* were favoured the most by *I. tenucaudatus*. They also found that the predator's population increased during summer when the *T. semipenetrans* population was high. It showed that *T. semipenetrans* offered as a better prey than *H. dihystera.*

Khan and Kim (2005) evaluated the effect of predatory nematode, *Mononchoides fortidens,* against the root knot nematode, *M. arenarea* on tomato plants cv. Pusa Rubi grown in pots. The root galling and the final population of *M. arenarea* were decreased and vegetative growth of tomato plants and root-mass production were increased when compared with plants having no predators. The beneficial effect of adding predatory nematodes to infested potted field soil increased exponentially with concentration upto 200 nematodes per pot.

Bar-Eyal *et al.* (2008) reported that when the predatory nematode, *Koerneria sudhausi* was introduced to a monoxenic culture of *M. javanica* on tomato roots on agar, the nematode fed on second stage juveniles and eggs. It reduced the root galling index in pot

experiments. It was suggested that *K. sudhausi* may serve as a candidate for a biological control agent against root-knot nematodes because the nematode can be easily cultured on bacteria and achieve a high reproduction rate.

Bilgrami *et al.* (2008) released a predatory nematode, *Mononchoides gaugleri* in the turf grass field for the first time for the control of different plant parasitic nematodes. Its application decreased individual genus as well as total populations of plant parasitic and non parasitic nematodes significantly. *M. gaugleri* caused maximum reduction in *Ditylenchus* and *Aphelenchus* spp. (39.9-45.0 %), moderate reduction in *Tylenchus* and *Tylenchorhynchus* spp. (20.3-34.6 %) and least in *Mesorhabditis* sp. (11.9 %).

CHAPTER-III

MATERIALS AND METHODS

Present investigations were carried out on prey range, prey preference, predation behaviour and survival of the predatory nematode, *Fictor composticola* Khan *et al.,* and its potential for the management of mycophagous nematodes in button mushroom, *Agaricus bisporus.* The procedure adopted and materials used in achieving the objectives of the study are given in detail in this chapter.

3.1. Experimental site

Experiments were carried out in the laboratories and mushroom house of the Department of Nematology, Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, Haryana during 2013-2015.

3.2. Mycological Techniques

3.2.1. Source of *Agaricus bisporus* and its culturing

Strain U3 of button mushroom (*A. bisporus*) and its spawn were procured from Mushroom Technology Laboratory (MTL), Department of Plant Pathology, CCS HAU, Hisar. *A. bisporus* was cultured on freshly prepared Potato Dextrose Agar (PDA) medium. For the PDA preparation, 200 g fresh potato were peeled, cut into small pieces and boiled in about 1 L of distilled water. Thereafter, 20 g agar-agar and additional water were mixed to make the volume 1 L. This medium was poured in sterilized 250 ml conical flasks and autoclaved at 15 psi pressure for 20 minutes. After cooling, a bit of actively growing *A. bisporus* mycelia was taken from the fresh culture of fungus with the help of sterilized inoculating needle and placed in the flasks containing PDA. The flasks were incubated at 25 °C until the fungus covered the entire PDA surface (Plate 1). Such flasks were used for culturing and multiplication of mycophagous nematodes *viz*., *Aphelenchus avenae*, *Aphelenchoides swarupi* and *Ditylenchus myceliophagus. A. bisporus* was sub cultured and used as and when required.

3.2.2. Mushroom compost

Pasteurized compost was procured from village, Siswala (Hisar). This compost was prepared by short method and pasteurized in tunnels in pasteurization chamber. Before filling in bags, the compost samples of the pasteurized compost were checked for the presence of nematodes. The compost was found free from all types of nematodes at the time of laying out the experiment.

3.2.3. Spawning

Spawn of U3 strain of *A. bisporus* grown on wheat grains was obtained from Mushroom Technology Laboratory (MTL), Department of Plant Pathology, CCS HAU, Hisar. The spawn was mixed in the compost @ 50 g/kg compost at the time of filling of bags. The bags were placed on wooden racks in laboratory.

3.2.4. Casing

The ash of rice husk was used as casing material. Before using, it was checked for the presence of nematodes. It was found free from any kind of nematodes. After 21 days of spawning with proper spawn run, casing was done in the compost bags and kept in the mushroom house.

3.2.5. Recording of spawn run and yield

Visual observation on spawn run in bags was taken and it was rated as poor, moderate or good. For recording the yield, mature fruiting bodies (sporophores) were picked in the button stage without disturbing the spawn run. These buttons were cleaned and their weight was recorded in grams. The observations on yield were recorded for the entire cropping period.

3.3. Nematological techniques

3.3.1. Preparation of agar plates

For laboratory experiments (prey range, prey preference, survival, strike rate and feeding behaviour) of *F. composticola,* 1 % water agar medium was prepared. For this purpose, 10 g agar-agar powder was boiled. During boiling, it was stirred with a glass rod to prevent clot formation. After proper mixing, it was poured in sterilized Petri plates of size 5 cm. dia. (Henceforth called agar plates) under laminar flow. After cooling these agar plates were used in experiments. This agar medium was prepared fresh whenever required.

3.3.2. Culturing mycophagous nematodes

For culturing mycophagous nematodes, ten males and ten females of each of the three nematodes i.e., *A. avenae, A. swarupi* and *D. myceliophagus* were handpicked in a cavity block having sterile distilled water. These nematodes were inoculated in different flasks having fresh culture of *A. bisporus* on PDA and incubated in a BOD at 25 °C. After two weeks, mycelia started turning brown showing nematode multiplication. All stages of nematodes (except egg) from these flasks were used for experimentation. Sub-culturing of these mycophagous nematodes was done from time to time to maintain culture.

3.3.3. Culturing *Fictor composticola*

Twenty individuals (10 male and 10 famale) of *F. composticola* were inoculated in the flasks having culture of mycophagous nematodes. The predator multiplied in the flasks and this culture was used for experimentation.

Plate 1: Culture of *Agaricus bisporus* on PDA

Plate 2: Effect of neem seed kernel extract on *Fictor composticola*

3.3.4. Culturing free-living nematodes

The free-living nematodes, *Panagrolaimus* sp. and *Bursilla* sp. were cultured on agar plates. Handpicked nematodes were released on the plates with a pinch of baby milk powder. After two weeks the nematodes multiplied in sufficient number which were used for further experimentation. The sub-culturing of these nematodes was done from time to time to maintain culture.

3.3.5. Surface sterilization of nematodes

Nematodes were collected by adding sterile water in culture flasks. The nematode suspension was poured in sterilization tube designed by Kanwar *et al.* (1994). The tube was immersed in beakers containing 0.1 % $HgCl_2$ for 5 minutes followed by 100 ppm of Streptocyclin sulphate and Penicillin for 5 minutes each. Finally the nematodes were rinsed three times by dipping the tube in beakers containing sterile distilled water. The nematodes thus sterilized were collected in small amount of water by backwashing the tube with a sterile micropipette and used for inoculation in agar plates.

3.3.6. Nematode inoculation

The surface sterilized nematodes were inoculated to the agar plates using a sterile micropipette, so as to deliver that required number of nematodes in each treatment. The entire procedure was followed strictly under asceptic condition in a laminar air flow chamber. The inoculated agar plates were kept at 25 °C and at room temperature as per the requirement of the experiments. For the inoculation in compost bags, the nematodes from culture flasks were extracted in sterile water and inoculated.

3.4. Extraction of nematodes

3.4.1. Compost and soil

After harvesting the mushroom crop, nematodes were extracted from the compost bags. After removing casing soil the whole compost of the bag was mixed properly on a polythene sheet. The sheet was washed properly before taking another sample. A 200 cc compost sample was taken from each replication of every treatment and processed and nematodes from compost and soil samples were extracted (Cobb's decanting and sieving method combined with modified Baermann funnel method (MBFT) (Schindler, 1961). The compost residues of the compost samples extracted through MBFT were processed through sugar centrifugal flotation technique (Andrassy 1956) . The supernatant was poured through 100 mesh sieve nested over 500 mesh sieve, was rinsed thoroughly under tap water and collected in a beaker. The suspension was observed under stereo-microscope for recording number of nematodes and their posture/position.

3.4.2. Extraction of nematodes from agar plates/flasks

For extracting nematodes from agar plates and flasks, they were filled with sterile water and kept for five minutes. After shaking well the nematode suspension was collected in

a beaker. This process was repeated thrice. Left over nematodes, if any, were counted in agar plates. The nematodes in the flasks were counted and used for the inoculation as per the requirement of the experiments.

3.4.3. Nematode identification

For identification, nematodes were killed and fixed on 4 % Formaldehyde They were processed by Seinhorst's slow method (Seinhorst 1959) and mounted on glass slides. de Man's formulae were used for nematode identification .

3.5. Estimation of nematode population

The nematode numbers were counted under a stereozoom binocular microscope by dilution method. An average of three counts was taken and multiplied to calculate the total population in suspension.

3.6. Counting of nematodes in agar plates

Nematode counting in agar plates was done by directly placing the plate under microscope. For convenience in counting, Petri-plates were divided in small squares (6 mm) by marking with a marker on the back side of bottom and counting was done in all the squares.

3.7. Statistical analysis

Data obtained were analysed by Completely Randomised Design (CRD), using OPSTAT software available on www.hau.ernet.in. Treatment means were compared with critical difference (CD) at P=0.05 level of significance for results. Necessary transformations of data were done.

3.8. Experimental details

3.8.1. Prey range of *Fictor composticola*

The experiment was done on agar plates. Two males and two females of *F. composticola* were released with 100 individuals of each nematode species, tested as prey (Table 3.1). The experiment was replicated three times. The populations of prey and predator was recorded under stereo-microscope after 24, 48, 72 and 96 hours of release.

Table 3.1. Nematode species tested as prey of *Fictor composticola*

Group	Nematode species
1. Mycophagous	*Aphelenchus avenae*
	Aphelenchoides swarupi
	Ditylenchus myceliophagus
2. Microbivorous	*Bursilla* sp.
	Panagrolaimus sp.
	Tylencholaimus sp.
	Rhabdolaimus sp.
	Aerolaimid
3. Plant parasitic	*Heterodera avenae* males
	Hoplolaimus sp.
4. Predator	*Nygolaimus harishi*
	Aporcelaimium sp.

3.8.2. Prey preference of *Fictor composticola*

The experiment was done in agar plates with four nematode species, *Aphelenchus avenae, Aphelenchoides swarupi, Ditylenchus myceliophagus,* (mycophagous nematodes) and one free living nematode, *Bursilla* sp. (Rhabditida) in following combinations:

i. Combinations of two prey nematodes
ii. Combinations of three prey nematodes
iii. Combination of four prey nematodes

i. Combinations of two prey nematodes: Paired combinations were made with *A. avenae, A. swarupi, D. myceliophagus* and *Bursilla* sp. Two females and two males of *F. composticola* were released with 50 individuals of each prey. The populations of both preys and predator were recorded after 24, 48, 72 and 96 hours of inoculation. Each combination was replicated three times. The prey combinations studied were :

i. *A. avenae* + *A. swarupi*
ii. *A. avenae* + *D. myceliophagus*
iii. *A. avenae* + *Bursilla* sp.
iv. *A. swarupi* + *Bursilla* sp.
v. *A. swarupi* + *D. myceliophagus*
vi. *D. myceliophagus* + *Bursilla* sp.

ii. Combinations of three prey nematodes : Two males and two females of *F. composticola* were released with 33 individuals of each prey nematode. The prey combinations studied were :

i. *A. avenae* + *A. swarupi* + *D. myceliophagus*
ii. *A. swarupi* + *Bursilla* sp. + *D. myceliophagus*
iii. *A. avenae* + *A. swarupi* + *Bursilla* sp.

iii. Combination of four prey nematodes: Two males and two females of *F. composticola* were released with 25 individuals of each prey nematode i.e., *A. avenae, A. swarupi, D. myceliophagus* and *Bursilla* sp.

The populations of the preys and predator were recorded after 24, 48, 72 and 96 hours, for all prey combinations. Each combination had three replications.

3.8.3. Strike rate of *Fictor composticola*

One female or male of *F. composticola* was released with 100 individuals of each of the five prey nematode species i.e., *A. avenae, A. swarupi, D. myceliophagus, Bursilla* sp. and *Panagrolaimus* sp. in separate agar plates. The experiment had ten replications each with male and female *F. composticola* . Observations were recorded under stereo-microscope for half an hour after release of the nematodes. Following observations were taken for each male and female *F. composticola,* separately :

i. Number of encounters made by the predator (E)
ii. Number of encounters resulting into attack (EA)
iii. Part of the prey body attacked
iv. Stage of the prey attacked (juvenile or adult)
v. Number of injured and dead preys after attack
vi. Duration of feeding

When the predator got a contact with the prey it was taken as encounter, E and when the predator attacked the prey irrespective of duration, it was EA. If the predator started feeding on the first encountered prey, it was counted as first prey and if it attacked other than first encountered prey, it was counted as other preys and their percentage was calculated respectively out of the total attacks. For taking observations on the part of the prey body attacked, it was divided into three parts i. e., anterior, middle and posterior. The anterior part included up to oesophagus, posterior part included post anal part and the rest was taken as middle part. The number of parts attacked were counted and percentage of each part attacked was calculated. For the stage of the prey, the total number of juveniles and adults attacked were counted and converted into percentage. The numbers of injured (when a prey was wounded but escaped) and dead preys were counted. The percentage of injured and dead preys was calculated out of the total preys attacked.

On the basis of above observations, strike rate, prey resistance and prey susceptibility were calculated using the following formulae (Bilgrami, 1989).

$$\% \text{ Strike rate (SR \%)} = \frac{EA}{E} \times 100$$

$$\% \text{ Prey resistance (PR \%)} = \frac{(EA-AW)}{EA} \times 100$$

Where

AW = Attacks resulting into injuries

% Prey susceptibility (PS %) = 100-PR%

3.8.4. Effect of prey density on predation efficiency of *Fictor composticola*

Prey density levels of mycophagous nematodes, *A. avenae, A. swarupi*, *D. myceliophagus* and *Panagrolaimus* sp. was tested for the feeding efficiency of *F. composticola* in agar plates with 2 males and 2 females of *F. composticola.* The number of prey consumed was recorded after 24 and 48 hours of release. Population of *F. composticola* was also recorded. There were four replicates for each level. The counting of nematodes at 100 and 200 prey density levels was done by direct method. At 400, 800 and 1600 levels, the plates were filled with water and

after half an hour it was poured in beaker and counted under stereo microscope. The nematodes left in the agar plates were also counted by directly placing the plate under microscope. The data were analysed by factorial CRD after square root transformation.

3.8.5. Survival of *Fictor composticola* in water agar plates

Fifty individuals of *F. composticola* were released in agar plates in five replications. No prey was given during the period of investigation. The number of *F. composticola* was recorded at an interval of 5 days until its population declined to zero/negligible. This experiment was done under following conditions :

i. At 25 °C in BOD
ii. At room temperature (15.6-26.7 °C) from February to April
iii. At room temperature (27.8-33.4 °C) from April to June - with moisture and without moisture : In sets with moisture, 2 ml of sterile water was added at every observation and the other set was kept without water.

3.8.6. The survival of *Fictor composticola* in spent mushroom compost

The spent mushroom compost was collected from Mushroom Technology Laboratory (MTL), Department of Plant Pathology, CCS, HAU, Hisar. It was stored in mushroom laboratory, Department of Nematology, CCS HAU, Hisar at room temperature from April to September 2015. Initial population (Pi) of *F. composticola* was estimated in compost.In indoor condition, two sets of experiment were conducted. In one set, compost was stored in polythene bags of one kg capacity (Plate 3) and in another set, compost was stored in cloth bags of one kg capacity (Plate 4). In outdoor condition, a heap of five quintal spent mushroom compost was kept in open field near mushroom laboratory. Compost samples (200 cc) were drawn at 15 days interval for nematode extraction (as under 3.5.1) and moisture content in cloth bags, polythene bags and heap of spent mushroom compost. Temperature and rainfall data for the experimental period were collected from Department of Meteorology.

3.8.7. Effect of neem seed kernel water extract (NSKWE) on *Fictor composticola*

A concentration of 4 % neem seed kernel water extract (NSKWE) was prepared by dipping 4 g coarsely ground neem seed kernel in 100 ml water for 24 hour. This was strained through 4-ply muslin and used in experiment after further dilutions of 2% and 1%. Fifty handpicked *F. composticola* were transferred in 5 ml of each concentration in 5 cm dia. Petri plates (Plate 2) with four replications. Sterile water was kept as control. Mortality of *F. composticola* was recorded after 24 and 48 h in NSKWE and compared with control.

3.6.8. Management of mycophagous nematode

This experiment was done in polythene bags of half kg and five kg capacity using pasteurized compost. U3 strain of *A. bisporus* obtained from, Department of Plant Pathology, CCS HAU, Hisar was used for experimentation. Spawn raised on boiled wheat grains was

mixed in compost @ 50 g/kg compost at the time of filling the bags. The treatments were laid out as follows in three replications-

i. Prey and predator at spawning
ii. Prey and predator at casing
iii. Prey at casing and predator at spawning
iv. Prey at spawning and predator at casing
v. Uninoculated control

Casing was done with ash of rice husk, 21 days after spawning. The inoculum levels for the predator (*F. composticola*) and prey (*Aphelenchoides swarupi*) were kept 10 and 100 nematodes per kg compost, respectively. The observations were taken for spawn run, population of prey and predator at harvesting and yield per bag (in 5 kg bags only) and spawn run and nematode population in half kg bag. The data were analysed by CRD.

Plate 3: Compost stored in polythene bags for survival studies on *Fictor composticola*

Plate 4: Compost stored in cloth bags for survival studies on *Fictor composticola*

CHAPTER-IV

RESULTS

The results obtained on the prey range, prey preference, predation behaviour, survival of *Fictor composticola,* effect of NSKWE on *F. composticola* and management of *Aphelenchoides swarupi* by *F. composticola* are presented in this chapter.

4.1. Prey range of *Fictor composticola*

The prey range of *F. composticola* was tested using 12 nematode species, *Aphelenchus avenae, Aphelenchoides swarupi, Ditylenchus myceliophagus, Bursilla* sp., *Panagrolaimus* sp., *Heterodera avenae* males, *Aporcelaimium* sp., *Hoplolaimus* sp., *Nygolaimus harishi, Rhabdolaimus* sp., Aerolaimid and *Tylencholaimus* sp. The feeding of *F. composticola* on some of these preys can be seen in Plates 5-13. The populations of the preys and predator along with per cent consumption of prey nematodes after 24, 48, 72 and 96 hours of release are presented in Tables, 4.1, 4.2, 4.3 and 4.4. The data in Table 4.1 (recorded after 24 hour) revealed that the population of *D. myceliophagus* left in the plate was minimum (26.7) and that of *Panagrolaimus* sp. was maximum (67.3), showing the maximum consumption by *F. composticola* (73.3 %) and minimum (32.7 %) in *D. myceliophagus* and *Panagrolaimus* sp., respectively.

Table 4.1. Number of prey and predator after 24 hours of release

Nematode prey species	Population per plate		
	Prey	% prey consumption	Predator
Aphelenchus avenae *	35.0	(65.0)	4.3
Aphelenchoides swarupi *	42.7	(58.0)	4.0
Ditylenchus myceliophagus *	26.7	(73.3)	4.3
Bursilla sp. #	65.0	(35.0)	4.7
Panagrolaimus sp. #	67.3	(32.7)	5.0
Rhabdolaimus sp. #	66.3	(33.7)	4.7
Aerolaimid #	27.3	(72.7)	4.3
Tylencholaimus sp. #	58.7	(41.3)	4.0
Nygolaimus harishi •	66.3	(33.7)	4.3
Aporcelaimium sp. •	59.0	(41.0)	4.3
Heterodera avenae males ¤	54.7	(45.3)	4.7
Hoplolaimus sp. ¤	44.3	(55.7)	4.0
C D at 5 %	7.8		NS

* Mycophagous nematodes, # Microbivorous nematodes, • Predatory nematodes, ¤ Plant parasitic nematodes

No. of nematodes released per plate: Predator-2 males and 2 females, Prey-100 individuals of each species

The populations of microbivorous nematodes except the Aerolaimid was significantly higher than the populations of mycophagous nematodes (*A. avenae, A. swarupi* and *D. myceliophagus*). Similarly, the numbers of predatory nematodes, *Aporcelaimium* sp. and *N. harishi* were significantly higher than the mycophagous nematodes. The populations of *D. myceliophagus* and Aerolaimid were statistically at par. Predator fed upon all the preys tested and its population remained almost same after 24 hours when released with different prey species (Table 4.1).

The populations of prey and predator left in the plates after 48 hours (Table 4.2) show that the preys left in the plate was minimum in case of *D. myceliophagus* (4.3) and maximum in *Rhabdolaimus* sp. (47.7). The population of *A. avenae, A. swarupi, D. myceliophagus* and Aerolaimid left in the plate was statistically at par. The populations of plant parasitic nematodes (*H. avenae* males and *Hoplolaimus* sp.), and predatory nematodes (*Aporcelaimium* sp. and *N. harishi*) left in the plate were significantly higher than the mycophagous nematodes (*A. avenae, A. swarupi* and *D. myceliophagus*). The number of microbivorous nematodes, *Panagrolaimus* sp. (36.0) and *Bursilla* sp. (34.7) did not differ significantly. Similarly, the number of *Rhabdolaimus* sp. (47.7), *Tylencholaimus* sp. (42.7) and *N. harishi* (46.3) were statistically similar. The population of *F. composticola* recovered after 48 h did not differ significantly on the prey nematodes and its population became almost double, except with *Panagrolaimus* where it was over 2.5 times than the initial release.

