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The Predation Behaviour of *Fictor composticola* on Parasitic Nematodes of Button Mushroom, *Agaricus bisporus*

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Abstract

In this study, the predation behaviour of male and female predatory nematode, *Fictor composticola*, was studied on five prey nematode species, *Aphelenchus avenae, Aphelenchoides swarupi, Ditylenchus myceliophagus, Bursilla* sp. and *Panagrolaimus* sp., found in the white button mushroom compost. The period of the study is of six months. The data recorded on number of encounters, part of the body of prey attacked, stage of the prey attacked, duration of feeding etc. The strike rate and prey susceptibility were calculated. The average number of encounters on all the five preys done by female *F. composticola* was 3.0 and that of the male was 6.0. Male *F. composticola* had more number of encounters on the prey nematode species than the females. Both the sexes preferred juvenile stages over adults as prey. The most attacked part by both females and males predator, was the posterior part of the prey body. In 80% of cases, female predators fed on the first encountered prey while males attacked the first encountered prey in 30% of cases only. The 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. The strike rate of the predator on different prey nematode species was found more on mycophagous nematodes than on microbivorous nematodes and minimum on *Panagrolaimus* sp. The average feeding duration of female *F. composticola* was 8 min and 31 sec and in the case of males it was 4 min and 11 sec.

Keywords: *Fictor composticola*, mycophagous nematodes, prey susceptibility, strike rate

1. Introduction

The mushroom cultivation is growing very fast in India. Although oyster mushroom is easily cultivable and favourable for women (Biswas, 2014), white button mushroom is more popular (Anonymous, 2007). It has many nutritional and medicinal properties (Funda et al., 2017). Insect pests, fungi, bacteria and nematodes are the biotic limiting factors in its cultivation (Singh and Sharma, 2016; Sharma et al., 2019). One of the major limiting factor is, myceliophagous nematodes, reported from many parts of India (Bajaj and Kanwar, 2011; Madhuri and Kanwar, 2016). They can cause a great loss to mushroom cultivation (Keshari and Kranti, 2020). The biocontrol agents are cheaper, non-toxic and provide pollution free control of pests and diseases. Amongst these biocontrol agents, predaceous nematodes has vital role in nematode management

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(Devi and George, 2018). 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). The majority of predatory nematodes belong to four major taxonomic groups of nematodes–Mononchida (Ahmad and Jairajpuri, 2015), Dorylaimida, Diplogasterida (Bajaj and Kanwar, 2015) and Aphelenchida. The diplogasterids are an excellent example of predators, feeding on nematodes as well as insects (Bajaj and Tomar, 2015). They are generally found abundantly in decomposing organic manure and predates on different groups of nematodes (Keshari, 2016; Bajaj and Kanwar, 2015). The nematodes can multiply in compost and become active at all stages of composting process (Steel et al., 2013). Their life cycle is short and they can be easily cultured and maintained on simple nutrient media containing bacteria (Yeates, 1969). Their feeding apparatus is cutting and sucking type. *Fictor composticola*, a diplogasterid predatory nematode was described from mushroom compost from Haryana and Bihar (Khan et al., 2008). It was found as a promising biocontrol agent of mushroom feeding nematodes. It also managed the root knot nematodes when applied along with organic amendments (Sidhu and Kanwar, 2020). *F. composticola* predated on the preys by random movement. It fed on any part of the prey body and fed on the contents for 3-4 minutes at a time and became motionless before it shifted to another prey. The main advantage of using diplogasterid predators is their short life cycle, high rate of predation, easy culturing, high fecundity (Bilgrami et al., 2005). They also survive the off-season through the spent mushroom compost (Keshari and Kanwar, 2016). This group of predators remained neglected until Yeates (1969) evaluated the predatory abilities of *Mononchus potohikus*. They 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). Successful biocontrol could be achieved if prey nematodes are susceptible to predation. Prey specificity is an important factor in biocontrol. 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 and Chitamber and Noffsinger, 1989). The present study was planned to study the predatory behaviour of *F. composticola* to explore its potential as a biocontrol agent of nematode pests of mushrooms.

2. Materials and Methods

This research was done in the year 2015 in Department of Nematology, College of Agriculture, CCS HAU, Hisar, Haryana as one of the objective of Ph. D. research. 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 period of the study is of six months. The experiment had ten replications each with male and female *F. composticola*. Observations were recorded under a stereo-microscope for half an hour after the release of the nematodes. The observations were taken for each male and female *F. composticola*, separately as number of encounters made by the predator (E), number of encounters resulting in attack (EA), part of the prey body attacked, stage of the prey attacked (juvenile or adult), number of injured and dead preys after the attack and duration of feeding.

When the predator get 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 prey 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 the oesophagus, the posterior part included the post anal part and the rest was taken as the middle part. The number of parts attacked, was counted and the 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 a percentage. The numbers of injured (when a prey was wounded but escaped) and dead prey were counted. The percentage of injured dead prey was calculated out of the total preys attacked.

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

3.1. Predatory behaviour of female Fictor composticola

3.1.1. On Aphelenchus avanae

The female *F. composticola* started feeding on the prey attacked and after the 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% of 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 the middle and posterior parts of the prey (about 45% in each case) than the anterior part (9.1%) (Table 1). As a result of feeding, 95% of the attacked prey were killed and 5% of them escaped after injuries. The average feeding duration was found 8 min and 4 sec.

3.1.2. On Aphelenchoides swarupi

On *A. swarupi,* it encountered 2.9 times. It captured the prey in 90% of cases in the first encounter and 10% in other encounters. In 73.1% of cases, juvenile preys were attacked and in 26.9% of 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 prey, respectively. During feeding, 92.3% of the attacked prey 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*

Table 1: Predation behaviour of female *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 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 the predator on prey; EA: Number of encounters resulted in attack

3.1.3. On Ditylenchus myceliophagus

On *D. myceliophagus,* the mean number of encounters of female *F. composticola* was 3.2. The predator attacked the first prey encountered in 70% of cases whereas it attacked the other than first prey in 30% chances. It preferred juveniles in 65% and adults in 35%. The posterior part of the preys was the most preferred (50%) part followed by the middle (42.3%) and anterior part (7.7%). In 91.7% of the cases, the attacked prey 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.

3.1.4. On Panagrolaimus sp.

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 the female predator on prey nematodes. On this prey, it attacked the first encountered prey in 80% cases and the other than the first prey 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 the 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 the female predator on this species was 8 min and 30 sec.

3.1.5. On Bursilla sp.

On *Bursilla* sp., female *F. composticola* encountered 2.8 times. It captured and attacked the prey in the first encounter in 70% of cases but failed to capture the first prey in 30% of 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 prey attacked, 87.5% were found dead while 12.5% were alive although they were having injuries. The mean feeding duration of the predator on this prey was found 8 min and 38 sec.

On 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% of cases while in 20% cases, the prey other than the first encountered prey. It preferred juveniles (72%) over adults (28%). It preferred the posterior part of the prey (42.9%) to 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 I to V.

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 2) and fed on many of them for a short duration (3–10 sec). It kept on moving in different directions.

3.2.1. On Aphelenchus avanae

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% of cases, it attacked the first encountered prey and in 70% of 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 the 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 was shown in Annexure VI to X.

Table 2: 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 prey	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 the predator on prey; EA: Number of encounters resulted in attack

3.2.2. On Aphelenchoides swarupi

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, the posterior part was the most preferred (47%) followed by the middle (35.3%) and the anterior (17.6%). Due to feeding, 58.3% of the prey 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 minimum feeding duration among the five prey nematode species.

3.2.3. On Ditylenchus myceliophagus

On *D. myceliophagus, the* mean number of encounters recorded was 6.0 and it preferred to feed on the prey which were encountered later (70%) as compared to those encountered first (30%). The nematode preferred juvenile prey 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.

3.2.4. On Panagrolaimus sp.

On *Panagrolaimus* sp., the mean number of encounters done by male *F. composticola* was 5.6. It fed on other than the first encountered preys in 70% cases and 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 prey, 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.