Table 4.2. Number of prey and predator after 48 hours of release

Nematode prey species	**Population per plate**		
	Prey	**% prey consumption**	**Predator**
Aphelenchus avenae *	5.3	(94.7)	8.0
Aphelenchoides swarupi *	9.0	(91.0)	8.0
Ditylenchus myceliophagus *	4.3	(95.7)	8.3
Bursilla sp. #	34.7	(65.3)	8.7
Panagrolaimus sp. #	36.0	(64.0)	10.3
Rhabdolaimus sp. #	47.7	(52.3)	8.0
Aerolaimid #	7.7	(92.3)	7.7
Tylencholaimus sp. #	42.7	(57.3)	7.0
Nygolaimus harishi •	46.3	(53.7)	9.0
Aporcelaimium sp. •	35.0	(65.0)	9.0
Heterodera avenae males ¤	33.3	(66.7)	8.3
Hoplolaimus sp. ¤	34.3	(65.7)	8.0
C D at 5 %	5.5		NS

* Mycophagous nematodes, # Microbivorous nematodes, • Predatory nematodes,
¤ Plant parasitic nematodes
No. of nematodes released per plate: Predator-2 males and 2 females, Prey-100 individuals of each species

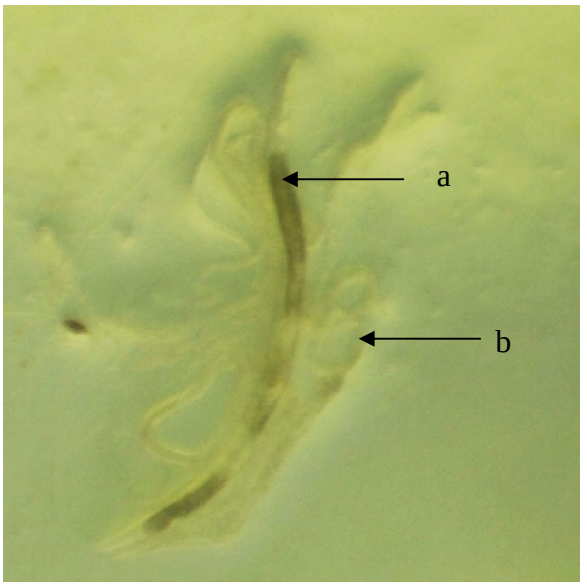


Plate 5: ***Fictor composticola*** **(a) feeding on** ***Aphelenchoides swarupi*** **(b)**

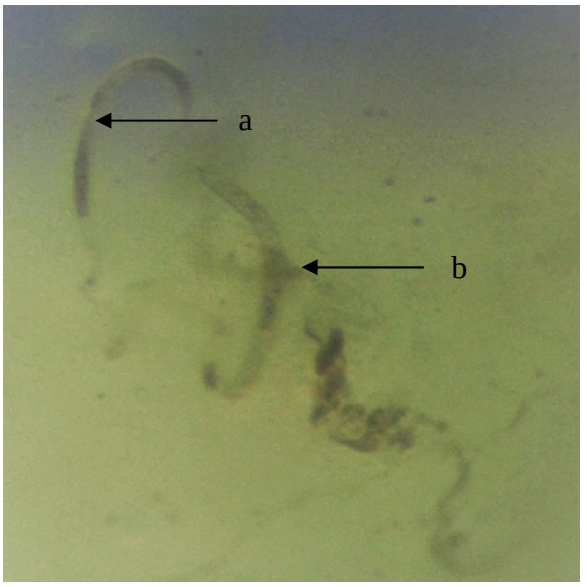


Plate 6: ***Fictor composticola*** **(a) feeding on** ***Aphelenchus avenae*** **(b)**

Plate 7: *Panagrolaimus* sp. with eggs

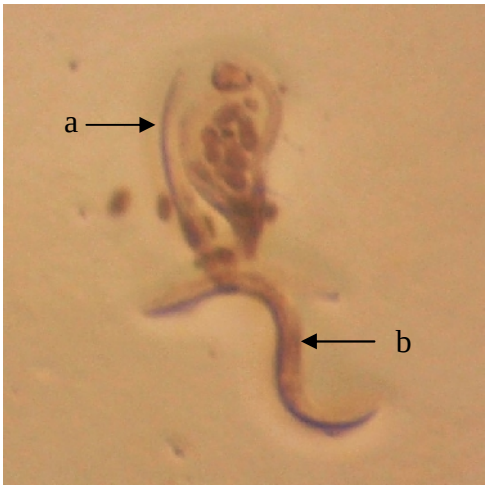


Plate 8: *Fictor composticola* (a) feeding on *Panagrolaimus* sp. (b)

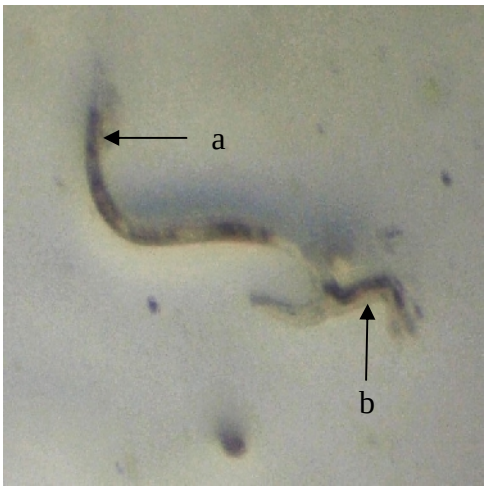


Plate 9: *Fictor composticola* (a) feeding on *Bursilla* sp. (b)

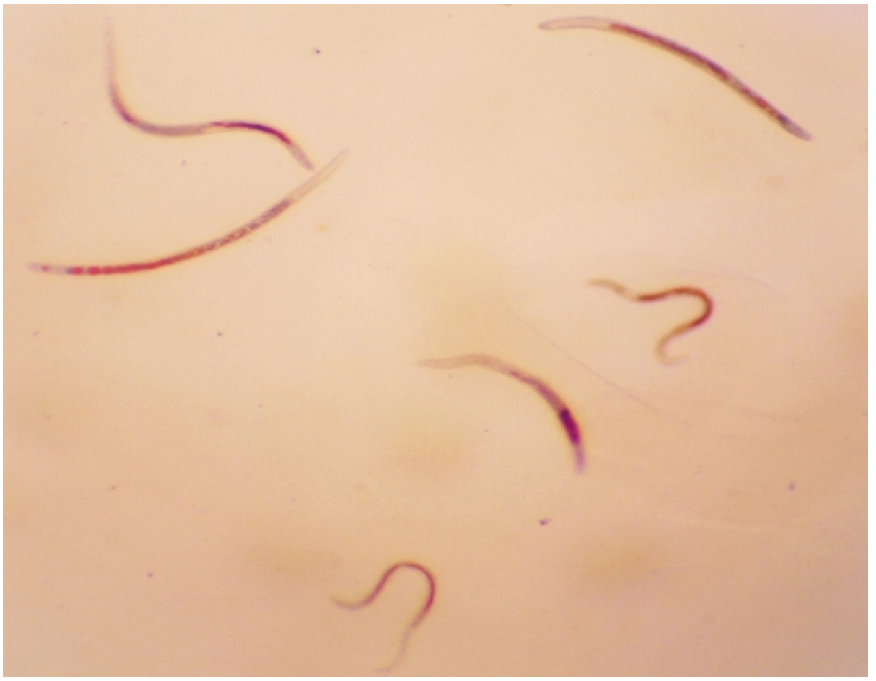


Plate 10: ***Tylencholaimus*** **sp. in agar plate**

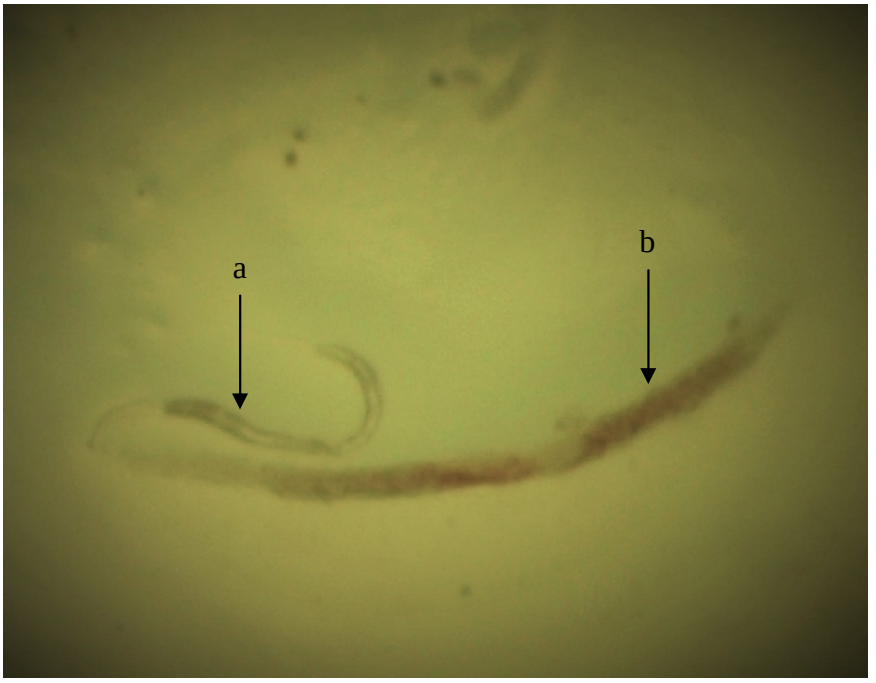


Plate 11: ***Fictor composticola*** **(a) feeding on** ***Tylencholaimus*** **sp. (b)**

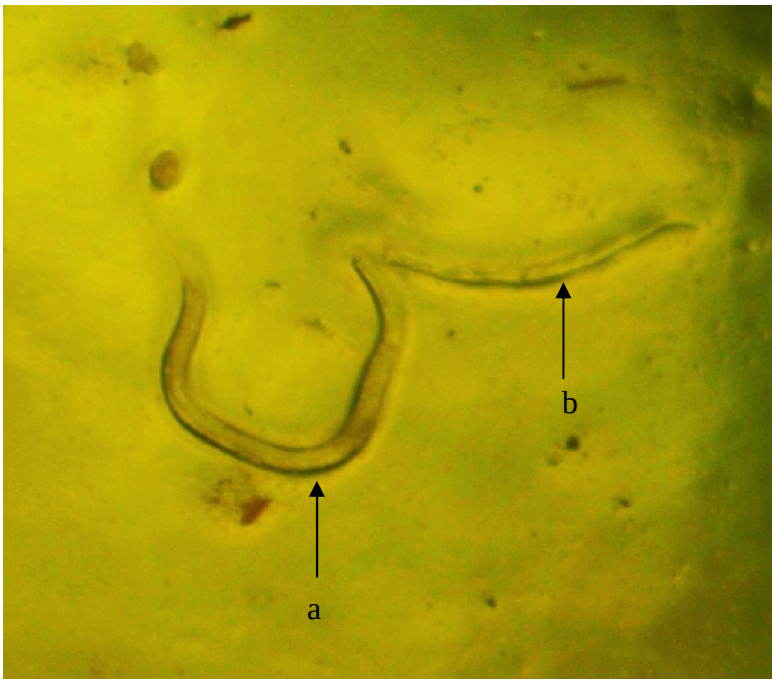


Plate 12: ***Fictor composticola*** **(a) feeding on** ***Ditylenchus myceliophagus*** **(b)**

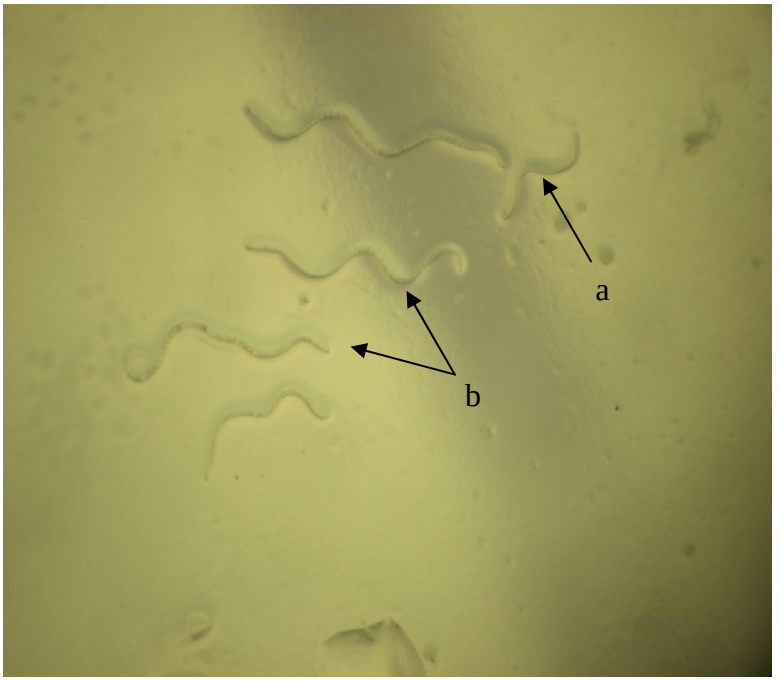


Plate 13: ***Fictor composticola*** **(a) feeding on** ***Heterodera avenae*** **males (b)**

The number of preys and predator recorded in the plate after 72 hours of release, is presented in Table 4.3. The data indicate that the populations of *A. avenae* and *D. myceliophagus* were showing maximum consumption (99 % in each case). The number left in mycophagous nematodes (*A. avenae, A. swarupi* and *D. myceliophagus*) and aerolaimid was statistically at par and was lower than all other nematodes. The number in plant parasitic nematodes, *Heterodera avenae* males (24.3) and *Hoplolaimus* sp. (22.3) was statistically similar. *F. composticola* multiplied three to five times on different prey species. It multiplied maximum (20.3) on *Panagrolaimus* sp. and minimum (12.3) on *Rhabdolaimus* sp. Its multiplication on *Panagrolaimus* sp. was significantly higher than on plant parasitic nematodes and predatory nematodes (Table 4.3). Multiplication of *F. composticola* multiplied on *A. swarupi, D. myceliophagus, Rhabdolaimus* sp., Aerolaimid, *Tylencholaimus* sp., *N. harishi, Aporcelaimium* sp., *H. avenae* males and *Hoplolaimus* sp. was statistically similar.

Table 4.3. Number of prey and predator after 72 hours of release

Nematode prey species	**Population per plate**		
	Prey	**% prey consumption**	**Predator**
Aphelenchus avenae *	1.0	(99.0)	18.0
Aphelenchoides swarupi *	2.7	(93.0)	15.3
Ditylenchus myceliophagus *	1.0	(99.0)	15.0
Bursilla sp. #	60.0	(40.0)	19.0
Panagrolaimus sp. #	73.7	(26.3)	20.3
Rhabdolaimus sp. #	43.0	(57.0)	12.3
Aerolaimid #	7.0	(93.0)	13.3
Tylencholaimus sp. #	30.7	(69.3)	12.7
Nygolaimus harishi •	36.7	(63.3)	15.0
Aporcelaimium sp. •	29.0	(71.0)	14.7
Heterodera avenae males ¤	24.3	(75.7)	15.0
Hoplolaimus sp. ¤	22.3	(77.7)	15.3
C D at 5 %	7.1	-	4.6

* Mycophagous nematodes, # Microbivorous nematodes, • Predatory nematodes,
¤ Plant parasitic nematodes
No. of nematodes released per plate: Predator-2 males and 2 females, Prey-100 individuals of each species

Table 4.4 shows the populations of preys and predator recovered after 96 hours of release in agar plates. The populations of *A. avenae, A. swarupi* and *D. myceliophagus* were consumed 99.0 %. Number of *Panagrolaimus* sp. and *Bursilla* sp. increased to 107.3 and 114.3, respectively while populations of other nematodes were reduced to much lower levels. The populations of mycophagous nematodes (*A. avenae, A. swarupi* and *D. myceliophagus*) and plant parasitic nematodes (*H. avenae* males and *Hoplolaimus* sp.) recovered in the plates were

statistically at par. The populations of *Tylencholaimus* sp. and *Aporcelaimium* sp. were significantly higher than the populations of mycophagous nematodes and Aerolaimid (Table 4.4). *F. composticola* multiplied on these prey species and its number increased to varying levels on different prey nematode species. The maximum multiplication was on *Panagrolaimus* sp. (38.3) and minimum on Aerolaimid (20.7).

Table 4.4. Number of prey and predator after 96 hours of release

Nematode prey species	Population per plate		
	Prey	% prey consumption	Predator
Aphelenchus avenae *	1.0	(99.0)	33.7
Aphelenchoides swarupi *	1.0	(99.0)	27.0
Ditylenchus myceliophagus *	1.0	(99.0)	26.7
Bursilla sp. #	107.3	(7.3)**	34.3
Panagrolaimus sp. #	114.3	(14.3)**	38.3
Rhabdolaimus sp. #	12.7	(87.3)	25.7
Aerolaimid #	1.7	(98.3)	20.7
Tylencholaimus sp. #	21.3	(78.7)	22.3
Nygolaimus harishi •	18.3	(81.7)	32.0
Aporcelaimium sp. •	25.0	(75.0)	25.3
Heterodera avenae males ¤	11.7	(88.3)	28.3
Hoplolaimus sp. ¤	10.0	(90.0)	31.3
C D at 5 %	10.4		7.0

* Mycophagous nematodes, # Microbivorous nematodes, • Predatory nematodes,
¤ Plant parasitic nematodes
No. of nematodes released per plate: Predator-2 males and 2 females, Prey-100 individuals of each species
** per cent increase

4.2.1. Prey preference of *Fictor composticola* in combinations of two preys

The prey preference of *F. composticola* in paired combinations of the nematodes, *A. avenae* + *A. swarupi*, *A. avenae* + *D. myceliophagus*, *A. avenae* + *Bursilla* sp., *A. swarupi* + *Bursilla* sp., *A. swarupi* + *D. myceliophagus* and *D. myceliophagus* + *Bursilla* sp. after 24, 48, 72 and 96 hours of release of nematodes in the agar plates has been shown in Figs. 4.1 to 4.4.

The data on prey and predator after 24h (Fig. 4.1) show that *F. composticola* had a distinct preference for some prey species over others. In combination of *A. avenae* and *A. swarupi*, the population of *A. avenae* was left less (16.3) than *A. swarupi* (33.7). But, when *A. avenae* was combined with *D. myceliophagus*, its population was more (39.3) than *D. myceliophagus* (14.7). When *A. avenae* was combined with *Bursilla* sp., its number per plate was less (22.7) than the number of *Bursilla* sp. (35.3). When *A. swarupi* was combined with *Bursilla* sp., its population remained per plate was less (29.0) than *Bursilla* sp. (40.3).

But, when *A. swarupi* was combined with *D. myceliophagus,* its population left per plate was more (43.7) than *D. myceliophagus* (11.0). In combination of *D. myceliophagus* and *Bursilla* sp., the population of *D. myceliophagus* was less (18.3) than that of *Bursilla* sp. (49.0). These data showed that *D. myceliophagus* was the most preferred prey of *F. composticola* amongst all the four prey nematodes. The order of preference of preys, after 24 hours, was : *D. myceliophagus* > *A. avenae* > *A. swarupi* > *Bursilla* sp. The population of *F. composticola* remained almost the same after 24 hours.

The data recorded after 48 hours of release are shown in Fig. 4.2. The number of preys and predator left in the plate after 48 hours revealed that in combination of *A. avenae* and *A. swarupi,* the number of *A. avenae* remained less (5.3) than *A. swarupi* (21.3). When *F. composticola* was released with *A. avenae* and *D. myceliophagus*, the number of *D. myceliophagus* was less (7.0) in plates than *A. avenae* (32.7). But, in the combination of *A. avenae* and *Bursilla* sp., population of *Bursilla* sp. increased from 35.3 to 61.3 in 24 to 48 hours of release and number of *A. avenae* decreased to 13.3.

Similarly, in the combination of *A. swarupi* and *Bursilla* sp., the population of *Bursilla* sp. increased to 48.7 which was 40.3 after 24h. The population of *D. myceliophagus* was reduced to 2.0 when combined with *A. swarupi* while *A. swarupi* reduced to only 38.0. Again, when *Bursilla* sp. was combined with *D. myceliophagus, F. composticola* preferred *D. myceliophagus* and diminished its number to 12.3 while *Bursilla* sp. increased to 75.7. These data indicate that when *D. myceliophagus* was in combination with other nematodes, it was preferred more than the others. *Bursilla* sp. increased their population after 48 hours of release from the population recorded after 24 hours. *F. composticola* multiplied to become two to three times of their original number.

After 72 hours of release, the data of preys and predator recorded and presented in Fig. 4.3. which clearly show that numbers of *A. avenae* and *A. swarupi* were left only 3.0 and 13.7, respectively. In *A. avenae* and *D. myceliophagus* combination, only 3.0 individuals of *D. myceliophagus* were left in the plate while numbers of *A. avenae* were 22.3. In combination of *A. avenae* and *Bursilla* sp., the population of *A. avenae* left was only 6.0 while *Bursilla* sp. increased to 126.3. Similarly, *Bursilla* sp. increased to 84.7 in combination of *A. swarupi* and *Bursilla* sp. while *A. swarupi* was almost completely consumed by *F. composticola*. In combination of *A. swarupi* and *D. myceliophagus, D. myceliophagus* was nearly finished and its negligible population was left in the plates while population of *A. swarupi* was 22.7. In combination of *D. myceliophagus* and *Bursilla* sp., *D. myceliophagus* was less in the plate (6.7) as compared to *Bursilla* sp. which increased to 123.0 after 72 hours of release. *F. composticola* increased to 19.7 to 29.7 in 72 hours.

After 96 hours of the release, the number of preys and predator in combination of *A. avenae* and *A. swarupi*, was reduced to 1.0 and 6.0 respectively (Fig. 4.4). In combination of *A. avenae* and *D. myceliophagus*, the number of *D. myceliophagus* left was less (0.7) than *A. swarupi* (10.3). The population of *A. avenae* was less in plates (0.7) than the population of *Bursilla* sp. when combined together. *Bursilla* sp. increased to 223.3 from the intial release (50). In combination of *A. swarupi* and *Bursilla* sp., the number of *A. swarupi* was almost finished (0.3) and *Bursilla* sp. increased to 182.3. When *F. composticola* was released with *A. swarupi* and *D. myceliophagus*, the population of *D. myceliophagus* was less (0.7) than *A. swarupi* (9.0). When *Bursilla* sp. was combined with *D. myceliophagus*, *Bursilla* sp. increased to 231.0 and *D. myceliophagus* decreased to 2.7 per plate.

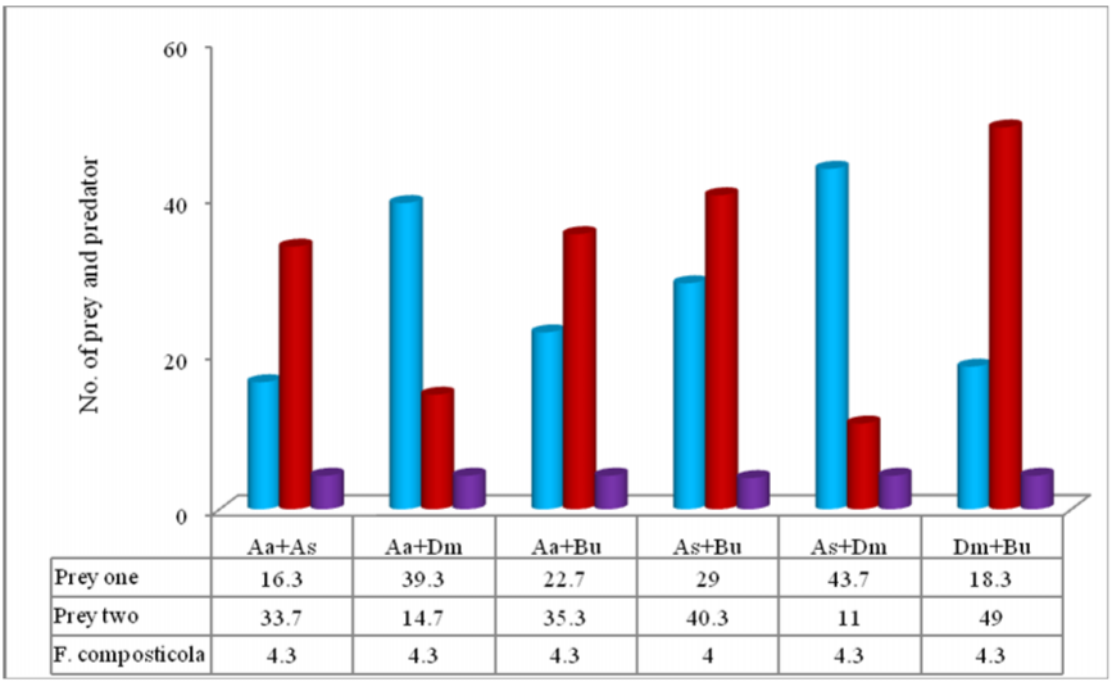
4.2.2. Prey preference of *Fictor composticola* in combination of three nematodes

The prey preference of *F. composticola* in the combination of three prey nematodes is shown in Fig. 4.5 to 4.8. The data in Fig. 4.5 presents the population of three preys and of *F. composticola* left in the plates after 24 hours of release. In this combination where all the three preys were mycophagous nematodes i. e., *A. avenae, A. swarupi* and *D. myceliophagus*, the population of *D. myceliophagus* was left less in plates (14.7) as compared to *A. avenae* (18.7) and *A. swarupi* (21.0).

In the second combination where *Bursilla* sp. was combined with *A. swarupi* and *D. myceliophagus*, similar to first combination, the number of individuals of *D. myceliophagus* left less (8.3) than the other two preys which reduced to 20.3 and 28.0 in case of *A. swarupi* and *Bursilla* sp., respectively.

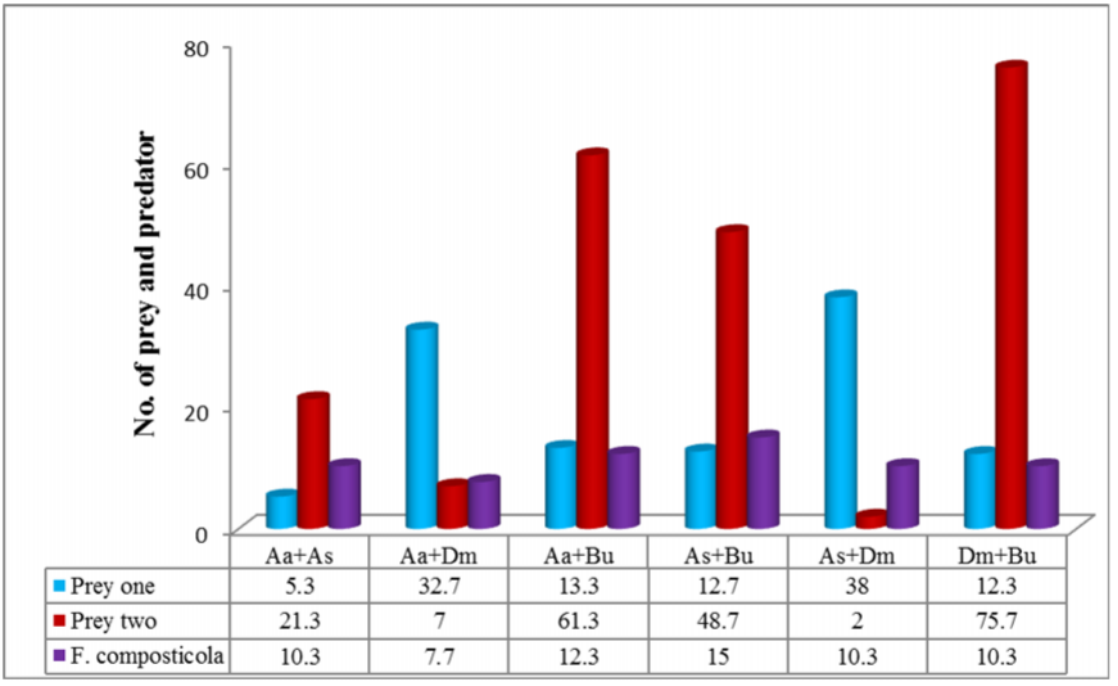
In the third combination having *A. avenae, A. swarupi* and *Bursilla* sp., the population of *A. avenae* was left less (14.3) than *A. swarupi* (29.0) and *Bursilla* sp. (26.3). The number of *F. composticola* remained almost the same after 24 hours.

The Fig. 4.6 presents the population of preys and predator left after 48 hours of release. In the first combination of three prey nematodes, *A. avenae, A. swarupi* and *D. myceliophagus*, the population of *D. myceliophagus*, became less (6.7) on an average than *A. avenae* (11.3) and *A. swarupi* (14.0). In the second combination where *Bursilla* sp. was combined with *A. swarupi* and *D. myceliophagus*, the number of *D. myceliophagus* and *A. swarupi* were reduced to 3.3 and 13.0 while the number of *Bursilla* sp. increased to 40.7 which was 28.0 after 24 hours of release. Similarly, in the third combination where *Bursilla* sp. was combined with *A. avenae* and *A. swarupi*, its population increased to 42.7 which was 26.3 after 24 hours of release. The populations of other two preys i. e., *A. avenae* and *A. swarupi* were reduced to 3.0 and 17.3. *F. composticola* preferred *A. avenae* over *A. swarupi* in this combination. The population of *F. composticola* increased from two to four times from its initial population after feeding on these prey nematodes for 48 hours.



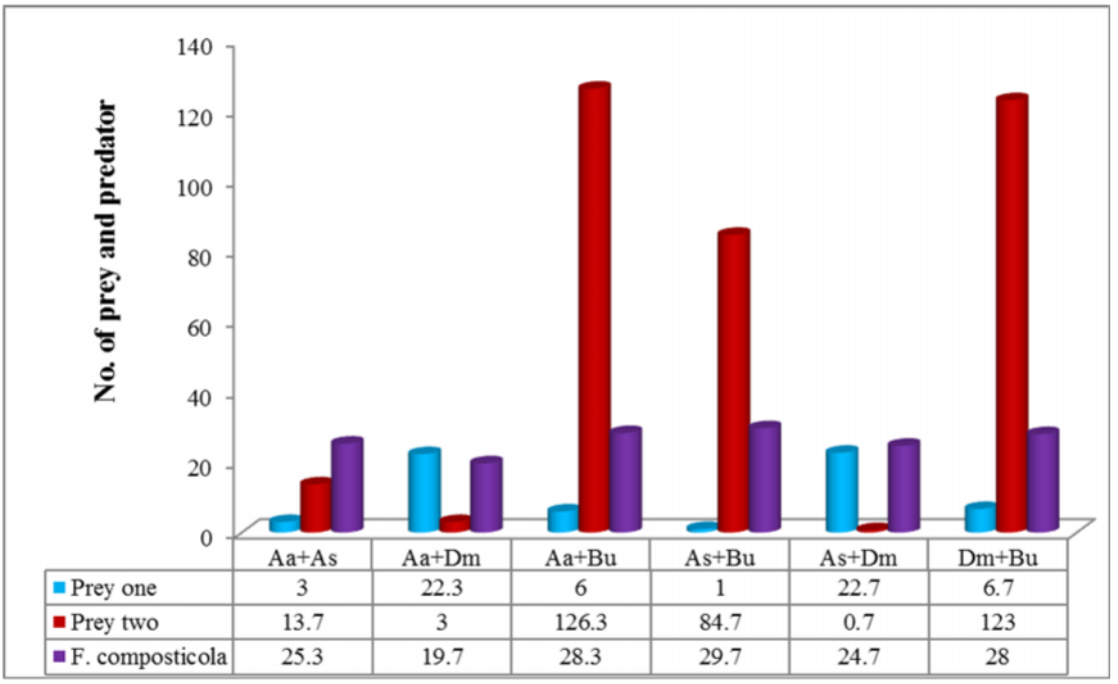
	Aa+As	Aa+Dm	Aa+Bu	As+Bu	As+Dm	Dm+Bu
Prey one	16.3	39.3	22.7	29	43.7	18.3
Prey two	33.7	14.7	35.3	40.3	11	49
F. composticola	4.3	4.3	4.3	4	4.3	4.3

Fig. 4.1 : Population of prey and predator after 24 hours showing prey preference of *Fictor composticola* in paired combinations of prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp.



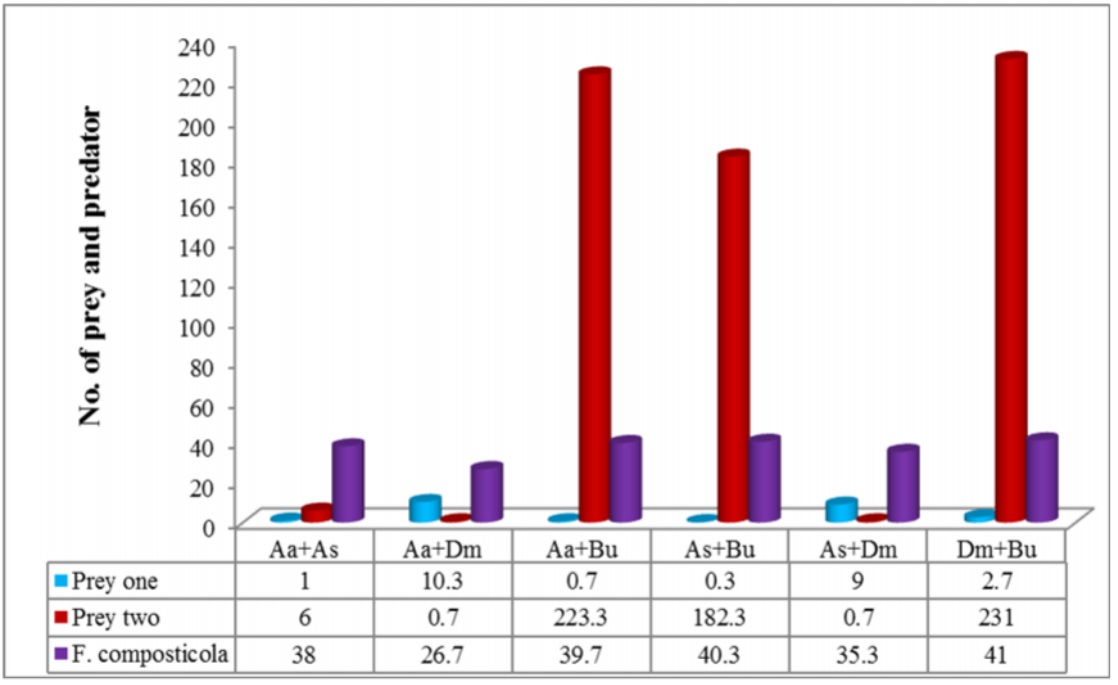
	Aa+As	Aa+Dm	Aa+Bu	As+Bu	As+Dm	Dm+Bu
Prey one	5.3	32.7	13.3	12.7	38	12.3
Prey two	21.3	7	61.3	48.7	2	75.7
F. composticola	10.3	7.7	12.3	15	10.3	10.3

Fig. 4.2: Population of prey and predator after 48 hours showing prey preference of *Fictor composticola* in paired combinations of prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp.



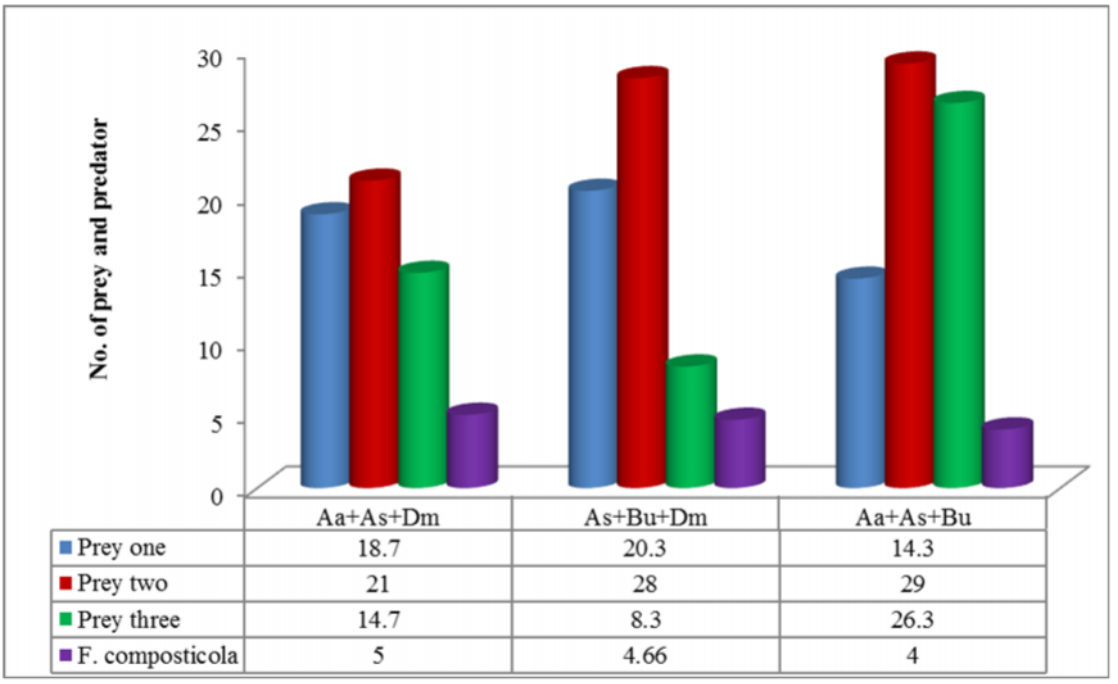
	Aa+As	Aa+Dm	Aa+Bu	As+Bu	As+Dm	Dm+Bu
Prey one	3	22.3	6	1	22.7	6.7
Prey two	13.7	3	126.3	84.7	0.7	123
F. composticola	25.3	19.7	28.3	29.7	24.7	28

Fig. 4.3: Population of prey and predator after 72 hours showing prey preference of *Fictor composticola* in paired combinations of prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp.



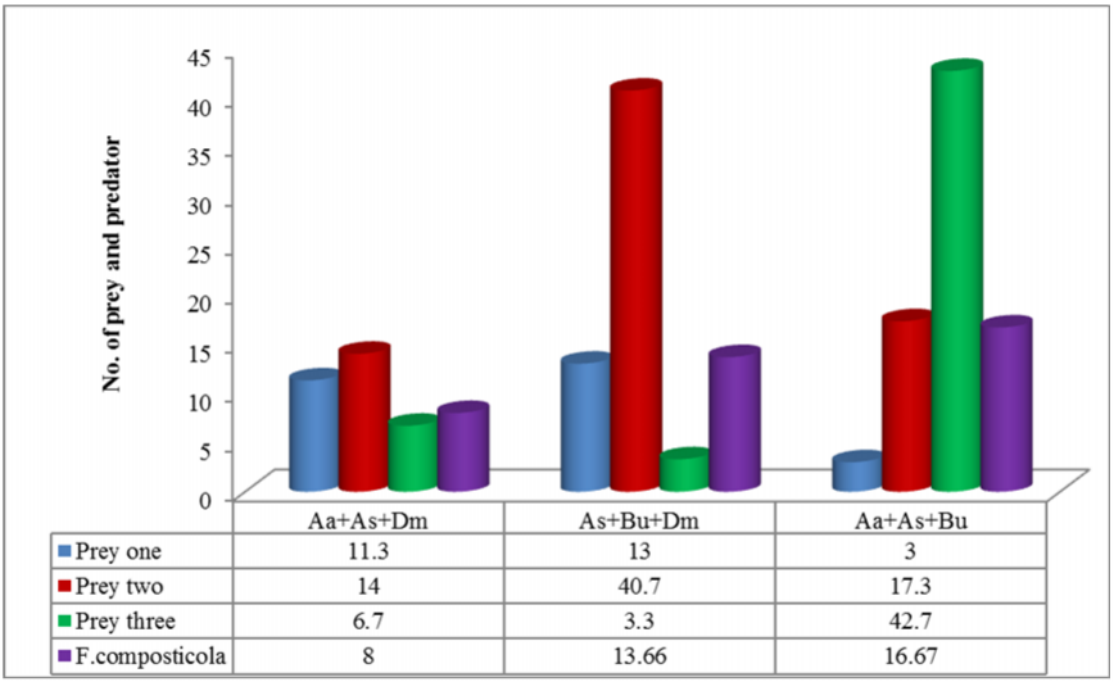
	Aa+As	Aa+Dm	Aa+Bu	As+Bu	As+Dm	Dm+Bu
Prey one	1	10.3	0.7	0.3	9	2.7
Prey two	6	0.7	223.3	182.3	0.7	231
F. composticola	38	26.7	39.7	40.3	35.3	41

Fig. 4.4 : Population of prey and predator after 96 hours showing prey preference of *Fictor composticola* in paired combinations of prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp.



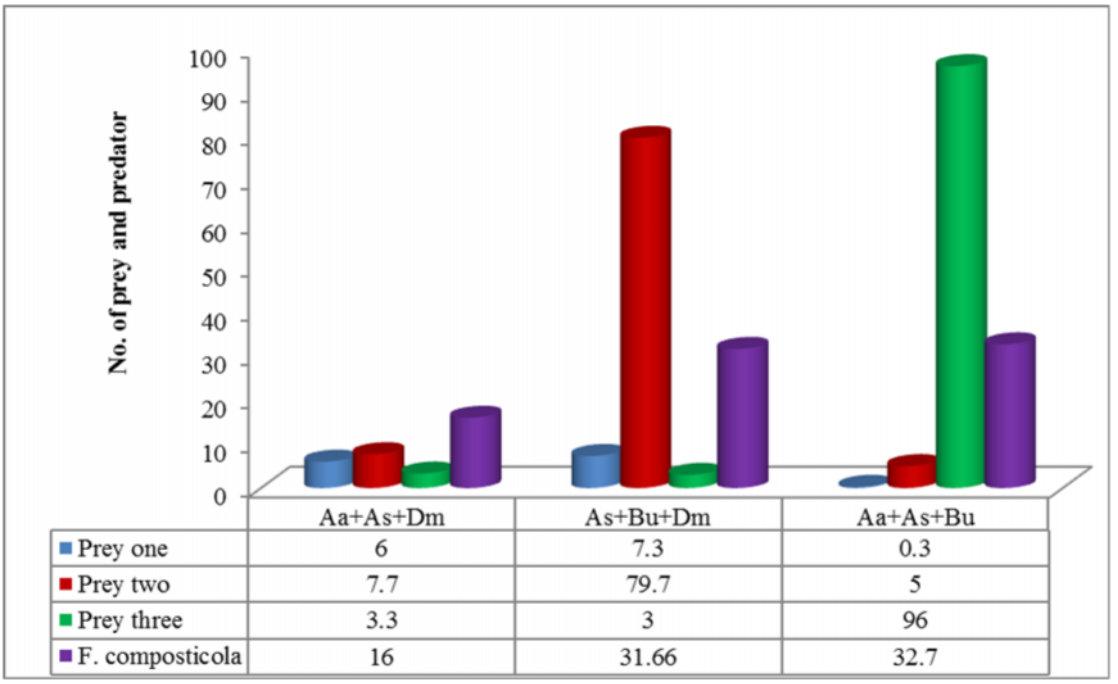
	Aa+As+Dm	As+Bu+Dm	Aa+As+Bu
Prey one	18.7	20.3	14.3
Prey two	21	28	29
Prey three	14.7	8.3	26.3
F. composticola	5	4.66	4

Fig. 4.5 : Population of prey and predator after 24 hours showing prey preference of *Fictor composticola* in combinations of three prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp.



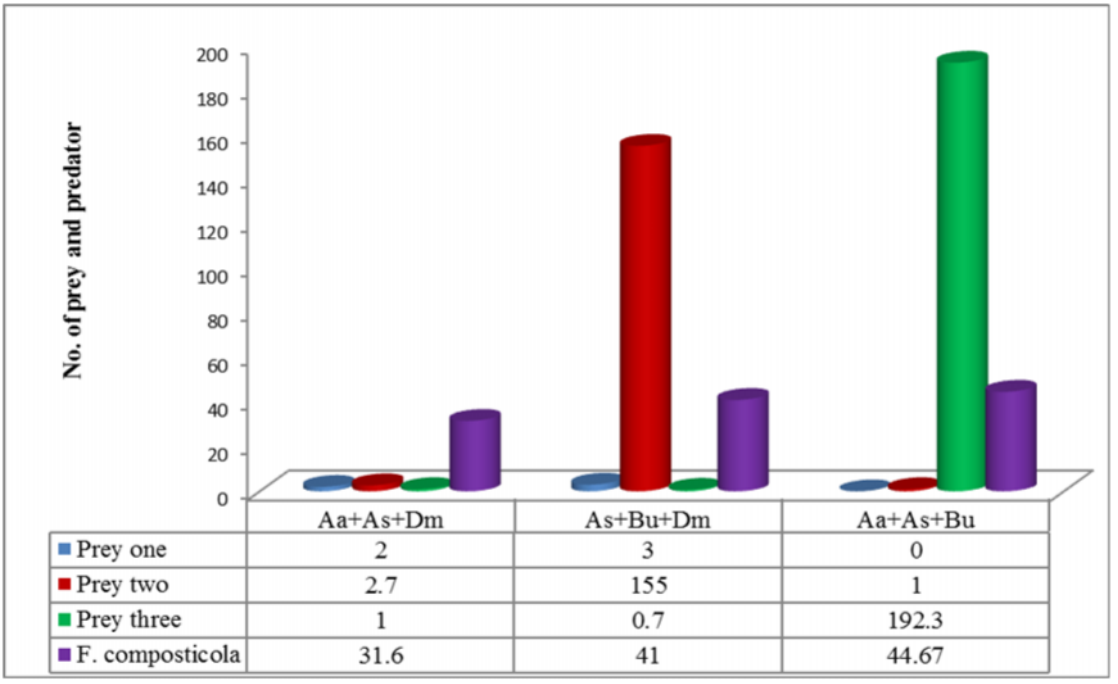
	Aa+As+Dm	As+Bu+Dm	Aa+As+Bu
Prey one	11.3	13	3
Prey two	14	40.7	17.3
Prey three	6.7	3.3	42.7
F.composticola	8	13.66	16.67

Fig. 4.6 : Population of prey and predator after 48 hours showing prey preference of *Fictor composticola* in combinations of three prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp.



	Aa+As+Dm	As+Bu+Dm	Aa+As+Bu
Prey one	6	7.3	0.3
Prey two	7.7	79.7	5
Prey three	3.3	3	96
F. composticola	16	31.66	32.7

Fig. 4.7 : Population of prey and predator after 72 hours showing prey preference of *Fictor composticola* in combinations of three prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp.



	Aa+As+Dm	As+Bu+Dm	Aa+As+Bu
Prey one	2	3	0
Prey two	2.7	155	1
Prey three	1	0.7	192.3
F. composticola	31.6	41	44.67

Fig. 4.8 : Population of prey and predator after 96 hours showing prey preference of *F. composticola* in combinations of three prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp.

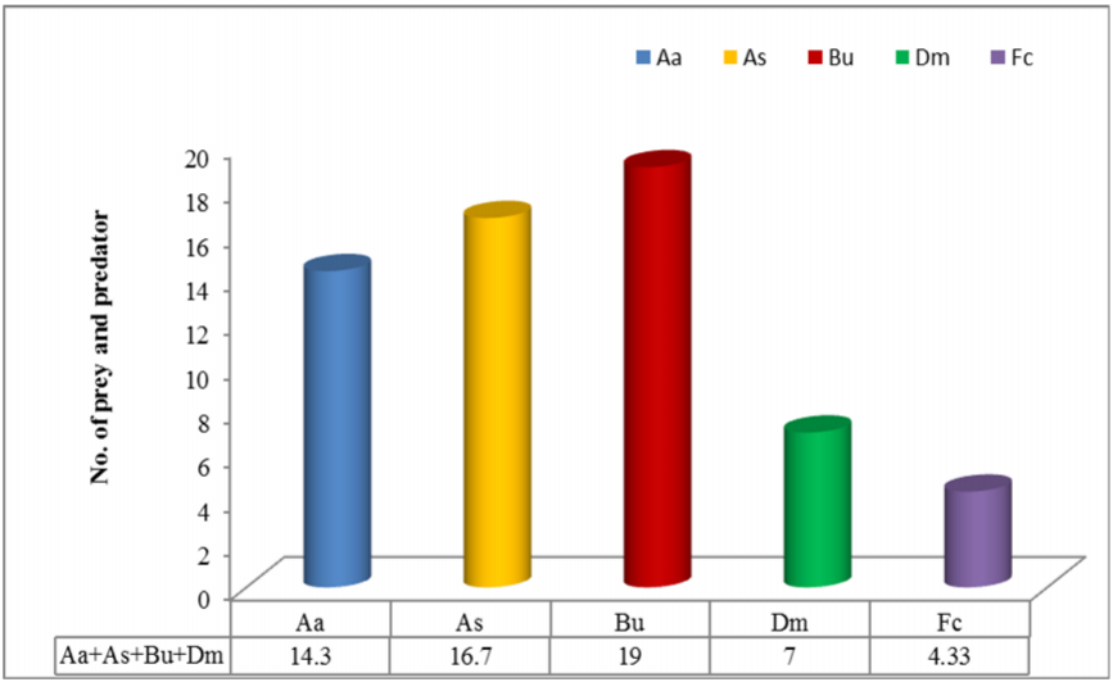


Fig. 4.9: Population of prey and predator after 24 hours and showing prey preference of *Fictor composticola* in combination of four prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp., Fc – *Fictor composticola*

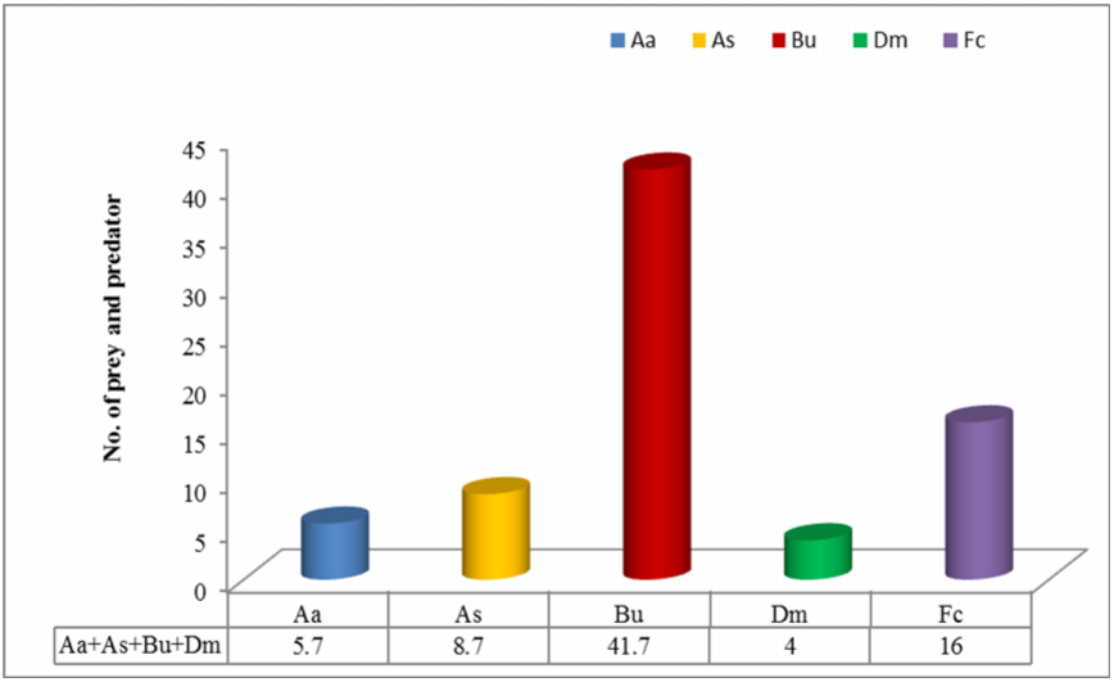


Fig. 4.10: Population of prey and predator after 48 hours and showing prey preference of *Fictor composticola* in combination of four prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp., Fc – *Fictor composticola*

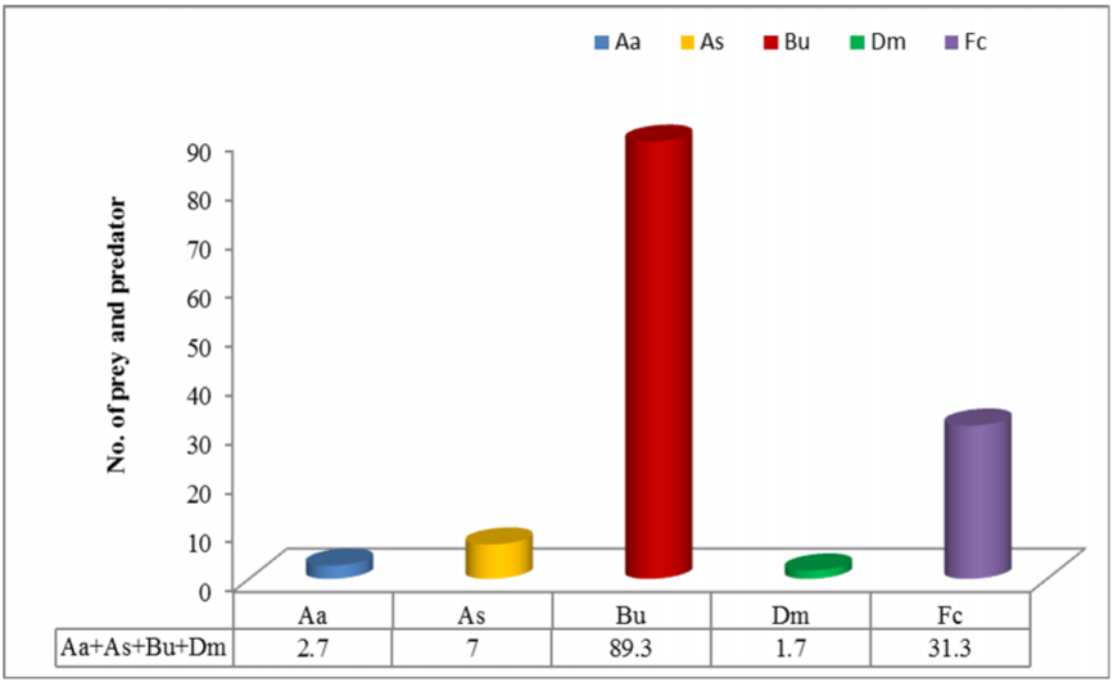


Fig. 4.11 : Population of prey and predator after 72 hours and showing prey preference of *Fictor composticola* in combination of four prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp., Fc – *Fictor composticola*

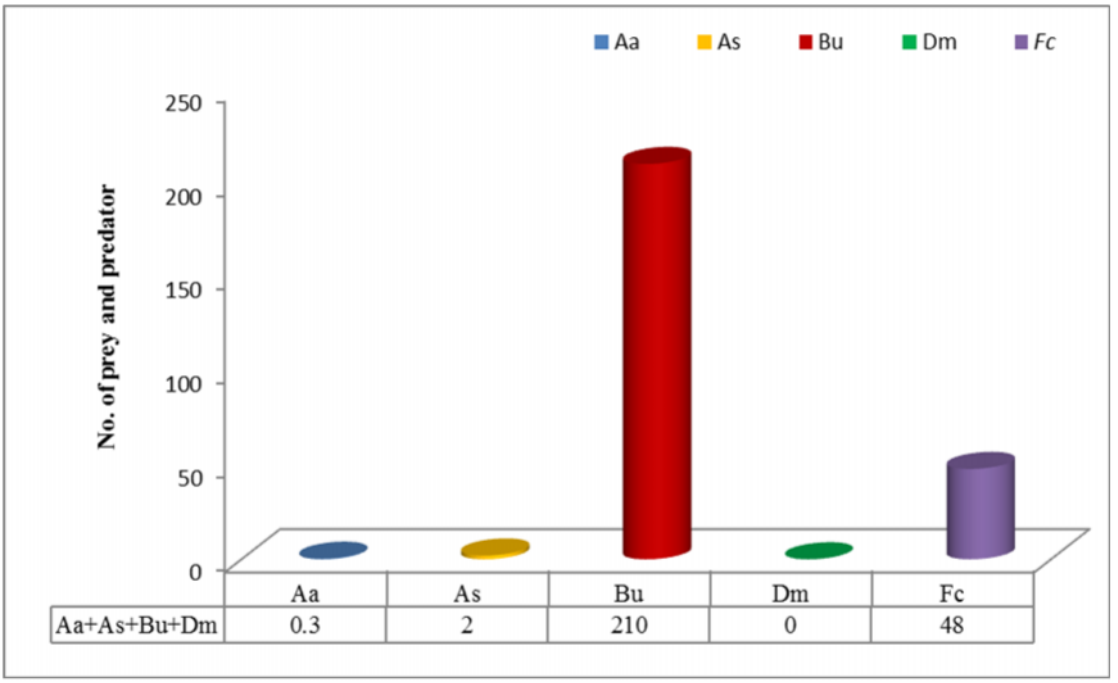


Fig. 4.12 : Population of prey and predator after 96 hours and showing prey preference of *Fictor composticola* in combination of four prey nematodes. Aa - *Aphelenchus avenae*, As - *Aphelenchoides swarupi*, Dm - *Ditylenchus myceliophagus*, Bu - *Bursilla* sp., Fc – *Fictor composticola*

The feeding preference of *F. composticola* on all three prey nematodes after 72 hours has been shown in Fig. 4.7. It is evident from data that in the combination of *A. avenae, A. swarupi* and *D. myceliophagus, F. composticola* preferred *D. myceliophagus* because its population remained less (3.3) than *A. avenae* (6.0) and *A. swarupi* (7.7). In second combination of *A. swarupi, Bursilla* sp. and *D. myceliophagus* also, *D. myceliophagus* was the most preferred prey for *F. composticola.* Here, the population of *D. myceliophagus* was reduced more (3.0) than the population of *A. swarupi* (7.3). The number of *Bursilla* sp. was increased to 79.7 from the initial release of 33 per plate. Also in the combination of *A. avenae, A. swarupi* and *Bursilla* sp., *A. avenae* was preferred more than *A. swarupi* and *Bursilla* sp. as the populations of *A. avenae* and *A. swarupi* were much less (0.3 and 5.0, respectively) than *Bursilla* sp. (Fig.4.7). *F. composticola* multiplied 4 to 8 times in different combinations after 72 h.

The number of preys and predator left in the plate after 96 hours of release of nematodes is shown in Fig. 4.8. The population of all the three nematodes, *A. avenae, A. swarupi* and *D. myceliophagus* was nearly finished when they were combined as test preys of *F. composticola.* In this combination, the number of *D. myceliophagus, A. avenae* and *A. swarupi* was 1.0, 2.0 and 2.7, respectively. In the second combination of *A. swarupi, Bursilla* sp. and *D. myceliophagus,* the number of *D. myceliophagus* was less (0.7) than the other two and population of *A. swarupi* was 3.0 whereas population of *Bursilla* sp. was increased to 155.0. In the combination of *A. avenae, A. swarupi* and *Bursilla* sp., the number of *A. avenae* and *A. swarupi* was negligible but population of *Bursilla* sp. increased to 192.3. The population of *F. composticola* increased 8 to 11 times in these combinations.

4.2.3. Prey preference of *Fictor composticola* in the combination of four prey nematodes

When four prey nematodes, *A. avenae, A. swarupi, Bursilla* sp. and *D. myceliophagus* were combined together and released with two males and females of *F. composticola,* their populations recorded after 24 hours of release were 14.3, 16.7, 19.0 and 7.0, respectively (Fig. 4.9). The population of *D. myceliophagus* was consumed more than the other three preys. After 48 hours of release, the population of *D. myceliophagus* was less (4.0) than *A. avenae* (5.7), *A. swarupi* (8.7) or *Bursilla* sp. (41.7) (Fig. 4.10).

The number of *F. composticola* remained almost same after 24 h but after 48 h, it multiplied to double its initial number. After 72 h, the population of *D. myceliophagus* was reduced to 1.7 only and populations of *A. avenae* and *A. swarupi* reduced to 2.7 and 7.0 while that of *Bursilla* sp. increased to 89.3 (Fig. 4.11). After 96 h of release, the number of *D. myceliophagus* was consumed by *F. composticola* completely while the populations of *A. avenae* and *A. swarupi* were 0.3 and 2.0 respectively. The number of *Bursilla* sp. increased to 210.0 per plate. *F. composticola* multiplied to 48.0 after 96 hours of release with prey nematodes (Fig. 4.12).

4.3. Predatory behaviour of *Fictor composticola*

Predatory behaviour of female and male *F. composticola* on mycophagous and microbivorous nematodes is shown in Tables 4.5 and 4.6, respectively. *F. composticola* started moving very fast and searched the prey immediately after release in the agar plates (Plate 14).

4.3.1. Predatory behaviour of female *Fictor composticola*

The female *F. composticola* started feeding on the prey attacked and after death of the prey, it continued feeding on the exudating material coming out of the body of the prey. On *A. avenae,* it encountered 2.4 times in half an hour. It fed the first encountered prey in 90 % cases and in 10 % cases, it attacked other than first prey. In 70 % of the cases, juveniles of *A. avenae* were attacked which were encountered during the feeding period and in 30 % chances adults were attacked. It preferred to attack on middle and posterior parts of the prey (about 45 % in each case) than the anterior part (9.1 %) (Table 4.5). As a result of feeding, 95 % of the attacked preys were killed and 5 % of them escaped after injuries. Average feeding duration was found 8 min and 4 sec.

On *A. swarupi,* it encountered 2.9 times. It captured the prey in 90 % cases in the first encounter and in 10 % in other encounters. In 73.1 % cases, juvenile preys were attacked and in 26.9 % cases, adults were attacked. In this species, the anterior, middle and posterior parts of the body of the prey were attacked in 25.9 %, 40.8 % and 33.3 % of preys, respectively. During feeding, 92.3 % of the attacked preys died while 7.7 % escaped. The mean feeding duration of *F. composticola* on *A. swarupi* was 8 min and 56 sec which was the highest feeding duration amongst all the preys tested on female *F. composticola* on *D. myceliophagus*, the mean number of encounters of female *F. composticola* was 3.2. The predator attacked the first prey encountered in 70 % cases whereas it attacked the other than first prey in 30 % chances. It preferred juveniles in 65 % and adults in 35 %. Posterior part of the preys was the most preferred (50 %) part followed by middle (42.3 %) and anterior part (7.7 %). In 91.7% of the cases, the attacked preys died while 8.3 % were able to escape. The mean feeding duration of *F. composticola* on *D. myceliophagus* was recorded 8 min and 26 sec.

Panagrolaimus sp., a microbivorous nematode, is an agile nematode. In this species, female *F. composticola* encountered on an average 3.7 times which was the highest number of encounters of female predator on prey nematodes. On this prey, it attacked the first encountered prey in 80 % cases and the other than the first preys in 20 % chances. The juveniles were attacked more (77.3 %) than the adults (22.7 %). The middle part of the prey was preferred more (44 %) than the posterior part (36 %) and anterior part was least preferred (20 %). Amongst the preys attacked, 85.7 % were killed after feeding and 14.3 % of these preys were alive but injured. The mean feeding duration of female predator on this species was 8 min and 30 sec.

Table 4.5. Predation behaviour of female *Fictor composticola* on different prey nematode species

Prey species	E	EA (%)		Prey life stage attacked (%)		Part of the prey body attacked (%)			Injured (%)	Dead (%)	Feeding duration
		First prey	Other prey	Adult	Juvenile	Anterior	Middle	Posterior			
Aphelenchus avenae	2.4	90	10	30	70	9.1	45.5	45.4	5.0	95.0	8 min 4 sec
Aphelenchoides swarupi	2.9	90	10	26.9	73.1	25.9	40.8	33.3	7.7	92.3	8 min 56 sec
Ditylenchus myceliophagus	3.2	70	30	35	65	7.7	42.3	50.0	8.3	91.7	8 min 26 sec
***Panagrolaimus* sp.**	3.7	80	20	22.7	77.3	20.0	44.0	36.0	14.3	85.7	8 min 30 sec
***Bursilla* sp.**	2.8	70	30	25	75	20.8	29.2	50.0	12.5	87.5	8 min 38 sec
Mean	3.0	80	20	28.0	72.0	16.7	40.4	42.9	9.6	90.4	8 min 31 sec

Each observation is mean of ten replications
E = Number of encounters of predator on prey
EA = Number of encounters resulted into attack

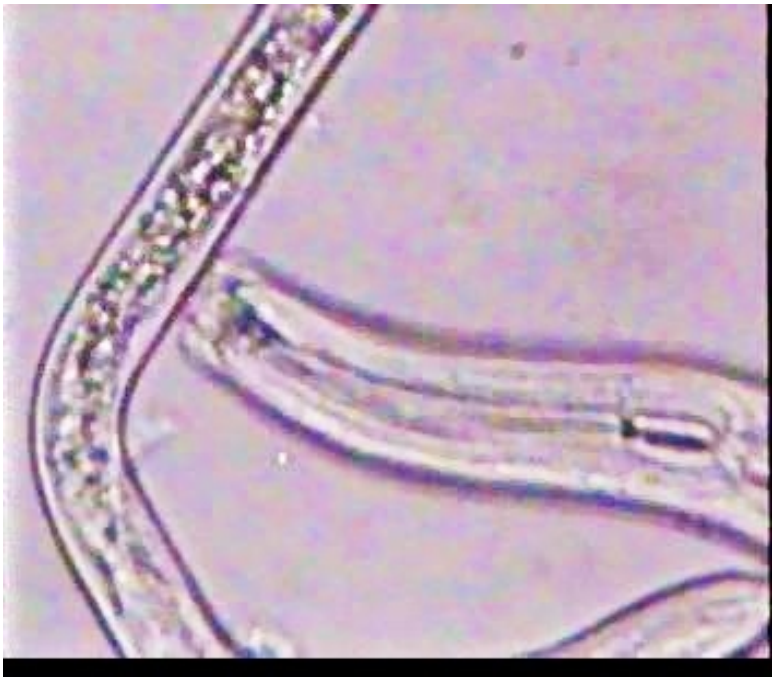
On *Bursilla* sp., female *F. composticola* encountered 2.8 times. It captured and attacked the prey in first encounter in 70 % cases but failed to capture the first prey in 30 % chances. In *Bursilla* sp., 75 % of the attacked individuals were juveniles and 25 % were adults. The posterior part of the prey was the most attacked part (50 %) than the middle (29.2 %) or the anterior (20.8 %) part. Amongst the preys attacked, 87.5 % were found dead while 12.5 % were alive although they were having injuries. Mean feeding duration of the predator on this prey was found 8 min and 38 sec.

On an average, female *F. composticola* had 3.0 encounters on all the five prey nematode species (*A. avenae*, *A.swarupi*, *D. myceliophagus*, *Panagrolaimus* sp. and *Bursilla* sp.). It encountered the first prey in 80 % cases while in 20 % cases, the preys other than the first encountered preys. It preferred juveniles (72 %) over adults (28 %). It preferred posterior part of the prey (42.9 %) than the middle (40.4 %) and anterior (16.7 %) parts. Among the attacked preys by female *F. composticola*, 90.4 % preys were found dead and 9.6 % were escaped after getting injuries. The average feeding duration of female *F. composticola* on all the five prey nematode species was 8 min and 31 sec. Its feeding behaviour on all five prey nematode species was shown in Annexure IV to VIII.

4.3.2. Predatory behaviour of male *Fictor composticola*

The male *F. composticola* has faster movements as compared to females and also its feeding was not consistent on one prey. During half an hour observation, it encountered many prey nematodes (Table 4.6) and fed on many of them for a short duration (3-10 sec). It kept on moving in different directions. On *A. avenae*, the male *F. composticola* encountered 7.1 times on an average and this is the maximum number of encounters done by *F. composticola* among the five prey nematode species. In only 30 % cases, it attacked the first encountered prey and in 70 % chances it attacked the other than the first prey nematodes. The juveniles were attacked more (96.9 %) than the adults (3.1 %). The posterior part of the preys was more preferred (59.4 %) than the middle or the anterior part (34.4 % and 6.2 %, respectively) for attack. The percentage of prey killed due to feeding was 84.8 and while 15.2 % were only injured. The mean feeding duration of male *F. composticola* on *A. avenae* was 3 min and 49 sec. The feeding behaviour of male *F. composticola* on all the five prey nematode species were shown in Annexure IX to XIII.

On *A. swarupi*, the male *F. composticola* encountered 5.5 times. In only 20 % of the chances, it attacked the first prey. Amongst the preys attacked, 75 % were juveniles and 25 % were adults. Regarding the part of the prey body preferred for feeding, posterior part was the most preferred (47 %) followed by middle (35.3 %) and the anterior (17.6 %). Due to feeding, 58.3 % of the preys were found dead while 41.7 % escaped after injury. The mean feeding duration was 2 min and 31 sec on this prey species. This was the mininmum feeding duration among the five prey nematode species.



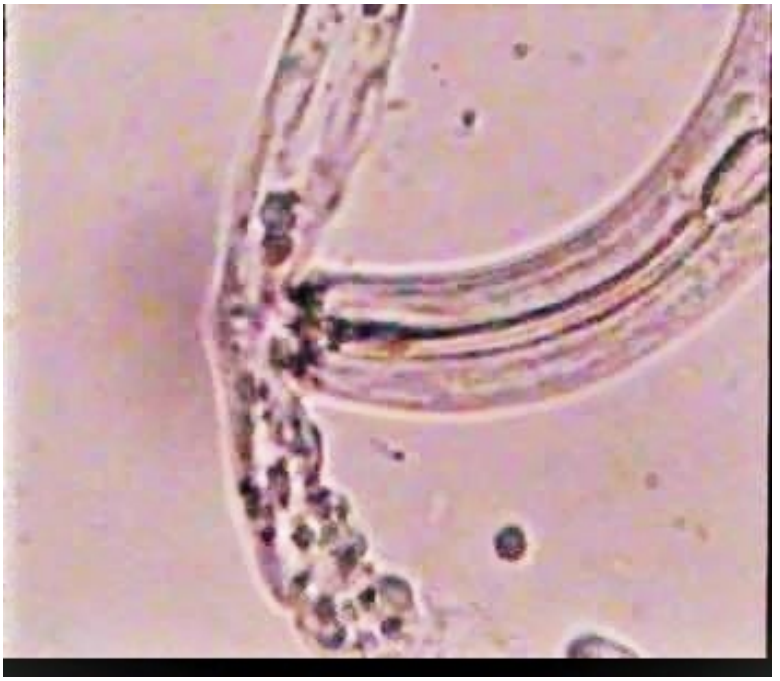


Plate 14: ***Fictor composticola*** **feeding on** ***Aphelenchus avenae*** **(at different stages of feeding)**

On *D. myceliophagus,* mean number of encounters recorded was 6.0 and it preferred to feed on the preys which were encountered later (70 %) as compared to those encountered first (30 %). The nematode preferred juvenile preys more (60 %) than the adults (40 %). The posterior part of the preys was the most preferred (56.7 %) over the middle (23.3 %) and anterior parts (20 %). Amongst the attacked preys, 83.3% were found dead while 16.7% escaped after getting injuries. The mean feeding duration was found 5 min and 42 sec which was the maximum feeding duration among all the five prey nematode species.

On *Panagrolaimus* sp., mean number of encounters done by male *F. composticola* were 5.6. It fed on other than the first encountered preys in 70 % cases and in 30 % cases, on first encountered prey. The juveniles were preferred (91.7 %) over the adults (8.3 %) of the prey species. The middle part of the prey body was attacked more in this prey (46.1 %) than the posterior (38.5 %) or anterior part (15.4 %). Among the attacked preys, 75 % were dead after feeding by the predator while 25 % of them escaped. The mean feeding duration was 5 min and 32 sec in this prey species.

On *Bursilla* sp., the number of encounters made by male *F. composticola* were 5.7 and it preferred to feed on the later encountered prey nematodes (80 %) than the first encountered ones (20 %). The juveniles were preferred (78.8 %) over the adults (21.2 %) as prey. The posterior part of the prey was more frequently attacked for feeding (58.3 %) than the middle (25 %) and the anterior (16.7 %) part. Among the preys attacked, 60.6 % died due to feeding and 39.4 % of them escaped after injury. The average feeding duration was recorded 4 min and 10 sec in *Bursilla* sp.

On an average, male *F. composticola* encouneterd 6.0 times on all the prey nematode species. It attacked more on the preys (74 %) which were encountered other than the first. The juveniles were attacked the most (80.5 %) than the adults (19.5 %). The posterior part of the preys were the most attacked part (52.0 %) than the middle (32.8 %) and anterior (15.2 %) parts. Among the attacked preys, 72.4 % of the preys were found dead while 27.6 % were escaped after getting injuries. The average feeding duration of male *F. composticola* was only 4 min and 11 sec.

Considering all the five prey nematodes, i.e., *A. avenae, A. swarupi, D. myceliophagus, Panagrolaimus* sp. and *Bursilla* sp., the mean number of encounters of male *F. composticola* were twice the number of encounters made by female. Male predator attacked the preys which were encountered later whereas female predator attacked the first encountered preys more. Male *F. composticola* preferred the juveniles over the adults similar to female. Like females, males preferred the posterior part of the prey body more than the anterior part of the preys. Both female and male predator were responsible for the maximum mortality of the preys. The average duration of feeding on male was half the feeding duration by female.

Table 4.6. Predation behaviour of male *Fictor composticola* on different prey nematode species

Prey species	E	EA (%)		Prey life stage (%)		Part of the prey body attacked (%)			Injured (%)	Dead (%)	Feeding duration
		First prey	Other preys	Adult	Juvenile	Anterior	Middle	Posterior			
Aphelenchus avenae	7.1	30	70	3.1	96.9	6.2	34.4	59.4	15.2	84.8	3 min 49 sec
Aphelenchoides swarupi	5.5	20	80	25	75	17.6	35.3	47.0	41.7	58.3	2 min 31 sec
Ditylenchus myceliophagus	6.0	30	70	40	60	20.0	23.3	56.7	16.7	83.3	5 min 42 sec
***Panagrolaimus* sp.**	5.6	30	70	8.3	91.7	15.4	46.1	38.5	25.0	75.0	5min 32 sec
***Bursilla* sp.**	5.7	20	80	21.2	78.8	16.7	25.0	58.3	39.4	60.6	4 min 10 sec
Mean	6.0	26	74	19.5	80.5	15.2	32.8	52.0	27.6	72.4	4min 11 sec

Each observation is mean of ten replications
E = Number of encounters of predator on prey
EA = Number of encounters resulted into attack

4.3.3. Strike rate of *Fictor composticola*

The strike rate (SR%) was calculated for male and female *F. composticola* on all the five prey nematodes, *A. avenae, A. swarupi, D. myceliophagus, Panagrolaimus* sp. and *Bursilla* sp. separately and have been shown in Fig. 4.13. The data revealed that strike rate of female *F. composticola* was higher than its male counterpart. The strike rate of the predator on different prey nematode species was found more on mycophagous nematodes (89.6 %) than on microbivorous nematodes and minimum on *Panagrolaimus* sp. (59.4 %). The average strike rate of female *F. composticola* considering all the prey nematodes together, was 78.6 % whereas strike rate of male was 48.2 %. The strike rate of male *F. composticola* was the highest (57.9 %) on *Bursilla* sp. and lowest (42.8 %) on *Panagrolaimus* sp. The range of strike rate of male was lower (42.8-57.9 %) as compared to the female (59.4-89.6 %).

4.3.4. Prey susceptibility of the prey nematode species to *Fictor composticola*

The prey susceptibility (PS %) of all the five prey species to *F. composticola* is presented in Fig. 4.14. The PS % of mycophagous nematodes to male *F. composticola* ranged from 83.3-87.9 % which was higher than microbivorous nematodes (62.5 % for *Panagrolaimus* sp. and 63.6 % for *Bursilla* sp.). Similar was the case with female *F. composticola*. The PS % of mycophagous nematodes to female *F. composticola* was higher (95.0 %, 92.3 % and 91.7 % for *A. avenae, A. swarupi* and *D. myceliophagus*, respectively) and that of *Panagrolaimus* sp. and *Bursilla* sp. to female predator were lower, i.e., 81.8 % and 83.3 %, respectively. The PS % of all the five prey nematodes to male *F. composticola* was lower (76.1 %) than to female *F. composticola* (88.8 %) however, for all the nematodes it was more than 60 %. Thus, the prey resistance of the prey nematodes was less than 40 %. The maximum PS % was shown by *A. avenae* (91.5 %) and minimum by *Panagrolaimus* sp. (72.1 %) for both male and female *F. composticola.*

4.4. Effects of prey density on the predation behaviour of *Fictor composticola*

The effect of prey density levels (100, 200, 400, 800 and 1600) of *Ditylenchus myceliophagus* on the predation efficiency of *F. composticola* is presented in Table 4.7. After 24 hours, the consumption was maximum (24.23) at 1600 prey density level, although the maximum per cent consumption (81 %) was at 200 prey density level and minimum per cent consumption (36 %) was at 1600 prey density level. The prey consumption at all levels after 24 hours of release, was highly different significantly to each other.

After 48 hours of release, the data revealed that with the increase in prey density levels, the consumption of prey increased more (33.19) at 1600 prey density level and minimum (9.84) at 100 prey density level. But, the per cent consumption was maximum (97.5 %) at 400 prey density level and minimum (68.0) at 1600 prey density level.

The data show that the maximum consumption of *D. myceliophagus* (28.72) was at prey density level of 1600 and minimum (9.28) at 100 prey density. But, the percentage consumption was minimum (52.0) at 1600 prey density. As the prey density increased, prey consumption also increased. The percentage consumption at 200 and 400 prey densities, were 87.5 and 88.5 respectively.

The maximum per cent consumption was at 400 prey density level (88.5). Irrespective of prey density levels, the prey consumption of *D. myceliophagus* was significantly higher (20.58) at 48 h than at 24 h (16.94). The prey consumption at all five prey density levels, was significantly different.

Table 4.7. Effect of prey density of *Ditylenchus myceliophagus* on the preying capacity of *Fictor composticola*

Prey density	Population consumed after								
	24h			48h			Mean		
100	75	(8.72)	**75.0**	96	(9.84)	**96.0**	85.5	(9.28)	**85.5**
200	162	(12.75)	**81.0**	188	(13.76)	**94.0**	175	(13.25)	**87.5**
400	319	(17.89)	**79.7**	390	(19.77)	**97.5**	355	(18.83)	**88.5**
800	446	(21.13)	**55.7**	693	(26.33)	**86.6**	570	(23.73)	**71.1**
1600	586	(24.23)	**36.0**	1101	(33.19)	**68.0**	844	(28.72)	**52.0**
Mean	318	(16.94)	**65.5**	494	(20.58)	**88.0**			

CD at 5% for:

Density = 0.38 Time = 0.24 Density × Time = 0.54

Each observation is mean of 4 replications

Value in parentheses indicate square root transformations

Figures in bold represent the % consumption

The effect of prey density levels (100, 200, 400, 800 and 1600) of *Aphelenchus avenae* on the predation efficiency of *F. composticola* is presented in Table 4.8. After 24 hours of observation, it was found that the consumption of prey increased with the increase in the prey density levels, maximum (22.88) being at 1600 and minimum (8.30) at 100 prey density level although the maximum per cent consumption (78.5) was at 200 prey density level and minimum (32.6) at 1600 level. The data of consumption recorded at all the inoculum levels were highly different significantly.

The consumption after 48 hours of release showed that the maximum consumption (32.61) was at highest (1600) prey density level and minimum (9.79) at lowest (100) level. However, at these inoculum levels, the per cent consumption was minimum (66.4) at the highest level and maximum (95.0) at lowest level. Here also, the consumption at all inoculum levels, were significantly different.

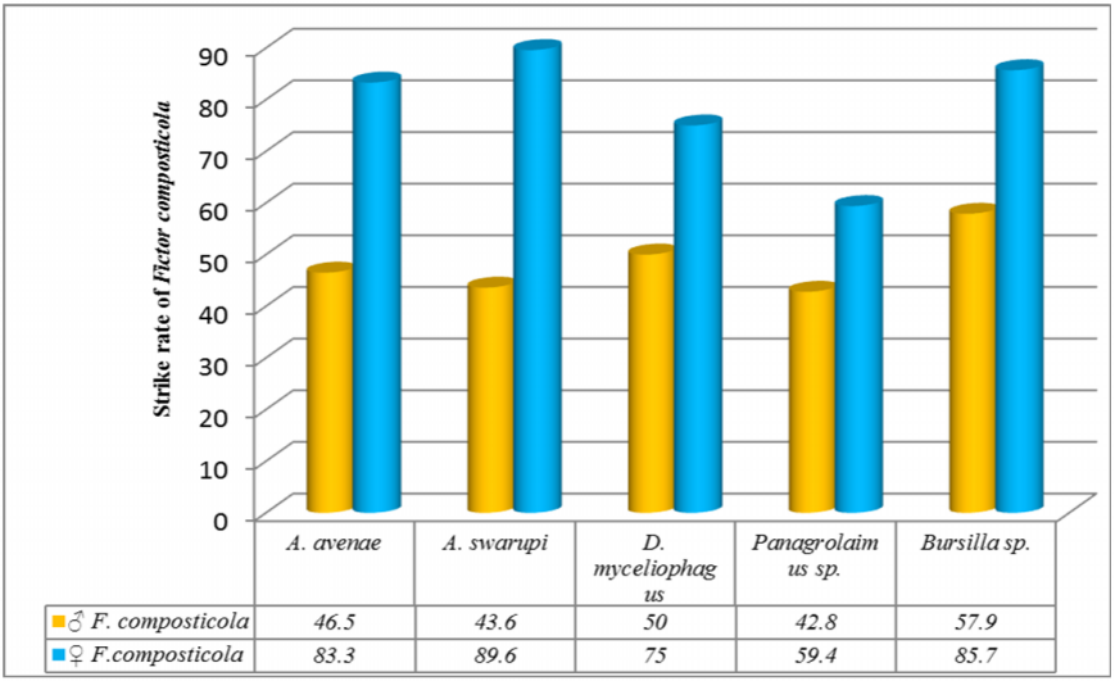


Fig. 4.13 : Strike rate of male and female *Fictor composticola* on different preys

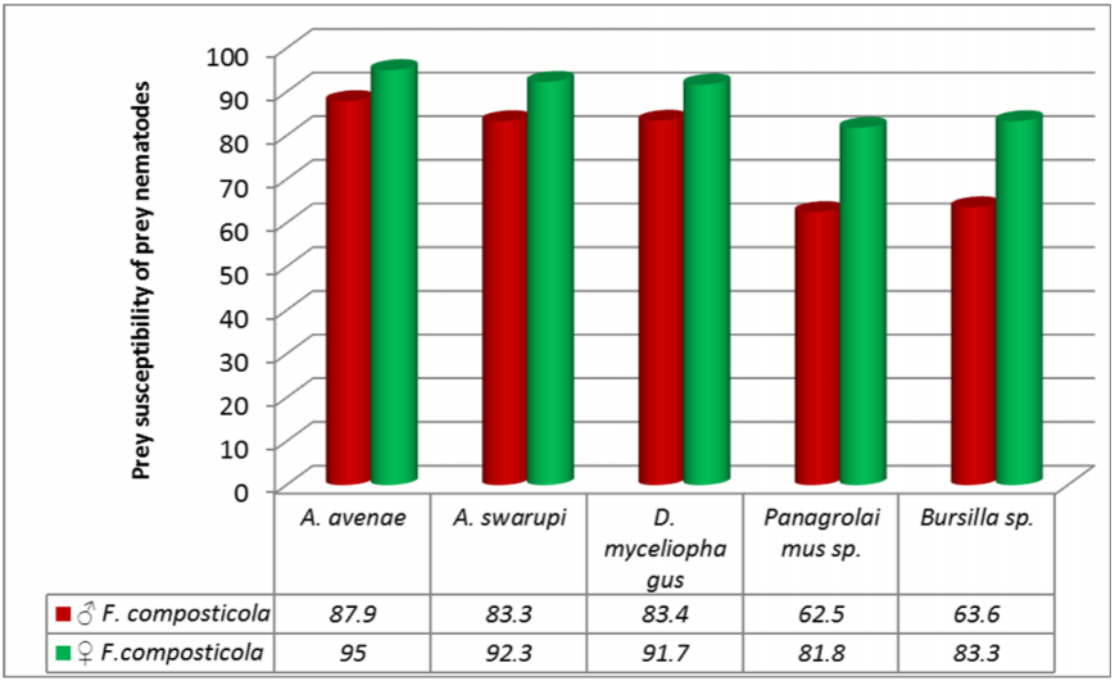


Fig. 4.14 : Prey susceptibility of different preys to *Fictor composticola*

The data show that the maximum mean consumption (27.75) of prey was at density level 1600 and minimum (9.05) at 100 prey density level. But, the per cent consumption was minimum (49.5) at highest prey density level (1600) and maximum (86 %) at 200 prey density levels. The consumption of *A. avenae* increased with increase in prey density levels. The prey consumption at all prey density levels was significantly different from each other. The prey consumption at different time period (24 h and 48 h) was also highly significant. The prey consumption of *A. avenae* after 48 h was higher (20.19) than after 24 h (16.32) (Table 4.8). The per cent consumption after 48 h was also higher (86) than after 24 h (61.5).

Table 4.8. Effect of prey density of *Aphelenchus avenae* on the preying capacity of *Fictor composticola*

Prey density	Population consumed after								
	24h			48h			Mean		
100	68	(8.30)	**68.0**	95	(9.79)	**95.0**	82	(9.05)	**82.0**
200	157	(12.57)	**78.5**	187	(13.69)	**93.5**	172	(13.13)	**86.0**
400	313	(17.73)	**78.2**	372	(19.30)	**93.0**	343	(18.51)	**85.6**
800	404	(20.10)	**50.5**	653	(25.55)	**81.6**	529	(22.83)	**66.0**
1600	523	(22.88)	**32.6**	1063	(32.61)	**66.4**	793	(27.75)	**49.5**
Mean	293	(16.32)	**61.5**	474	(20.19)	**86.0**			

CD at 5% for:
Density = 0.52, Time = 0.33, Density × Time = 0.74
Each observation is mean of 4 replications Value in parentheses indicate square root transformations
Figures in bold represent the % consumption

The data on the effect of different prey density levels (100, 200, 400, 800 and 1600) of *Aphelenchoides swarupi* on the predation efficiency of *F. composticola* are presented in Table 4.9 which revealed that the number of prey consumed increased with the increase in prey density level. After 24 hours of release, *F. composticola* consumed maximum (22.46) of *A. swarupi* at 1600 inoculum level and minimum (7.66) at 100 inoculum level. The percent consumption was maximum (74.0) at 200 prey density level and minimum (31.5) at 1600 prey density level. The number of consumption at all inoculum levels were highly different significantly.

The observation after 48 hours of release showed that the population of prey consumed was maximum (31.07) at 1600 prey density level and minimum (9.64) at 100 prey density level. The per cent consumption was highest (92.0) at 100 inoculum level and minimum (60.3) at 1600 inoculum level. However, at all inoculum levels, the prey consumption was significantly different. The population consumed by *F. composticola* was minimum (8.65) when the level of prey density was kept at 100 per plate and maximum

(26.77) was recorded at the highest level i. e., 1600 per plate. The number of preys consumed at all five prey density levels was significantly different. Irrespective of prey density levels, the preys consumed after 48 h was higher (19.61) than that after 24 h (15.68). The per cent consumption was also higher after 48 hours (82.0) than after 24 hours (56.0). Although there was increase in the rate of consumption of prey by *F. composticola* with the increase in prey density levels, the consumption percentage was minimum (46) at 1600 prey density and maximum at 200 (82) prey density. At all prey density levels, the percentage consumption after 48 h was higher than after 24 h.

Table 4.9. Effect of prey density of *Aphelenchoides swarupi* on the preying capacity of *Fictor composticola*

Prey density	Population consumed after		
	24h	48h	Mean
100	58 (7.66) **58.0**	92 (9.64) **92.0**	75 (8.65) **75.0**
200	148 (12.18) **74.0**	179 (13.41) **89.5**	163.5 (12.8) **81.7**
400	282 (16.81) **70.5**	354 (18.33) **88.5**	318 (17.82) **80.0**
800	371 (19.27) **46.3**	629 (25.09) **78.6**	500 (22.18) **62.0**
1600	504 (22.46) **31.5**	965 (31.07) **60.3**	735 (26.77) **46.0**
Mean	273 (15.68) **56.0**	444 (19.61) **82.0**	

CD at 5% for:
Density = 0.35, Time (D) = 0.22, Density × Time = 0.50
Each observation is mean of 4 replications Value in parentheses indicate square root transformations
Figures in bold represent the % consumption

The data recorded on the predation efficiency of *F. composticola* at different prey density levels (100, 200, 400, 800 and 1600) of *Panagrolaimus* sp. are presented in Table 4.10. The consumption of *Panagrolaimus* sp. was highest (21.24) at 1600 prey density level and minimum (6.52) at lowest (100) prey density level but, it was not the same when the per cent consumption was calculated. It was highest (70.5 %) at 200 prey density level and lowest (28.0 %) at 1600 level although the consumption at all prey density levels were different significantly.

After 48 hours of release, the consumption of *Panagrolaimus* sp. was highest (28.02) at 1600 inoculum level and minimum (9.21) at 100 level while the per cent consumption was highest (84.0) when *F. composticola* was released with 100 preys per plate and lowest (49.0) when it was released with 1600 preys per plate. However, the consumption data at all inoculum levels were different significantly.

The data clearly show that with the increase in prey density levels, the mean prey consumption by *F. composticola* was also increased. The prey consumption at all prey density

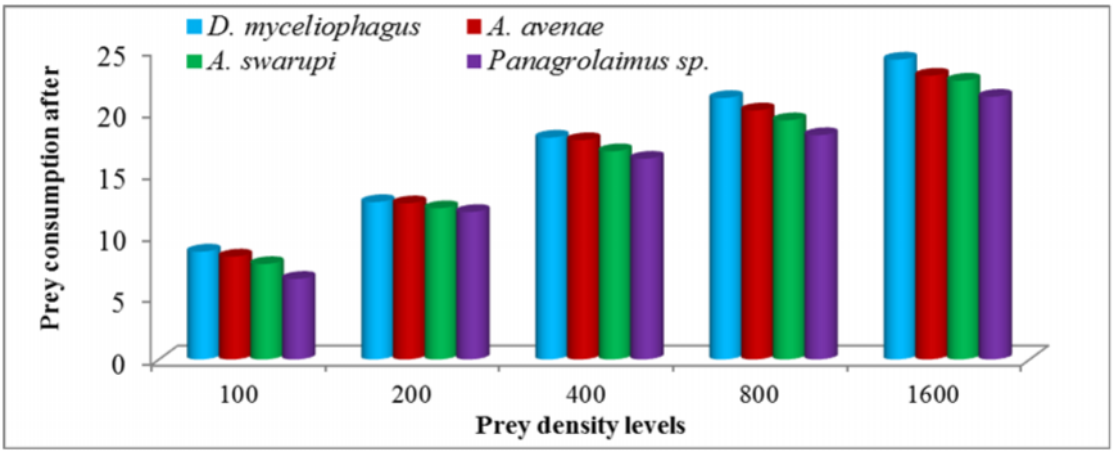


Fig. 4.15. Prey consumption by *Fictor composticola* on *Aphelenchus avenae, Aphelenchoides swarupi, Ditylenchus myceliophagus* and *Panagrolaimus* sp. at different prey density levels after 24 hours

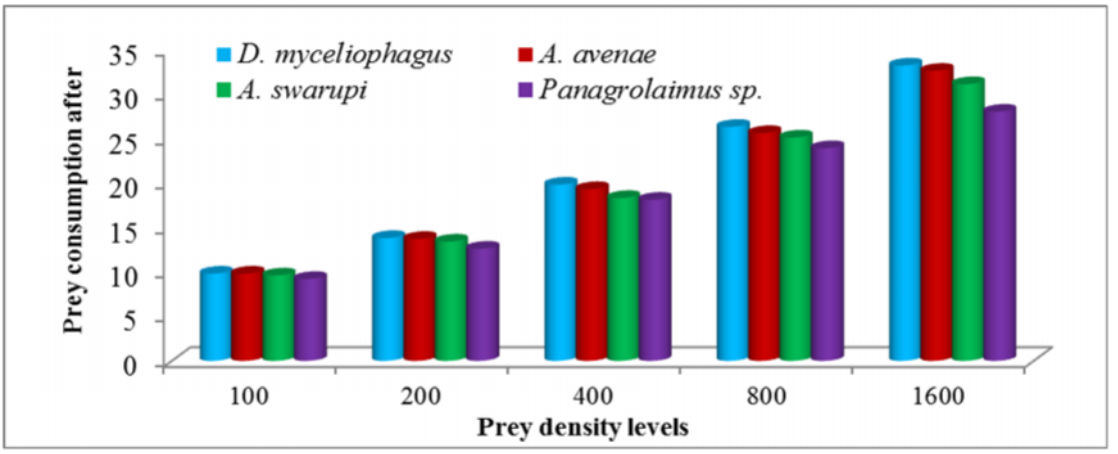


Fig. 4.16. Prey consumption by *Fictor composticola* on *Aphelenchus avenae, Aphelenchoides swarupi, Ditylenchus myceliophagus* and *Panagrolaimus* sp. at different prey density levels after 48 hours

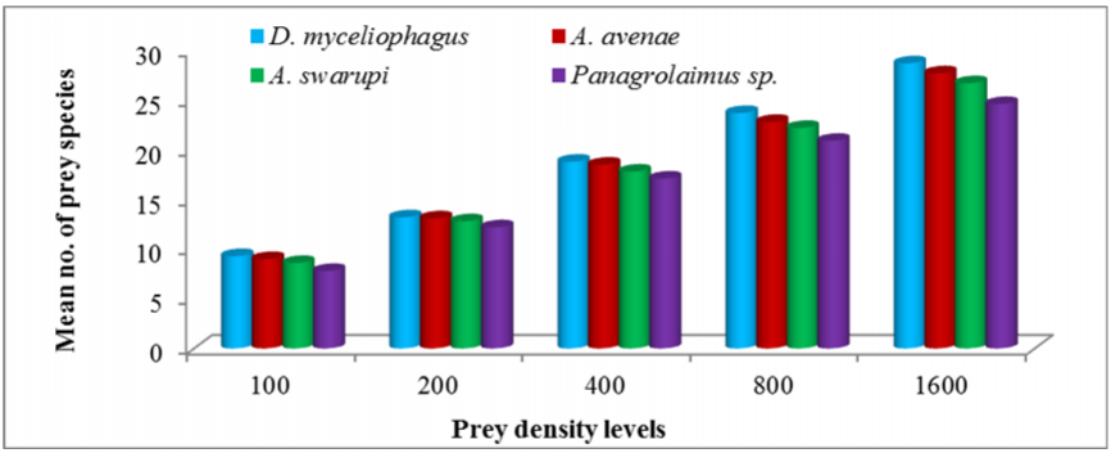


Fig.4.17. Mean prey consumption by *Fictor composticola* on *Aphelenchus avenae, Aphelenchoides swarupi, Ditylenchus myceliophagus* and *Panagrolaimus* sp. at different prey density levels

levels differed significantly. Similar trends of prey consumption were found at both periods of observation (Table 4.10). The prey consumption after 48 h was more (18.34) than 24 h (14.8). The per cent consumption was also higher after 48 h (72.7) than after 24 h (49.4). The mean prey consumption was maximum (24.63) at 1600 prey density and minimum (7.86) at 100 prey density. But, the per cent consumption was minimum (38.5 %) at 1600 prey density and maximum (74.5) at 200 prey density level.

Table 4.10. Effect of prey density of *Panagrolaimus* sp. on the preying capacity of *Fictor composticola*

Prey density	Population consumed after		
	24h	48h	Mean
100	42 (6.52) **42.0**	84 (9.21) **84.0**	63 (7.86) **63.0**
200	141 (11.92) **70.5**	157 (12.56) **78.5**	149 (12.24) **74.5**
400	263 (16.23) **65.7**	325 (18.06) **81.2**	294 (17.14) **73.4**
800	326 (18.08) **40.7**	569 (23.86) **71.1**	448 (20.97) **56.0**
1600	450 (21.24) **28.0**	785 (28.02) **49.0**	618 (24.63) **38.5**
Mean	244 (14.80) **49.4**	384 (18.34) **72.7**	

CD at 5% for:
Density = 0.50, Time = 0.32, Density × Time = 0.71
Each observation is mean of 4 replications
Value in parentheses indicate square root transformations
Figures in bold represent the % consumption

The Figure 4.15 presents the prey consumption by *F. composticola* on different preys after 24 hours of release. Although the prey consumption increased with the increase in prey density levels, the maximum consumption was at 200 prey density level in all the four prey nematode species (81 % in *D. myceliophagus*, 78.5 % in *A. avenae*, 74 % in *A. swarupi* and 70.5 % in *Panagrolaimus* sp.). The maximum consumption per cent was found when *F. composticola* was released with *D. myceliophagus* and minimum in case of *Panagrolaimus* sp. although there was very little difference.

The Figure 4.16 presents the consumption of preys by *F. composticola* after 48 hours. Here, the data show that the maximum prey consumption was at the prey density level, 100 per plate for the three prey nematode species, *A. avenae, A. swarupi,* and *Panagrolaimus* sp. except in *D. myceliophagus* where the maximum consumption (97.5 %) was at 400 prey density level. The prey consumption increased with the increase in prey density levels and the prey consumption was significantly diffrerent from each other.

The data on mean prey consumption by *F. composticola* on *A. avenae, A. swarupi, D. myceliophagus* and *Panagrolaimus* sp. are presented in Fig. 4.17. These data show that the rate of prey consumption by *F. composticola* was the lowest in *Panagrolaimus* sp. (24.63)

and the highest (28.72) in *D. myceliophagus*. Rate of prey consumption by *F. composticola* for different prey nematodes was *D. myceliophagus* > *A. avenae* > *A. swarupi* > *Panagrolaimus* sp. There was an increase in rate of consumption with the increase in prey density levels. There was minimum difference in the mean populations of all the five prey species at the inoculum level of 200 prey individuals per plate and maximum when 1600 prey individuals were inoculated per plate.

4.5. Survival of *Fictor composticola* in agar plates

4.5.1. During April to June 2015 (27.8 to 33.4 °C)

This experiment was done under two conditions (sets), (i) By adding 2-3 drops of water at every observation and (ii) without adding water. The data on population recorded are presented in Fig. 4.18. The data show that the population of *F. composticola* decreased in first five days and this decrease in set with moisture was less (35) than in set without moisture (46). After 5 days, the number increased sharply up to 15 days (76 and 99 with water) and in set without water, it again decreased to 37 after 10 days and then increased sharply to 77. But, after 20 and 25 days, there was a sharp decline in number of *F. composticola* was observed in both the sets (82 and 43 with water , 54 and 32 without water) with the increase in laboratory temperature, which was 31.8 °C.

After 30 days of release, the population shoot up sharply in plates with moisture (74) but slight increase was found in plates without moisture (38). In the next observation (35 days), the population of *F. composticola* declined sharply (51) in plates with moisture but it slightly increased (41) in plates without moisture and after this, the population of *F. composticola* slowly decreased to zero after 65 days in the set where water was not added whereas the trend was different in set with moisture. It fluctuated up to 60 days and then it continuously decreased to zero after 75 days even if the room temperature was almost same. *F. composticola* survived up to 60 and 70 days in plates without moisture and with moisture, respectively.

4.5.2. During February to April (15.6 to 26.7 °C)

This experiment was done at room temperature (RT) and at 25 °C in BOD. The data (Fig. 4.19) show that in first five days, the number of *F. composticola* declined sharply to 30 (at RT, 15.6 °C) and 28 (at 25 °C). At room temperature, the population further declined sharply to 6 but at 25 °C it declined only to 22. After that the population increased slightly in both sets (14 at RT and 24 at 25 °C). After 20 days, the number of *F. composticola* recorded was 159 at RT which shows a sharp increase while there was only a slight increase (28.5) in the set at 25 °C. The number again decreased slightly to 116 at RT and 28 at 25 °C after 25 days.

But, at next observation (after 30 days), the population declined sharply to 45 at RT but showed slight increase (34) at 25 °C. The population again shoot up to 74 and declined to 50 (at RT) after 35 and 45 days, respectively while there was decrease (31) and then increase (42) at

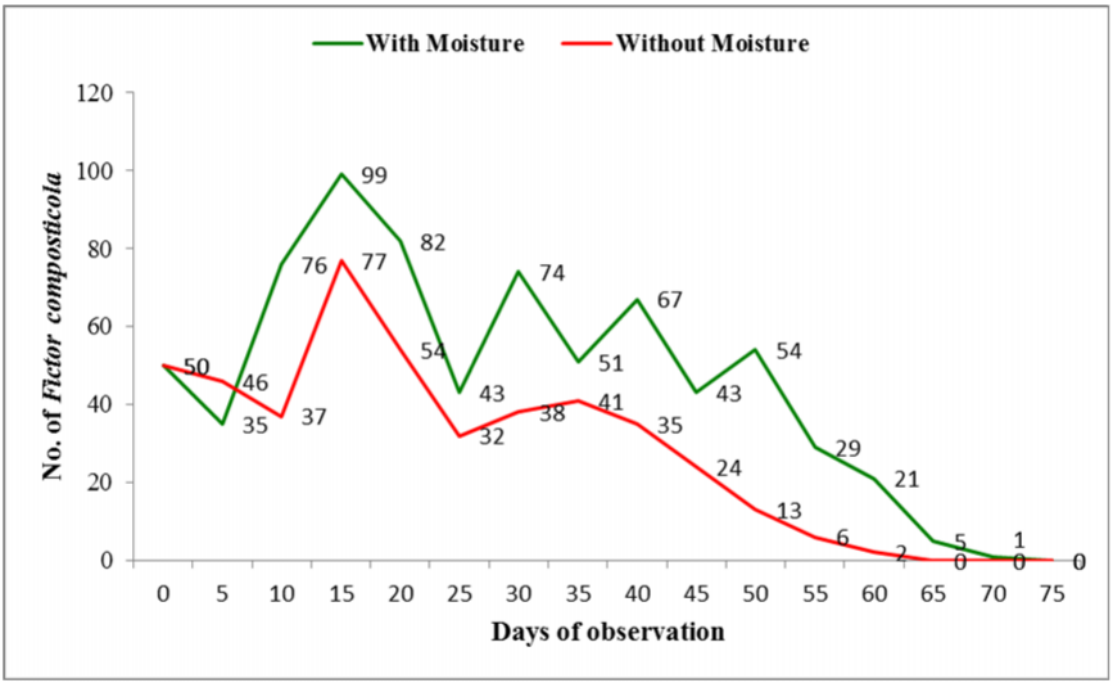


Fig. 4.18. Population of *Fictor composticola* in agar plates with and without moisture at room temperature from April to June 2015

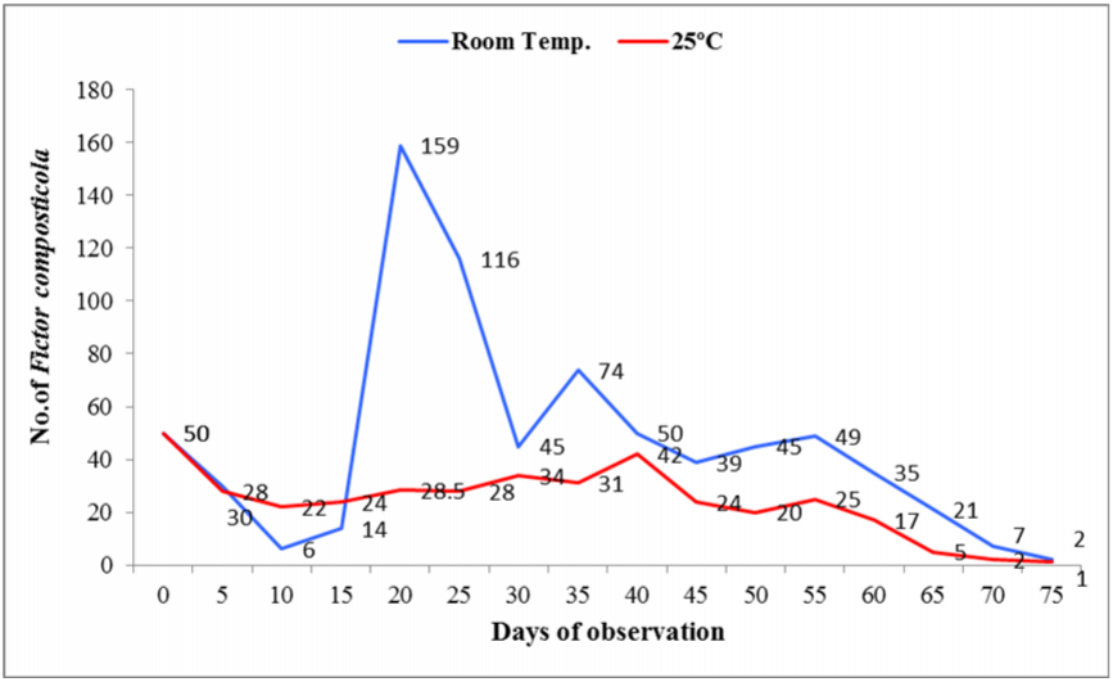


Fig. 4.19. Population of *Fictor composticola* in agar plates at room temperature (February to April 2015) and at 25 ℃.

25 °C after 35 and 45 days, respectively. After 45 to 55 days, there was a slow increase in population of *F. composticola* (39 to 49) at RT when the temperature ranged from 21 °C to 22.5 °C. At 25 °C set (constant temperature), the population did not show much fluctuation at these observations (24 to 25). But, at RT after 55 days, the population declined and reached to only two after 75 days when there was slight increase in temperature (22.5 to 26.7 °C). Similarly, at 25 °C, the population of *F. composticola* reached to one after 75 days. Although there was a great fluctuation in number in set which was kept at room temperature, the population almost remained the same in case of 25 °C set up to 60 days and after 60 days, a decline in number of *F. composticola* was observed in both the sets.

The posture of nematodes in agar plates changed with passage of time. First, its activity slowed down subsequently then its body became transluscent (Plate 15). They became motionless but responded to the touch with a nematode pick.

4.6. Survival of *Fictor composticola* in spent mushroom compost

This experiment was conducted under two situations, i. e., indoor (in bags) and outdoor (heap). Compost infested with *F. composticola* was taken and the nematodes were recovered after every 15 days. In indoor condition, the spent mushroom compost was stored in one kg capacity polythene bags (PB) and cloth bags (CB) in mushroom laboratory of the Department of Nematology, CCS HAU, Hisar. The population data on *F. composticola* recovered in both types of bags are presented in Fig. 4.20 and moisture content in Annexure I. The data show that, after first 15 days, there was a sharp decline in population in both types of bags (9.36 in cloth bags and 32.95 in polythene bags).

The decline in cloth bags was more than in polythene bags and the moisture was 16.96 and 34.49 in cloth bags and polythene bags, respectively at this time of observation (Annexure I). After 30 days of storing, the population declined to 2.79 and 20.3 in cloth bags and polybags, respectively. In cloth bags, the population recovered after 30, 45 and 60 days were similar. In polythene bags, it decreased to 13.78, 1.91 and 1.52 after 45, 60 and 75 days, respectively. After 90 days, *F. composticola* was not recovered from any type of bag. The data show that the population of *F. composticola* recovered in polythene bags was higher up to 60 days than in cloth bags. After 75 days, the population recovered was same (1.52).

4.6.1. Survival of *Fictor composticola* in compost heap stored in outdoor condition

Survival of *F. composticola* was studied in the compost heap left in open field during May to September 2015. The population of *F. composticola* and other nematodes extracted after every 15 days, are presented in Fig. 4.21. The initial population of *F. composticola* (18.73 per 200 cc compost) decreased to 13.23 after first 15 days. The initial moisture content was 72.57 % in the compost. The population of *F. composticola* after 75 and 105 days was almost the same (10.72 and 10.61, respectively). The population was maximum (34.52) after 30 days of storing the compost and the moisture content of the compost was 33.16 % at this

time (annexure II). The minimum population of *F. composticola* (3.51) was recovered after 90 days.

Populations of other nematodes in the compost sample (Fig 4.21) were also recorded. During the whole period of observations *F. composticola* and other nematodes extracted were in active state. Other nematodes included mainly *Aphelenchoides* sp., *Ditylenchus* sp., *Panagrolaimus* sp., *Bursilla* sp. and some Aerolaimids. Their total population ranged from 5.91 to 114.98 per 200 cc compost. Up to 90 days the population of other nematodes increased slowly (5.91 to 57.25) but in the next 15 days, there was a steep increase (106.36) in population (Fig. 4.21). Again there was a sharp decline after 120 days (74.94) while it increased to 114.98 after 135 days and again declined to 98.98 after 150 days. The maximum population of other nematodes was found after 135 days. The population of *F. composticola* at this time was minimum (3.51). It was also observed after 75 days that when number of *F. composticola* increased the number of other nematodes decreased.

The posture of *F. composticola* recovered from spent mushroom compost processed through sugar centrifugal flotation technique was distorted and disintegrated but not coiled (Plate 16).

4.7. Effect of neem seed kernel water extract (NSKWE) on *Fictor composticola*

The mortality of nematodes, *F. composticola* at 4%, 2% and 1% concentrations of NSKWE for 24 and 48 hours, is presented in Table 4.11 which revealed that the treatment where only sterile water was used with *F. composticola*, was significantly very different (lower) with the other three treatments. The mortality at different periods (24 and 48h) was non-significant. The treatments where NSKWE was used as 4%, 2% and 1% concentrations, were statistically at par. The mortality of *F. composticola* at 4%, 2% and 1% NSKWE was 99.24%, 99.24% and 99%, respectively. The interaction results between treatments and time periods was found non-significant.

Table 4.11 Number of *Fictor composticola* killed in different concentrations of neem seed kernel extract after 24 and 48 hours

Treatments	Number of *Fictor composticola* killed after					
	24h		48h		Mean	
4% NSKWE	49.75	(7.19)	49.5	(7.16)	49.62	(7.17)
2% NSKWE	49.5	(7.17)	49.75	(7.19)	49.62	(7.18)
1% NSKWE	49.75	(7.19)	49.25	(7.16)	49.5	(7.17)
Sterile water	0.0	(1.41)	0.0	(1.41)	0.0	(1.41)
Mean	37.25	(5.74)	37.12	(5.73)		

CD @ 5%
Treatment (T) = 0.04 Period (P) = NS Interaction (T×P) = NS
The data in parentheses represent square root transformed values

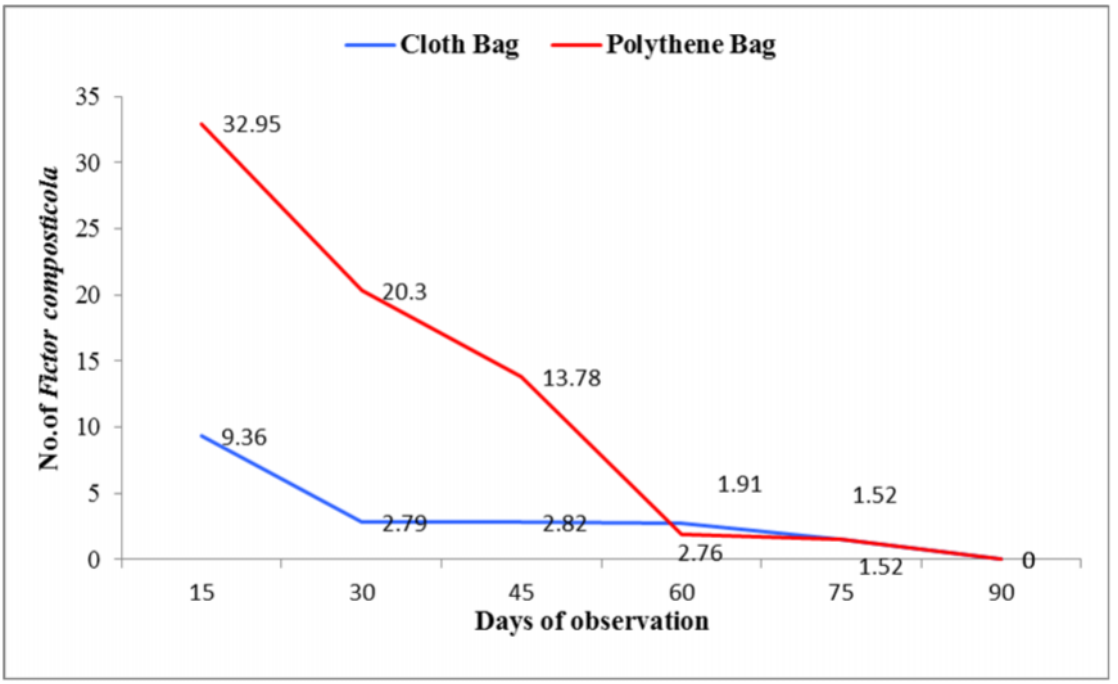


Fig. 4.20. Population of *Fictor composticola* in polythene bags and cloth bags from April to September 2015

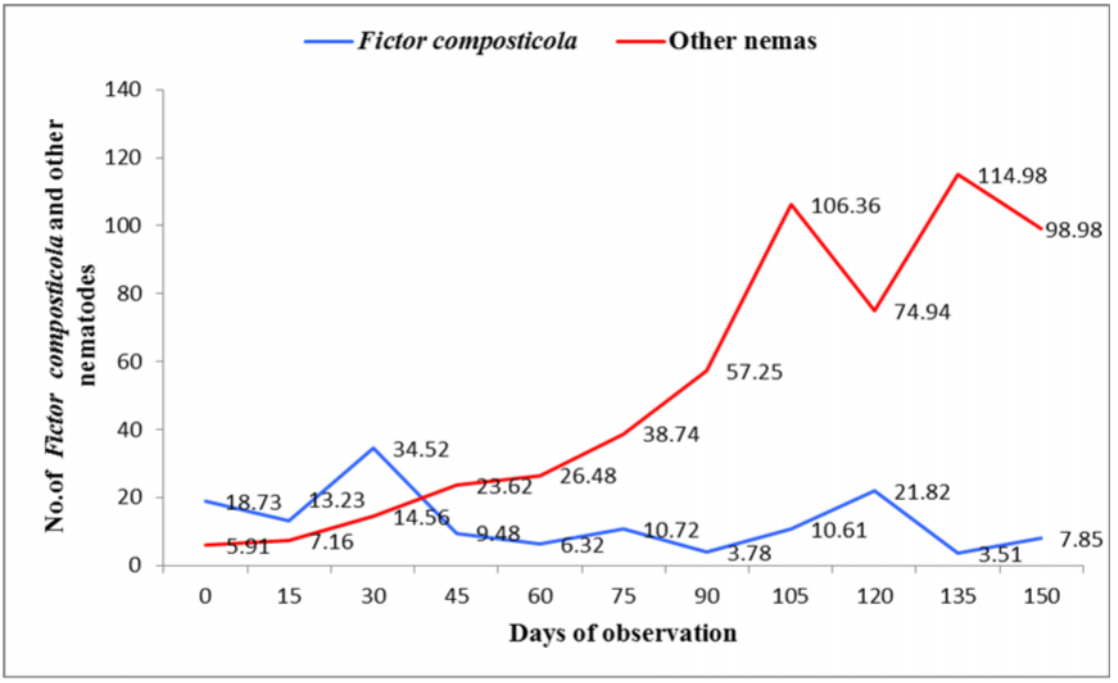


Fig. 4.21. Population of *Fictor composticola* and other nematodes (square root transformed values) in heap of spent mushroom compost (May to September 2015)

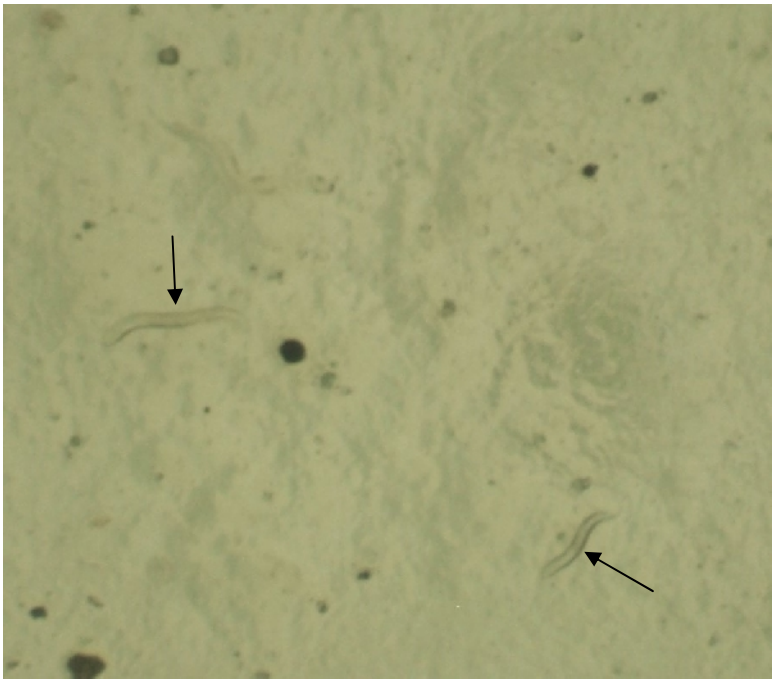


Plate 15: *Fictor composticola* (arrow) drying in agar plate

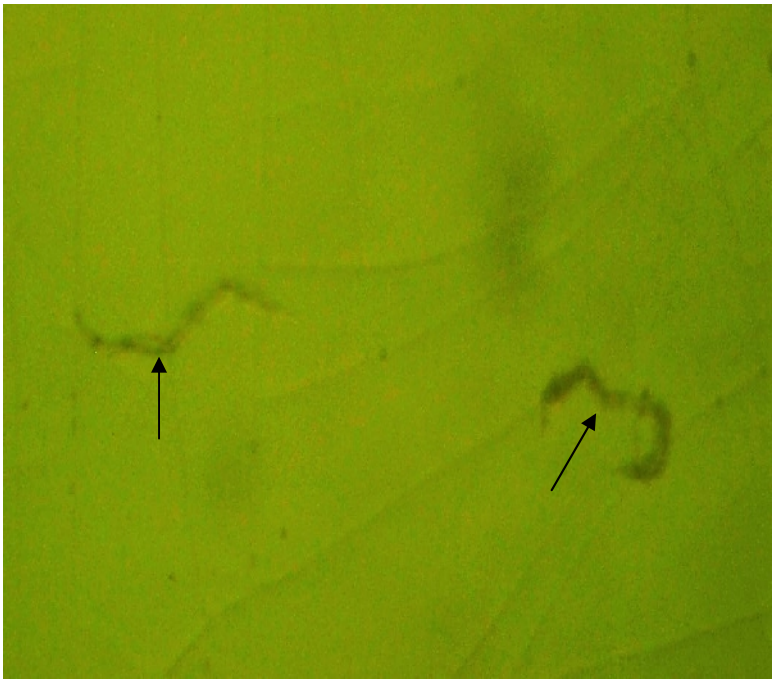


Plate 16: *Fictor composticola* (arrow) recovered from spent mushroom compost

4.8. Management of *Aphelenchoides swarupi* by *Fictor composticola* in button mushroom (*Agaricus bisporus*)

4.8.1. Management of *Aphelenchoides swarupi* by *Fictor composticola* in half kg compost bags

In half kg bags of button mushroom compost, the population of *A. swarupi* was found maximum (55.34) when it was inoculated at spawning and predator at casing. The reproduction factor in this case was 153.5 which, was maximum of all the treatments where *A. swarupi* was inoculated. No significant difference in the mean population of *F. composticola* in the treatments was observed where the prey and predator were inoculated at casing (13.37) or prey at casing and predator at spawning (11.81).

The treatments where the prey and predator were inoculated at spawning (41.26) and prey at spawning and predator at casing (55.34), have significantly higher population of *A. swarupi* than the other two treatments (Table 4.12). The reproduction factor was minimum (6.9) when prey was inoculated at casing and predator at spawning. The spawn run was poor in the treatment where the prey was inoculated at spawning and predator at casing, moderate in the treatment where prey and predator both were inoculated at spawning while it was good in the rest three treatments.

Table 4.12. Population of *Aphelenchoides swarupi* and spawn run in half kg compost bags

Treatments	Population of *A. swarupi* (200 cc compost)	Rf	Spawn run
Prey and predator at spawning	1704.5 (41.26)	85.2	Moderate
Prey and predator at casing	180.5 (13.37)	9.0	Good
Prey at casing and predator at spawning	138.75 (11.81)	6.9	Good
Prey at spawning and predator at casing	3069.75 (55.34)	153.5	Poor
Uninoculated control	-	-	Good
CD at 5%	(3.27)	-	-

Number of nematodes inoculated : Prey : 50 per bag Predator : 6 (3 females & 3males) per bag
The figures in parentheses are square root transformed values

4.8.2. Management of *Aphelenchoides swarupi* by *Fictor composticola* in five kg compost bags

In this experiment, the population recovered after the harvest of the crop, was maximum (55.23) when the prey was inoculated at spawning and predator at casing, and minimum (29.76) when the time of inoculation was reversed for both the prey and predator. The population of *A. swarupi* recovered after harvest was significantly higher in treatments where prey and predator were inoculated at spawning (44.39) and when prey was inoculated at spawning and predator at casing (55.23) than the treatments where prey and predator were inoculated at casing (35.7) and when prey was inoculated at spawning and predator at casing (29.76) (Table 4.13).

Table 4.13.Population of *Aphelenchoides swarupi*, spawn run and yield in 5 kg compost bags

Treatments	Population of *A. swarupi* (200 cc compost)	Rf	Spawn run	Yield per bag (g)	reduction in yield (%)
Prey and predator at spawning	2006.25 (44.39)	100.31	Moderate	540	50.0
Prey and predator at casing	1279.0 (35.70)	63.95	Good	625	25.6
Prey at casing and predator at spawning	890.25 (29.76)	44.51	Good	720	14.3
Prey at spawning and predator at casing	3055.5 (55.23)	152.77	Poor	327.5	60.7
Uninoculated control	-	-	Good	840	-
CD at 5%	(6.46)	-	-	14.56	-

Number of nematodes inoculated : Prey : 500 per bag Predator : 50 per bag
The figures in parentheses are square root transformed values

The reproduction factor was maximum (152.77) among all the treatments, when prey was inoculated at spawning and predator at casing. In this treatment, the spawn run was also poor. Spawn run was moderate when both prey and predator were inoculated at spawning. It was found good in the treatments where prey and predator were inoculated at spawning, and prey at casing with predator at spawning. Significant reduction in the mean weight of buttons between treated and control bags also occurred (Table 4.13). The maximum yield reduction (60.7 %) was recorded when the prey was inoculated at spawning and predator at casing and the minimum (14.3 %) when the prey was inoculated at casing and predator at spawning. Population of *F. composticola* was not recovered at the time of termination of experiment.

CHAPTER-V

DISCUSSION

In this chapter, results obtained on the prey range, prey preference, predation behaviour and survival of *Fictor composticola* and management of *Aphelenchoides swarupi* by *F. composticola* are discussed. The results obtained on the various aspects of this study have been compared with the findings of earlier workers.

5.1. Prey range of *Fictor composticola*

The predatory nematodes are voracious feeders on several prey nematode species. The prey range of *F. composticola* was tested on different groups of nematodes like mycophagous, microbivorous, predatory nematodes and plant parasitic nematodes. It preyed upon all the nematode species tested although the number of prey nematodes consumed differed with different groups and at different periods of time. Similar results were obtained by Bilgrami and Jairajpuri (1989) when they studied the prey range of *Mononchoides longicaudatus* and *M. fortidens* on juveniles of plant parasitic nematodes, ectoparasitic nematodes and free living nematodes. Both the predators fed on all the prey species.

In the present investigation, the mycophgous nematodes were consumed more than the plant parasitic nematodes and predatory nematodes. The per cent prey consumption ranged from 32.7 (*Panagrolaimus* sp.) to 73.3 (*Ditylenchus myceliophagus*) after 24 hours. After 48 hours, it ranged from 52.3 (*Rhabdolaimus* sp.) to 95.7 % (*D. myceliophagus*). After 72 hours the per cent consumption ranged from 26.3 (*Panagrolaimus* sp.) to 99.0 (*Aphelenchus avenae* and *D. myceliophagus*) and the number of *A. avenae* and *D. myceliophagus* was almost finished in plates.

After 96 hours, the populations of *Aphelenchoides swarupi* and Aerolaimid were also totally consumed. Bajaj and Kanwar (2015) also reported the results where the mycophagous nematodes (*A. swarupi, A. asterocaudatus, A. avenae* and *A. radicicolus*) were consumed 100 % after 8 days, by *F. composticola*. It also fed upon *Mesorhabditis* sp., *Bursilla* sp. and *Panagrolaimus* sp. and the second stage juveniles of plant parasitic nematodes (*Heterodera avenae, H. cajani, H. sorghi, H. zeae, Meloidogyne incognita, Tylenchulus semipenetrans*).

In present study, the prey nematode species *Bursilla* sp. and *Panagrolaimus* sp. were consumed less than the mycophagous, plant parasitic and other microbivorous nematodes. The prey range of predatory nematodes depends on their feeding habits which varies in different groups. Thus they may show variation in their prey preferences.

Although the predatory nematodes (*Aporcelaimium* sp. and *Nygolaimus harishi*) taken as prey here, were consumed by *F*. composticola, whether these preys were also feeding on *F*. composticola, it was not recorded during the experiment. The predation in *F. composticola* was found due to chance encounter as also suggested by Nelmes (1974), Cohn and Mordechai (1974), Grootaert and Maertens (1976), Bilgrami *et al*. (1983, 1984) in other predators.

5.2. Prey preference of *Fictor composticola*

Host preference is a key feature for selection of a biological control candidate. A broad or indiscriminate prey range can be an undesirable feature in a biocontrol agent intended for field release. Conversely, highly specific natural enemies present limitations in having utility against fewer target pests and also tending to be difficult to mass culture. In this study, the mycophagous and microbivorous nematodes were tested for preference of *F. composticola* in combinations of two, three and four nematode species. It was found that *F. composticola* preferred mycophagous nematodes over the microbivorous nematodes (Figs. 4.1 to 4.12). Amongst the mycophagous nematodes, the most preferred prey was *D. myceliophagus* followed by *A. avenae* and *A. swarupi*.

Bilgrami and Kulshreshtha (1993) found that the predatory nematode, *Mylonchulus dentatus* exhibited prey preference on second stage juveniles of endoparasitic nematodes, *M. incognita, T. semipenetrans, H. mothi* and *Anguina tritici* over the ectoparasitic prey species tested. The preferential behaviour of *F. composticola* may be attributed to the lack of anti-predation adaptation of the prey nematode species tested. The mycophagous nematodes lack the characteristics which provide resistance against predation (Bilgrami and Jairajpuri 1989, Bilgrami 1990, Jairajpuri and Bilgrami 1990).

The diplogasterid predators have the capacity to discriminate among prey species (Bilgrami and Jairajpuri 1989, Chitamber and Noffsinger 1989). The microbivorous nematodes, *Bursilla* sp. and *Panagrolaimus* sp., in present study were consumed less and their population also increased. Their high number in the plates after 48, 72 and 96 hours of release seems due to their multiplication rate exceeding their consumption. Their high mobility might have helped them to escape the predation. Preferential behaviour was also observed by Shafqat *et al.* (1987), Bilgrami and Jairajpuri (1983, 1989), Bilgrami (1992).

The preference was also shown by *Mononchoides gaugleri* when it highly preferred juveniles of *M. incognita, H. mothi* and *A. tritici* than the adults of *Hirschmaniella oryzae, Tylenchorhynchus mashhoodi, Xiphinema americanum, Paratrichodorus christiei, Longidorus attenuatus, Helicotylenchus indicus, Hemicriconemoides mangiferae* and *Hoplolaimus indicus* (Bilgrami *et al.* 2004).

The food preference was also reported by *Paractinolaimus elongatus* which preferred second stage juveniles of *M. incognita* to a maximum extent followed by *A. tritici* but, the adults of *T. mashhoodi* and *H. oryzae* were preferred moderately while *Hoplolaimus indicus, X. basiri* and *Longidorus* sp., the least.

The differences in attack could be attributed to the size and type of prey and the activity of the predators and prey, as also to the physical and behavioural characteristics of the prey that may determine resistance or susceptibility of the prey nematodes to predation (Grootaert *et al.* 1977, Small and Grootaert 1983, Esser 1987, Jairajpuri *et al.* 1990, Khan *et al.* 1995). Prey selectivity was also reported in *Butlerius* and *Mononchoides* sp. (Grootaert *et al.* 1977, Bilgrami and Jairajpuri 1989, Bilgrami *et al* 2005), where juveniles of endoparasitic nematodes were preferred over ectoparasitic species.

5.3. Predation behaviour of *Fictor composticola*

The predatory nematodes possess different mechanisms to overpower their prey and to feed upon them. Similarly, the prey nematodes also have characteristics, hereditary or acquired, to defend themselves from predation (Bilgrami 1990, Jairajpuri and Bilgrami 1990). Prey was attacked more frequently when the head of the predator made full contact with the prey, than when there were glancing contacts.

Male *F. composticola* had more number of encounters on the prey nematode species than the females. It may be because the males did not feed continuously on one prey but they roamed here and there and left many preys without wounding them but females mostly fed on the first encountered preys (70 %) continuously. The juveniles of the prey species were preferred more by both male and female *F. composticola,* than the adults. The juveniles are small in size and have soft cuticle, so they are more vulnerable to attack.

The posterior part of the prey body was the most attacked part by both male and female *F. composticola.* This may be because the posterior part has less mobility and hence show less resistance to predation. The per cent of injured prey nematodes in case of female predator was less than the male predator. The males encountered more prey species but in most of the cases, the preys escaped after probing while females in 80 % chances, grasped the first prey, killed and completely consumed it.

The feeding duration of males was less (2 min. 31 sec in *A. swarupi,* 5 min. 42 sec in *D. myceliophagus,* 8 min 4 sec in *A. avenae* to 8 min 56 sec in *A. swarupi*) than the females (Tables 4.5 and 4.6). Feeding time required to consume an individual depended upon the size of the prey. Bilgrami (1995) reported that it was maximum on *Paralongidorus citri* and minimum on *Cephalobus* sp. The body cuticle, cuticle texture, quality, quantity and chemical composition of prey contents also influenced feeding by predators on different preys (Bilgrami 1995).

Probing before attack was seen in case of *F. composticola,* which has been described by Grootaert and Wyss (1979). In assessing the effect of predatory nematodes on prey nematode populations the ability to wound the prey, is the important determinant. *F. composticola* fed the nematodes by cutting and sucking the prey body. A wounded prey loses the pressure of the hydrostatic skeleton and hence, locomotion is seriously affected. The lower strike rate in case of *Bursilla* sp. and *Panagrolaimus* sp. (Fig. 4.13) may be due to their active body undulations and vigorous escape response as observed by Small and Grootaert (1983) in *Rhabditis oxycerca, Pelodera* sp. and *Plectus* sp. These nematodes have the characteristics providing resistance against predation.

Strike rate of male and female *F. composticola* on mycophagous nematodes was higher than on the microbivorous nematodes (Fig. 4.13). Similar results were obtained by Bilgrami (1992, 1995) in the dorylaimid predator, *Mesodorylaimus bastiani* which had higher strike rate on endoparasitic nematodes than the ectoparasitic, saprophagous and predacious nematodes. The female *F. composticola* showed higher strike rate than the male *F. composticola,* on all the prey nematode species. This may be due to more energy/food requirement by the female for the reproduction process.

The prey susceptibility of mycophagous nematodes to *F. composticola* was higher than the free living nematodes (Fig.4.14). The high susceptibility may be due to their slow rate of movement (Bilgrami *et al.* 1983) and thin body cuticle as they lack anti-predation devices (Small and Grootaert 1983). In the present study, the high degree of susceptibility of mycophagous nematodes, *A. avenae, A. swarupi* and *D. myceliophagus* may be attributed to their relatively soft and smooth body cuticles which are easily pierced. The lack of their anti-predation characteristics such as thick cuticle, annulations, sheath and rapid escape also contribute to their high predation (Khan *et al.* 1994). Higher prey susceptibility in endoparasitic nematodes than in the predaceous and ectoparasitic nematodes has been reported by Bilgrami (1995).

5.4. Effect of prey density on the predation efficiency of *Fictor composticola*

Biological control agents that show density-dependent relationships with prey are the most valued because they are most likely to stabilise pest populations. In the present investigation, the prey nematode species consumed by *F. composticola* increased as the prey density increased from 100 to 1600 per plate. The per cent consumption of the preys was maximum when the prey density was 200 or 400, in different prey species and the minimum at prey density 1600 per plate (Tables 4.7 - 4.10). Theoretically, the increase in the number of prey should also increase the probability of contacts and consequently the rate of predation. But, it was not so practically when the experiments were conducted at different prey density levels.

In the present sudy, an increase in the number of prey significantly increased the consumption but not the per cent consumption. These observations are supported by earlier findings (Bilgrami *et al*. 1985, Yeates 1969, Bilgrami and Jairajpuri 1989) indicating increasing population of prey increased rate of predation by *Mylonchulus dentatus* in and the predation depended on the number of prey. This increased predation may be attributed to increased chances of contacts between predator and prey at higher densities. Similar results were obtained by Bilgrami and Kulshreshtha (1993) who found that more preys were killed by the predatory nematode, *Mylonchulus dentatus* when prey population was increased from 25 to 200 individuals. Maximum predation occurred in a population of 200 prey individuals and minimum in 25 individuals.

The predators, *Enoploides longispiculosus* (Moens *et al*. 2000) and *Adoncholaimus fuscus* showed strong prey density-dependent predation rates. A maximal predation rate on 4 monhysterid prey nematodes, for each predator per 24 hour was found in *E. longispiculosus* at prey densities of 200 individuals per Petri dish. The higher predation rate may be because at higher densities, there was more predator-prey encounters, resulting in reduced search duration, increased predation, and increased feeding duration.

Predation rate often depends on chance encounter and thus density dependent (Yeates 1969, Osman 1988, Bilgrami 1993). Bilgrami *et al.* (2005) also reported that the predation of *Mononchoides gaugleri* was density depended. The feeding duration was positively correlated with prey density, being shortest at densities of 25-50 and longest at densities of 225-250. In the present study, the predation rate differed with the prey species, maximum being on *D. myceliophagus* (Table 4.7) and minimum on *Panagrolaimus* sp. (Table 4.10).

Environmental factors such as temperature, moisture, pH, soil type etc. affect the predation rate and predation efficiency of predators. Predation depends upon the type and activity of prey (Bilgrami *et al.* 1983), type of body cuticle, annulations, body secretions and other behavioural patterns (Bilgrami and Jairajpuri 1989). The other factors governing the predation rate are, age of predators (Yeates 1969, Jairajpuri and Bilgrami 1990), prey density, temperature (Bilgrami *et al.* 1984, 1985), starvation of predators (Khan *et al.* 1991, Kulshreshtha *et al.* 1993), seasonal fluctuations, soil conditions, soil pH and the chemical composition of soil etc. Bilgrami *et al*. (1984) while working with *Mononchus aquaticus* did not observe any effect of prey density on its rate of predation.

5.5. Survival of *Fictor composticola*

Temperature is an important environmental factor for organisms including nematodes. Different organisms have their own optimal temperatures for normal activities and high and low temperature limits they can tolerate. In nematodes, survival without food is also influenced by temperature because consumption of the reserved energy is dependent on

the level of activity which is affected by temperature. There is meagre information available on effect of temperature on the longevity of predatory nematodes.

In the present study, survival of *Fictor composticola* was studied (1) in agar plates at different temperatures with and without additional moisture in plates and (2) in spent mushroom compost, to get the information about its survival during off season. In spent mushroom compost, survival was studied in the compost stored in laboratory in bags, and in a heap in open.

5.5.1. Survival of *Fictor composticola* in agar plates

The results revealed that the number of predator at 25 °C showed little fluctuation up to 55 days whereas at room temperature, more fluctuations occurred in its population (Fig.4.19). After 20 days, the temperature remained almost constant up to 55 days ranging from 20 to 22 °C. The population of *F. composticola* in both sets, multiplied and showed alternate rise and fall up to 55 days.

After 55 days, the population in both the sets showed decline and vanished after 75 days. At room temperature, initially the temperature was low which was not favourable for *F. composticola* so the population declined in the next 10 days. These results are supported by Bajaj and Kanwar (2015) who found that *F. composticola* can not multiply at low temperature. After 15-20 days of release, when temperature increased to 18-20 °C, the population increased sharply from 14 to 159 per plate. This increase is attributed to favourable temperature which favoured its fast multiplication. Its number decreased to 116 in next five days. This was probably due to cannibalistic nature of *F. composticola* (Bajaj and Kanwar 2015) in absence of food leading to reduction in its population. Its population gradually declined to negligible after 70 and 75 days at 25 °C and room temperature, respectively.

Another experiment was done during April to June, 2015 when temperature ranged from 27.8 to 33.4 °C. This experiment was done with moisture and without additional moisture in plates. The nematode survived for 70 days in plates in which moisture was added but for 60 days in plates without moisture. The temperature at the initial observation was below 30 °C after which it ranged between 31-34 °C. During the whole observation period, population of *F. composticola* first decreased and then increased in both the sets up to 15 days. But, after 15 days, the population declined continuously in the set without moisture except a little increase after 30 and 35 days.

In the set with moisture, the population increased and decreased alternately at every observation up to 50 days. After 50 days, there was a continuous fall in number of predator in both sets. Moisture film is necessary for normal nematode activity (Wallace 1973) and therefore, moisture, relative humidity and related environmental factors directly affect

nematode survival. Water is an essential factor for biochemical reactions and plays an important role in the structure of biological macromolecules and membranes.

To cope with desiccation stress, nematodes have a limited option since they depend upon the presence of a film of water for their active movement. Another factor for the survival of *F. composticola* in the agar plates without food may be the presence of some bacteria in the agar plates that might have served as food for predator helping in its longer survival in plates with moisture. Such observations were also reported by Bar-Eyal *et al* (2008) in predatory nematode, *Koerneria sudhausi.*

F. composticola does not seem to undergo anhydrobiosis or in coiling stage as no such stages were recovered from compost or seen in agar plates. However, it became transluscent and size was reduced at the later stage of experiment in agar plates (Plate 15). Whether such nematodes can gain normal activity after getting moisture, remains to be seen. Low cuticular permeabilities appear to be a characteristic of nematodes exposed to harsh environments (Wharton *et al.* 1988).

When fourth stage larvae of *D. dipsaci* were exposed to desiccation there was marked reduction in the rate of water loss with a permeability slump occurring soon after the onset of desiccation (Wharton 1996). The permeability slump could result from a decrease in the depth of width of the cuticular annulations, which may represent more permeable areas of the cuticle (Wharton 1996, Wharton and Lemmon 1998). The permeability of the cuticle could decrease as it dried, slowing the rate of water loss of the body (Ellenby 1968, Perry 1977).

Coiling is a widespread response to desiccation in nematodes and has been described in a variety of plant parasitic and free-living nematodes. In some cases, coiling appears to be essential for survival (Womersley and Ching 1989). During desiccation structural and membrane activity is maintained and the cytoplasm become condensed. In *D. dipsaci* changes in the muscle cells were the most noticeable (Wharton and Barret 1985, Wharton and Lemmon 1998).

F. composticola is not able to survive at temperature below 15 °C while several other plant parasites and microbivorous nematodes can survive at this temperature. It seems to have some different mechanisms of survival and needs further studies.

5.5.2. Survival of *Fictor composticola* in spent mushroom compost

Survival of *F. composticola* in spent mushroom compost, was studied in cloth bags and polythene bags in mushroom laboratory, and in heap under outdoor conditions.

Results showed that the survival of *F. composticola* was better in polybags than in cloth bags (higher number of *F. composticola* was recovered in polybags and less number in cloth bags up to 60 days) (Fig. 4.20). This is attributed to higher moisture content in polythene bags than in the cloth bags (Annexure I). Mani (1999) found that *Pratylenchus jordanensis* stored in polyethylene bags survived for 124 days at 30 °C.

F. composticola recovered from compost samples by the sugar centrifugal flotation technique were distorted and disintegrated (Plate 16) while the other nematodes recovered like *Bursilla* sp., *Panagrolaimus* sp. etc. were not coiled or distorted although they were dead but intact.

In the compost heap, *F. composticola* survived throughout the observation period although its population fluctuated (Fig. 4.21). Microbivorous and myceliophagous nematodes were also recovered in the samples at each observation. All nematodes were in active state during the period of investigation. Initially, the moisture content of the compost was 72.57 % but after 15 days, it declined and remained almost constant varying between 31-34 % (Annexure II).

The population of *F. composticola* decreased after 30 days but after that it increased and there was no much variation in its number up to 90 days. Then its population increased sharply up to 120 days after which it declined. When the population of *F. composticola* increased, the population of other nematodes decreased showing its efficient predator of these nematodes. The population both for *F. composticola* and the other nematodes was in dynamic state. The rainfall during the month of June to September 2015 (Annexure III) may be the reason. The changing nematode community in compost is the result of both differential survival and colonization capacities of different species as stated by Steel *et al.* (2013).

5.6. Management of *Aphelenchoides swarupi* by *Fictor composicola*

For the management of myceliophagous nematodes in mushroom, the chemical method of control is not adopted due to residual problem in sporophores. Use of plant parts or their products may provide an alternative as they have been found promising for managing plant parasitic nematodes (Singh and Sitaramaiah 1967). This study was planned with a view to integrate Neem seed kernel water extract with *F. composticola*, for the management of *A. swarupi* in button mushroom.

NSKWE (4 % @ 7.5 litre/q compost) has been found effective and recommended to control the myceliophagous nematodes in mushroom without affecting yield **(**Anno. 1999**).** But, when NSKWE was tested against *F. composticola* at 1, 2 and 4 % for 24 and 48 hours, even at 1 %, it killed the predator after 24 hours (Table 4.11), showing its incompatibility with predator. Hence, further experiments were done with *F. composticola* only.

In both types of bags, the spawn run was good in the treatments where both the prey and predator were inoculated at casing time or when prey was inoculated at casing time and predator at spawning time. It was so because by the time of casing, spawn run was complete and *A. swarupi* inoculated at this time, got less time to damage the spawn as compared to when it was inoculated at spawning. Similar results were obtained by Gitanjali and Nandal (2005) while working with *A. composticola* and *A. bisporus*.

Khanna (1991) and Kumar *et al.* (1991) have also reported similar observations when studying the effect of nematode inoculation at spawning and casing time. *F. composticola* may have a role in reduction of the number of *A. swarupi*. The population of *A. swarupi* was less in these two treatments as compared to the treatments where *A. swarupi* was inoculated at spawning.

Population of *A. swarupi* was recorded maximum when it was inoculated at spawning and predator at casing due to the fast multiplication of *A. swarupi* in absence of the predator up to casing, and availability of spawn. The reproduction factor was also maximum in this treatment. Maximum reduction of yield over control (60.7 %) was found when prey was inoculated at spawning and predator at casing. This may be due to the reasons that *A. swarupi* got longer time to multiply, affecting spawn run and, the predator was introduced in the bags at casing time when the temperature was low.

So, *F. composticola* was not able to suppress prey population as after casing the temperature dipped to less than 10 °C affecting the predation and life cycle of *F. composticola.* This also seems the reason for non-recovery of *F. composticola* in the compost. This is also supported by our observations where in spite of presence of high population of *F. composticola* (2700/200 cc compost), it was not recovered in the crop season from the compost in Mushroom Technology Laboratory, Department of Plant Pathology, CCS HAU, Hisar. Bajaj and Kanwar (2015) also suggested that *F. composticola* can not survive at temperature < 15 °C.

Significant differences in the mean weight of the mushroom buttons between treated and control beds were recorded. *F. composticola* might have helped in increasing the yield of mushroom indirectly by reducing the populations of *A. swarupi***.** It may be presumed that *F. composticola* has played role in declining the population of prey at initial stage when temperature was favourable.

The results of laboratory experiments in the present study suggest that *F. composticola* has potential as a biological control agent for mycophagous nematodes as they are preferred over microbivorous nematodes. Predation of plant parasitic nematodes by *F. composticola* in present and earlier study (Bajaj and Kanwar 2015) also suggested its use as biocontrol agent of plant parasitic nematodes particularly in organic farming and polyhouses. Hence, it may be useful and should be explored for the control of plant parasitic nematodes.

In absence of recovery of *F. composticola* at the end of crop season, it can not be concluded with certainty that to what extent the predator controlled *A. swarupi* in compost bags. However, at higher densities under commercial mushroom farming where optimum temperature can be maintained, it may serve as an important bioagent for management of mushroom nematodes.

Majorities of small farmers prepare compost by long method and grow mushroom in traditionally low cost mushroom houses. In the North region of India like Himachal Pradesh, Haryana where mushroom cultivation is done, the temperature goes very low after the month of November (below 10 °C) and at such low temperature, the activity and survival of *F. composticola* are adversely affected. This poses a problem in use of this predator as a biocontrol agent of the mushroom nematodes.

Further studies are required with higher population and repeated release of predator at different timings. The large number of predators increase the probability of encounters between predators and prey, and chances of survival under unfavourable conditions. *F. composticola* also feeds on bacteria as reported by Hollis (1957), Yeates (1987), Bilgrami *et al.* (2005) and Bar-Eyal *et al.* (2008). Therefore, its food reference between nematodes and bacteria also needs to be investigated.

A series of studies on the other diplogasterids, *Mononchoides longicaudatus* and *M. fortidens*, also suggested that diplogasterid predators are good candidates for several reasons : (1) they can be cultured on bacteria, (2) their life cycle is short, (3) they have a high rate of predation and wide host range (Bilgrami and Jairajpuri 1988, 1989; Bilgrami and Brey 2005, Bilgrami *et al.* 2005). They have also a good efficacy of predation on plant-parasitic nematodes. *M. fortidens* and *M. longicaudatus* resulted in a reduced root galling index of tomato plants grown in *Meloidogyne* infested soil in pots (Fauzia *et al.* 1998, Khan and Kim 2005).

The rare and highly desirable advantage of diplogasterids over other biological control agents lies in their anticipated ability to survive periods of low prey densities by switching between feeding modes. These predators switch food sources between nematode and bacteria (Bilgrami 1997) thereby serving as a powerful stabilizing mechanism (Hassell 1978). Further studies are required to understand the field persistence and optimum culture conditions for *F. composticola*, and the biotic and abiotic soil factors affecting its biological control efficacy and its ability to reduce the myceliophagous nematode populations in compost.

CHAPTER-VI

SUMMARY AND CONCLUSION

Investigations were carried out to explore the prey range and prey preference of *Fictor composticola,* to study its predation behaviour, *in vitro* survival without prey, survival in compost and to explore its potential for the management of mycophagous nematodes in button mushroom, *Agaricus bisporus.* These experiments were conducted in laboratory and mushroom house of Department of Nematology, CCS HAU, Hisar during 2013-2015. Objective wise salient findings of the investigations are summarised in this chapter.

In the first experiment, prey range of *F. composticola* was studied on agar plates for twelve prey nematodes *viz*., *Aphelenchus avenae, Aphelenchoides swarupi, Ditylenchus myceliophagus* (mycophagous); *Panagrolaimus* sp., *Bursilla* sp., *Rhabdolaimus* sp., Aerolaimid and *Tylencholaimus* sp. (microbivorous); *Heterodera avenae* males and *Hoplolaimus* sp. (plant-parasitic) and *Aporcelaimium* sp. and *Nygolaimus harishi* (predator). The numbers of prey and predator per plate after 24, 48, 72 and 96 hours of release were recorded. *F. composticola* fed on all the prey nematodes tested. *F. composticola* consumed maximum number of *D. myceliophagus* and minimum number of *Panagrolaimus* sp.

In the second experiment, prey preference of *F. composticola* was tested in agar plates using four prey nematodes commonly found in mushroom compost. The preference was tested in 1% agar plates in combination of two, three and four prey nematode species, using equal number of each prey. It was found that *F. composticola* preferred *D. myceliophagus* the most, followed by *A. avenae*. *Bursilla* sp. was the least preferred species in all the prey combinations.

In the third experiment, predation behaviour of male and female *F. composticola* was studied on five prey nematode species, namely, *A. avenae, A. swarupi, D. myceliophagus, Bursilla* sp. and *Panagrolaimus* sp. Taking all the five preys together the average number of encounters done by female *F. composticola* was 6.0 and that of male was 3.0. Both the sexes preferred juveniles over adults as prey. The most attacked part by both females and males was the posterior part of the prey body. In 80 % cases, female predator fed on the first encountered prey while males attacked the first encountered prey in 30 % cases only. Strike rate of female *F. composticola* was more (78.6 %) than the male (48.2 %). Mycophagous nematodes were more susceptible to predator's attack than the microbivorous nematodes. Average feeding duration of female *F. composticola* was 8 min and 31 sec and in case of male it was 4 min and 11 sec.

In the experiment on effect of different prey densities of the preys, *A. avenae, A. swarupi, D. myceliophagus* and *Panagrolaimus* sp., on the predation efficiency of *F. composticola,* studied after 24 and 48 hours of release, it was found that the predation efficiency increased with the increase in prey density levels from 100 to 1600 per plate, highest being at 1600 and lowest at 100. However, the per cent consumption was lowest at 1600 and highest at 200 level of prey density. The prey consumption after 48 h was higher than after 24 h.

Survival of *F. composticola* was studied in heap of spent mushroom compost, polythene bags and cloth bags during off-season (April-September). Compost samples were taken at fortnightly interval for the extraction of nematodes. In the heap, *F. composticola* survived throughout the season although its population fluctuated. Free living and mycophagous nematodes were also recovered in active state. Survival of *F. composticola* was found better in polybags than in cloth bags.

In survival studies done in agar plates under *in vitro* conditions, it survived up to two months without food at 25 °C. At room temperature, (27.8 to 33.4 °C), it survived for 70 days with water but for 60 days without adding water. *F. composticola* survived for 75 days without prey in 1 % agar plates at lower room temperature (15.6-26.7 °C).

When effect of 1, 2 and 4 % neem seed kernel water extract on *F. composticola* was studied, it was found that even the lowest concentration (1 %) caused 99.5 % nematode mortality after 24 h. Hence, it can not be combined with *F. composticola* for the management of mushroom nematodes.

In the experiment on management of *Aphelenchoides swarupi* by *F. composticola*, the treatments where *A. swarupi* was inoculated at spawning, the final population of *A. swarupi* was higher than the treatments where it was inoculated at casing time. The yield was better in the treatments where prey was inoculated at casing. Similarly, the spawn run was good when *A. swarupi* was inoculated at casing and poor when it was inoculated at spawning and *F. composticola* at casing. The reproduction factor of *A. swarupi* was maximum when it was inoculated at spawning and predator at casing but minimum when predator at spawning and prey at casing. *F. composticola* was not recovered after the harvest in any of the treatments.

On the basis of these findings, the following conclusions can be drawn.

- *Fictor composticola* can feed on a wide variety of nematode preys.
- It proved a very efficient predator of mycophagous nematodes.
- Its preference for mycophagous over free living nematodes makes it a potential candidate for bio control of mushroom nematodes.
- The juveniles were preferred over adults (70-80%) and posterior part of the prey was the most preferred part for predation

- All juvenile stages and adults of *F. composticola* are voracious feeder and females are more efficient predator than males.
- The feeding duration of female *F. composticola* was more (8 min 31 sec) than the males (4 min 11 sec)
- *A. avenae*, *A. swarupi* and *D. myceliophagus* showed more susceptibility to *F. composticola* than other preys tested.
- *F. composticola* survived for more than two months in agar plates without prey at room temperature (15.6-26.7 °C)
- In heap of spent mushroom compost, *F. composticola* survived up to at least five months and the population of other nematodes decreased with the increase in its population.
- Under *in vitro* test, *F. composticola* could not survive even at 1% neem seed kernel water extract (NSKWE) after 24 h exposure. So, it was not found compatible with NSKWE.
- In management experiment, minimum population of *A. swarupi* was recorded when *F. composticola* was inoculated at spawning although no population of *F. composticola* was recovered from compost at the end of crop season.
- Further studies with its higher inoculum levels under controlled conditions in mushroom and for management of plant parasitic nematodes are required.

CHAPTER VII

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CHAPTER -VIII

ANNEXURE

Annexure I. Population of *Fictor composticola* recovered in cloth and polythene bags vis-à-vis moisture content in compost

Days of observation	Cloth Bag		Polythene Bag	
	% Moisture	*F. composticola*	% Moisture	*F. composticola*
15	16.96	86.6 (9.36)	34.49	1086 (32.95)
30	1.11	7.0 (2.79)	33.12	411.3 (20.3)
45	0.39	7.0 (2.82)	22.58	189.67 (13.78)
60	1.40	6.7 (2.76)	17.58	2.67 (1.91)
75	1.31	1.33 (1.52)	12.21	1.33 (1.52)

The values in parentheses are square root transformations.
Initial moisture content of the compost : 72.57 %

Annexure II. Population of *Fictor composticola* and other nematodes recovered in heap of spent mushroom compost

Day	Moisture %	Population recovered	
		Fictor composticola	Other nematodes
0	72.57	350 (18.73)	34 (5.91)
15	33.5	174 (13.23)	50.5 (7.16)
30	33.16	1191 (34.52)	205 (14.56)
45	31.18	89 (9.48)	557 (23.62)
60	32.38	39 (6.32)	700 (26.48)
75	34.43	114 (10.72)	1500 (38.74)
90	33.33	13.5 (3.78)	3277 (57.25)
105	32.67	111.5 (10.61)	11311.5 (106.36)
120	31.67	475 (21.82)	5614.5 (74.94)
135	31.67	11.5 (3.51)	13220.5 (114.98)
150	31.67	60 (7.85)	9796 (98.98)

The values in parentheses are square root transformations.

Annexure III. Data of temperature and rainfall during May to September 2015

Months	Average Teperature (°C)		Total rainfall (mm)	Temperature (°C)	
	Maximum	Minimum		Maximum	Minimum
May 2015	40.4	23.0	0.0	43.9	18.9
June 2015	38.2	25.0	161.0	43.0	22.0
July 2015	34.5	26.0	156.1	38.0	23.5
August 2015	34.7	26.1	54.8	37.6	25.0
September 2015	35.8	22.6	19.8	38.9	18.5

Annexure IV. Predatory behaviour of female *Fictor composticola* on *Aphelenchus avenae*

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	4	1st		Juvenile			Y	-	1	1	35
				Adult		Y		1	-	0	03
				Adult		Y		-	1	1	17
				Adult		Y		-	1	5	53
R_2	1	1st		Juvenile		Y		-	1	3	48
R_3	1	1st		Juvenile	Y		Y	-	1	13	47
R_4	4	1st		Juvenile			Y	-	1	8	35
				Juvenile		Y		-	1	0	50
				Juvenile			Y	-	1	0	55
				Adult			Y	-	1	2	10
R_5	2	1st		Adult	Y	Y		-	1	9	0
				Juvenile		Y		-	1	0	34
R_6	1	1st		Juvenile			Y	-	1	2	17
R_7	2	1st		Juvenile			Y	-	1	5	33
				Juvenile			Y	-	1	3	14
R_8	3	1st		Juvenile		Y		-	1	1	39
				Juvenile		Y		-	1	0	38
				Juvenile			Y	-	1	2	10
R_9	5		5th	Adult			Y	-	1	7	31
R_{10}	1	1st		Juvenile		Y		-	1	9	15
Mean	2.4	90%	10%	Adults-30% Juveniles-70%	9.09%	45.45%	45.45%	5%	95%	8	4.4

Annexure IV. Predatory behaviour of female *Fictor composticola* on *Aphelenchus avenae*

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	4	1st		Juvenile			Y	-	1	1	35
				Adult		Y		1	-	0	03
				Adult		Y		-	1	1	17
				Adult		Y		-	1	5	53
R_2	1	1st		Juvenile		Y		-	1	3	48
R_3	1	1st		Juvenile	Y		Y	-	1	13	47
R_4	4	1st		Juvenile			Y	-	1	8	35
				Juvenile		Y		-	1	0	50
				Juvenile			Y	-	1	0	55
				Adult			Y	-	1	2	10
R_5	2	1st		Adult	Y	Y		-	1	9	0
				Juvenile		Y		-	1	0	34
R_6	1	1st		Juvenile			Y	-	1	2	17
R_7	2	1st		Juvenile			Y	-	1	5	33
				Juvenile			Y	-	1	3	14
R_8	3	1st		Juvenile		Y		-	1	1	39
				Juvenile		Y		-	1	0	38
				Juvenile			Y	-	1	2	10
R_9	5		5th	Adult			Y	-	1	7	31
R_{10}	1	1st		Juvenile		Y		-	1	9	15
Mean	2.4	90%	10%	Adults-30% Juveniles-70%	9.09%	45.45%	45.45%	5%	95%	8	4.4

Annexure V. Predatory behaviour of female *Fictor composticola* on *Aphelenchoides swarupi*

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	2	1st		Adult			Y	-	1	0	48
				Adult	Y			-	1	2	37
R_2	1	1st		Juvenile			Y	1	-	0	18
R_3	5		4th	Juvenile			Y	-	1	5	53
				Juvenile	Y			-	1	1	37
R_4	3	1st		Juvenile	Y			-	1	10	25
				Juvenile	Y			-	1	9	54
				Adult		Y		-	1	4	31
R_5	2	1st		Juvenile	Y			-	1	2	38
				Juvenile		Y	Y	-	1	1	48
R_6	3	1st		Juvenile	Y			-	1	8	13
				Juvenile		Y		-	1	5	13
				Juvenile		Y		-	1	2	13
R_7	3	1st		Adult			Y	1	-	1	02
				Adult	Y			-	1	2	11
				Juvenile		Y		-	1	2	58
R_8	3	1st		Adult		Y		-	1	1	25
				Juvenile		Y		-	1	1	30
				Juvenile		Y		-	1	2	12
R_9	3	1st		Adult			Y	-	1	9	05
				Juvenile		Y		-	1	1	15
				Juvenile			Y	-	1	3	10
R_{10}	4	1st		Juvenile		Y		-	1	0	58
				Juvenile		Y		-	1	0	20
				Juvenile			YY	-	1	3	00
				Juvenile				-	1	4	10
Mean	2.9	90%	10%	Adults-26.9% Juveniles-73.1%	25.9%	40.8%	33.3%	7.7%	92.3%	8	56.4

Annexure VI. Predatory behaviour of female *Fictor composticola* on *Ditylenchus myceliophagus*

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	4		4th	Adult			Y	-	1	20	44
R_2	4	1st		Juvenile		Y		-	1	1	32
				Juvenile		Y		-	1	3	21
				Adult			Y	-	1	2	40
				Adult		Y		-	1	1	15
R_3	4		3rd	Adult		Y		-	1	1	18
				Juvenile			Y	-	1	10	54
R_4	5		4th	Juvenile			Y	1	-	0	05
				Adult		Y		-	1	0	21
R_5	3	1st		Juvenile			Y	-	1	2	32
				Adult		Y		-	1	7	24
				Juvenile			Y	-	1	1	08
R_6	2	1st		Juvenile		Y		-	1	0	45
				Juvenile			Y	-	1	2	09
R_7	1	1st		Adult	Y	Y	Y	-	1	10	00
R_8	2	1st		Juvenile			Y	-	1	2	15
				Juvenile	Y			-	1	2	02
R_9	3	1st		Juvenile		Y		-	1	1	40
				Adult			Y	-	1	1	30
				Adult		Y		-	1	1	04
R_{10}	4	1st		Adult			Y	-	1	4	02
				Juvenile			Y	-	1	2	10
				Adult			Y	1	-	0	05
				Adult		Y		-	1	3	25
Mean	3.2	70%	30%	Adults-50% Juveniles-50%	7.7%	42.3%	50%	8.3%	91.7%	8	26.1

Annexure VII. Predatory behaviour of female *Fictor composticola* on *Panagrolaimus* sp.

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	2	1st		Adult		Y		-	1	1	16
				Juvenile		Y		-	1	14	05
R_2	3	1st		Juvenile			Y	-	1	7	55
				Juvenile			Y	-	1	6	20
				Juvenile		Y		1	-	2	00
R_3	10		4th	Juvenile		Y	Y	-	1	11	47
				Adult			Y	-	1	6	42
R_4	10		8th	Juvenile			Y	-	1	4	18
				Two juveniles	Y	Y	Y	-	1	8	29
R_5	2	1st		Juvenile		Y		1	-	0	44
				Juvenile	Y			1	-	1	10
R_6	2	1st		Juvenile	Y			-	1	0	48
				Juvenile		Y		-	1	1	02
R_7	3	1st		Juvenile		Y		-	1	1	44
				Adult		Y		-	1	1	35
				Adult		Y		-	1	2	40
R_8	2	1st		Juvenile			Y	-	1	0	35
				Juvenile		Y		-	1	5	37
R_9	1	1st		Adult	Y		Y	-	1	3	21
R_{10}	2	1st		Juvenile	Y			-	1	1	35
				Juvenile			Y	-	1	1	25
Mean	3.7	80%	20%	Adults-22.72% Juveniles-77.27%	20%	44%	36%	14.28%	85.71%	8	30.8

Annexure VIII. Predatory behaviour of female *Fictor composticola* on *Bursilla* sp.

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	3	1st		Juvenile			Y	-	1	3	12
				Adult		Y		-	1	4	52
				Juvenile			Y	-	1	3	23
R_2	4	1st		Juvenile			Y	1	-	0	53
				Juvenile			Y	-	1	4	25
				Juvenile		Y		-	1	3	04
				Adult		Y		-	1	4	07
R_3	3	1st		Juvenile	Y			-	1	3	54
				Adult		Y		-	1	5	21
				Juvenile			Y	-	1	7	13
R_4	3	1st		Juvenile	Y			-	1	0	18
				Juvenile	Y			-	1	4	25
				Juvenile			Y	-	1	3	27
R_5	2		2nd	Adult		Y		-	1	5	34
R_6	4		2nd	Juvenile	Y			1	-	0	15
				Juvenile		Y		-	1	4	17
				Juvenile			Y	-	1	4	28
R_7	1	1st		Juvenile	Y			-	1	3	20
R_8	2	1st		Adult			Y	-	1	5	23
				Juvenile			Y	-	1	3	18
R_9	3	1st		Adult		Y		-	1	5	43
				Juvenile			Y	-	1	2	20
				Juvenile			Y	1	-	0	15
R_{10}	3		3rd	Juvenile			Y	-	1	2	53
Mean	2.8	70%	30%	Adults-25% Juveniles-75%	20.8%	29.2%	50%	12.5%	87.5%	8	38

Annexure IX. Predatory behaviour of male *Fictor composticola* on *Aphelenchus avenae*

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	7		2nd	Juvenile			Y	-	1	2	52
R_2	5		5th	Juvenile			Y	-	1	2	08
R_3	9	1st		Juvenile		Y		-	1	1	00
				Adult		Y		-	1	1	02
				Juvenile			Y	-	1	1	05
				Juvenile			Y	1	-	0	03
R_4	5		3rd	Juvenile			Y	-	1	1	04
				Juvenile			Y	-	1	1	05
				Three juveniles	Y	Y	Y	-	3	5	25
R_5	4	1st		Juvenile			Y	1	-	0	07
				Juvenile			Y	1	-	0	05
				Juvenile		Y		-	1	1	17
				Juvenile		Y		-	1	2	03
R_6	10	1st		Juvenile		Y		-	1	1	00
				Juvenile			Y	1	-	0	03
				Juvenile			Y	-	1	2	04
				Juvenile			Y	1	-	0	05
				Four juveniles	Y	Y	Y	-	4	5	25
R_7	6		2nd	Juvenile			Y	-	1	2	05
				Juvenile		Y		-	1	1	05
				Juvenile			Y	-	1	1	44
R_8	10		5th	Juvenile		Y		-	1	1	10
				Juvenile			Y	-	1	1	12
R_9	7		2nd	Juvenile			Y	-	1	2	41
										1	11
R_{10}	8		5th	Juvenile		Y		-	1	1	07
				Juvenile			Y	-	1	1	03
				Juvenile			Y	-	1	0	48
				Juvenile		Y		-	1	2	12
Mean	7.1	30%	70%	Adults-3.1% Juveniles-96.9%	6.25%	34.4%	59.4%	15.2%	84.8%	3	49

Annexure X. Predatory behaviour of male *Fictor composticola* on *Aphelenchoides swarupi*

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	2	1st		Juvenile		Y	Y	-	1	5	07
R_2	10		7th	Juvenile			Y	1	-	0	07
				Juvenile	Y			1	-	0	03
				Juvenile			Y	-	1	2	21
R_3	7		3rd	Adult		Y	Y	-	1	5	32
R_4	10		9th	Juvenile			Y	1	-	0	29
R_5	2		2nd	Adult		Y		1	-	0	28
R_6	3		3rd	Juvenile		Y		1	-	0	29
R_7	4	1st		Juvenile	Y			-	1	1	27
R_8	9		3rd	Juvenile			Y	-	1	0	57
R_9	4		2nd	Juvenile	Y	Y	Y	-	1	1	57
R_{10}	4		4th	Adult		Y	Y	-	1	6	21
Mean	5.5	20%	80%	Adults-25% Juveniles-75%	17.6%	35.5%	47%	41.7%	58.3%	2	31.8

Annexure XI. Predatory behaviour of male *Fictor composticola* on *Ditylenchus myceliophgaus*

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	8		7th	Juvenile		Y		-	1	2	07
				Adult			Y	-	1	1	23
R_2	5	1st		Adult			Y	-	1	2	28
				Juvenile	Y			-	1	1	30
				Juvenile	Y			-	1	0	40
				Adult	Y			-	1	5	26
R_3	5		3rd	Adult	Y			-	1	2	23
				Juvenile		Y		-	1	1	12
				Juvenile			Y	1	-	0	07
R_4	6		4th	Juvenile			Y	-	1	2	08
				Juvenile	Y			-	1	1	59
				Juvenile			Y	-	1	2	32
R_5	12		6th	Adult			Y	1	-	0	06
				Adult			Y	1	-	0	10
				Juvenile			Y	-	1	1	50
				Adult			Y	1	-	0	05
				Adult		Y		-	1	1	52
R_6	5	1st		Adult		Y		-	1	4	18
				Juvenile			Y	-	1	0	23
				Juvenile			Y	1	-	0	08
R_7	5		3rd	Adult		Y		-	1	2	34
				Juvenile			Y	-	1	2	13
R_8	7		4th	Adult			Y	-	1	2	23
				Juvenile			Y	-	1	2	43
				Juvenile	Y			-	1	1	33
R_9	4		3rd	Adult		Y		-	1	5	26
				Juvenile			Y	-	1	2	02
R_{10}	3	1st		Juvenile			Y	-	1	1	03
				Juvenile			Y	-	1	2	15
				Juvenile		Y		-	1	2	07
Mean	6.0	30%	70%	Adult – 40% Juvenile – 60%	20%	23.33%	56.7%	16.7%	83.3%	5	42.6

Annexure XII. Predatory behaviour of male *Fictor composticola* on *Panagrolaimus* sp.

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	7		8th	Juvenile		Y		-	1	14	19
R_2	5	1st		Juvenile			Y	-	1	1	01
				Juvenile	Y	Y	Y	-	1	17	54
R_3	6		6th	Juvenile			Y	-	1	2	37
R_4	7		4th	Juvenile		Y		-	1	1	02
				Juvenile		Y		1	-	0	02
				Juvenile		Y		-	1	1	06
				Juvenile		Y		-	1	1	16
R_5	3	1st		Juvenile		Y		-	1	1	04
				Juvenile		Y		1	-	0	02
				Juvenile		Y		-	1	1	52
R_6	7		5th	Juvenile		Y		-	1	0	27
				Juvenile			Y	1	-	0	03
				Adult	Y			1	-	0	15
R_7	4		3rd	Juvenile			Y	-	1	1	50
				Juvenile		Y		-	1	1	35
R_8	7	1st	4th	Juvenile	Y			1	-	0	21
				Juvenile			Y	-	1	0	48
R_9	4		2nd	Juvenile			Y	-	1	0	53
				Juvenile	Y			-	1	2	09
				Juvenile			Y	1	-	2	28
R_{10}	6		4th	Juvenile			Y	-	1	1	38
				Juvenile	Y			-	1	1	02
				Adult			Y	1	-	0	23
Mean	5.6	30%	70%	Adult – 8.33% Juvenile – 91.67%	15.38%	46.15%	38.46%	25%	75%	5	32.2

Annexure XIII. Predatory behaviour of male *Fictor composticola* on *Bursilla* sp.

Replications	Encounters	Attack after encounters		Prey life stage	Part of prey body attacked			Status of prey after attack		Feeding duration	
		First	Others than first		Anterior	Middle	Posterior	Injured	Dead	Min	Sec
R_1	6		5th	Juvenile			Y	-	1	2	18
				Juvenile			Y	1	-	0	12
R_2	7		4th	Juvenile			Y	-	1	2	07
				Juvenile		Y		1	-	0	03
				Juvenile			Y	1	-	0	05
				Adult		Y	Y	-	1	2	12
R_3	3	1st		Juvenile			Y	-	1	2	11
				Juvenile			Y	-	1	1	05
				Juvenile	Y			-	1	1	52
R_4	4		3rd	Juvenile	Y			1	-	0	10
				Adult		Y		-	1	1	48
R_5	8		6th	Juvenile	Y			-	1	1	53
				Adult		Y		-	1	2	06
				Adult		Y	Y	-	1	1	32
R_6	5		2nd	Juvenile	Y			1	-	0	05
				Juvenile			Y	1	-	0	02
				Juvenile			Y	-	1	2	12
				Juvenile		Y		-	1	2	02
R_7	4	1st		Juvenile			Y	1	-	0	03
				Juvenile			Y	1	-	0	07
				Juvenile			Y	-	1	2	02
				Juvenile	Y			1	-	0	21
R_8	7		5th	Adult		Y	Y	-	1	2	10
				Juvenile			Y	-	1	3	08
				Juvenile			Y	1	-	0	13
R_9	5		3rd	Juvenile			Y	-	1	2	13
				Adult		Y		-	1	2	05
				Juvenile	Y			1	-	0	03
R_{10}	8		4th	Juvenile			Y	-	1	2	12
				Juvenile			Y	-	1	2	02
				Adult			Y	-	1	1	05
				Juvenile			Y	1	-	0	03
				Juvenile		Y		1	-	0	05
Mean	5.7	20%	80%	Adult – 21.2% Juvenile – 78.8%	16.7%	25%	58.3%	39.4%	60.6%	4	10.4

ABSTRACT

Title of thesis	**:**	**Predatory behaviour of *Fictor composticola* Khan *et al.* and its potential for the management of nematode pests of button mushroom**
Name of degree holder	**:**	**Nishi Keshari**
Admission Number	**:**	**2012A32D**
Title of degree	**:**	**Doctor of Philosophy in Nematology**
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Degree Awarding University/ Institute	**:**	**CCS Haryana Agricultural University** **Hisar-125 004, India**
Major subject	**:**	**Nematology**
Number of page in thesis	**:**	**81**
Number of words in Abstract	**:**	**294**

Keywords: *Fictor composticola*, prey range, predation behaviour, prey preference, survival, prey density, bio-management, mycophagous nematodes, microbivorous nematodes, spent mushroom compost, button mushroom,

Investigations were carried out on prey range, prey preference, strike rate, predation behaviour, effect of prey density on predation rate of *Fictor composticola*, survival of *F. composticola* in agar plates and spent mushroom compost and management of mycophagous nematode, *Aphelenchoides swarupi* (mushroom pest) in button mushroom.

F. composticola preyed upon all the twelve nematode species tested including fungal feeders (*Aphelenchus avenae*, *A. swarupi* and *Ditylenchus myceliophagus*), microbivorous (*Panagrolaimus* sp., *Bursilla* sp., *Tylencholaimus* sp., *Rhabdolaimus* sp. and Aerolaimid), plant parasitic (*Heterodera avenae* males and *Hoplolaimus* sp.) and predatory nematodes (*Aporcelaimium* sp. and *Nygolaimus harishi*). *F. composticola* preferred mycophagous nematodes over microbivorous nematodes and *D. myceliophagus* among the fungal feeders. Female *F. composticola* was more voracious feeders than males. Strike rate of female *F. composticola* was 78.6 and 48.2 in males. The myceliophagous nematodes have more prey susceptibility than the microbivorous nematodes. The feeding duration of female and male *F. composticola* was 8 min 31 sec and 4 min 11 sec, respectively. It preferred juveniles over adults and posterior part of preys over other parts. Predation efficiency of *F. composticola* increased with increase in prey density but, the per cent consumption was minimum at highest prey density level (1600 per plate). The optimum per cent prey consumption was at 200 and 400 prey density levels. *F. composticola* could survive in agar plates up to two months. In spent mushroom compost, its survival was better in polythene bags than in cloth bags (75 days in polythene bags v/s 60 days in cloth bags). In compost heap stored in open, *F. composticola* survived in active stage during off-season (April to September). No anhydrobiotic survival was seen under moisture stress conditions. In mushroom bags, population of *A. swarupi* was found minimum when *F. composticola* was inoculated at spawning.

MAJOR ADVISOR **SIGNATURE OF STUDENT**

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(10) Publications

Keshari, N., Kanwar, R.S. & Singh, S. (2014) Mycophagous nematodes : A threat to button mushroom cultivation in Haryana. pp. 136. 8th International conference on "Mushroom biology and mushroom products". World society of mushroom biology and mushroom products, ICAR, DMR, Mushroom society of India, Solan held at New Delhi, India from 19-22 November 2014.

Keshari, N. & Kanwar, R.S. (2015) Prey capturing and prey preference of *Fictor composticola* Khan *et al*. National Symposium on "*Nematode management: A challenge to Indian Agriculture in the changing climate*". 129-130. Nematological Society of India, New Delhi held at YASHADA, Pune, India from 8-10 January, 2015.

Keshari, N., Madhuri, Kanwar, R.S. & Bajaj, H.K. (2015) New host records of *Meloidogyne arenarea* and *M. incognita*. National Symposium on "N*ematode management* : *A challenge to Indian Agriculture in the changing* climate". 83. Nematological Society of India, New Delhi held at YASHADA, Pune, India from 8-10 January, 2015.

I hereby, declare that all the information given in the resume is true to the best of my knowledge.

Dated

Place **Nishi Keshari**

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I**, Nishi Keshari,** Admission No. **2012A32D** undertake that I give copyright to the Chaudhary Charan Singh Haryana Agricultural University, Hisar of my thesis entitled, "**Predatory behaviour of *Fictor composticola* Khan *et al.* and its potential for the management of nematode pests of button mushroom"**

I also undertake that, patent, if any, arising out of the research work conducted during the program shall be filed by me only with due permission of the competent authority of CCS HAU, Hisar.

Signature of student