3.2.5. On Bursilla sp.

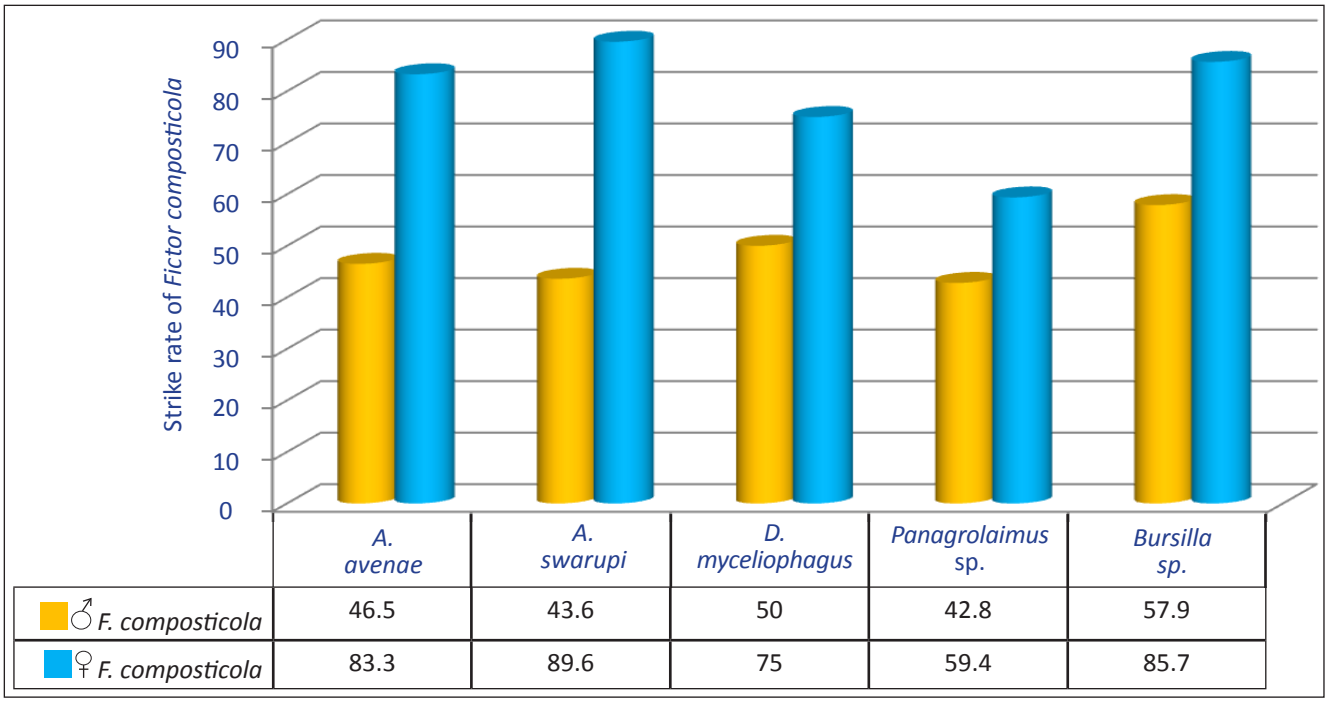
On *Bursilla* sp., the number of encounters made by male *F. composticola* were 5.7 and it preferred to feed on the later encountered prey nematodes (80%) than the first encountered ones (20%). The juveniles were preferred (78.8%) over the adults (21.2%) as prey. The posterior part of the prey was more frequently attacked for feeding (58.3%) than the middle (25%) and the anterior (16.7%) part. Among the prey 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 average, male *F. composticola* encountered 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 the female. Male predators attacked the prey which were encountered later whereas female predators attacked the first encountered preys more. Male *F. composticola* preferred the juveniles over the adults similar to females. Like females, males preferred the posterior part of the prey body more than the anterior part of the prey. Both female and male predators were responsible for the maximum mortality of the prey. The average duration of feeding on the male was half the feeding duration by the female.

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 Figure 1. The data revealed that the strike rate of female *F. composticola* was higher than its male counterpart.



	A. avenae	*A. swarupi*	*D. myceliophagus*	*Panagrolaimus* sp.	*Bursilla sp.*
♂ *F. composticola*	46.5	43.6	50	42.8	57.9
♀ *F. composticola*	83.3	89.6	75	59.4	85.7

Figure 1: Strike rate of male and female *Fictor composticola* on different preys

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 the strike rate of the 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 the male was lower (42.8-57.9%) as compared to the female (59.4–89.6%).

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.*

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.

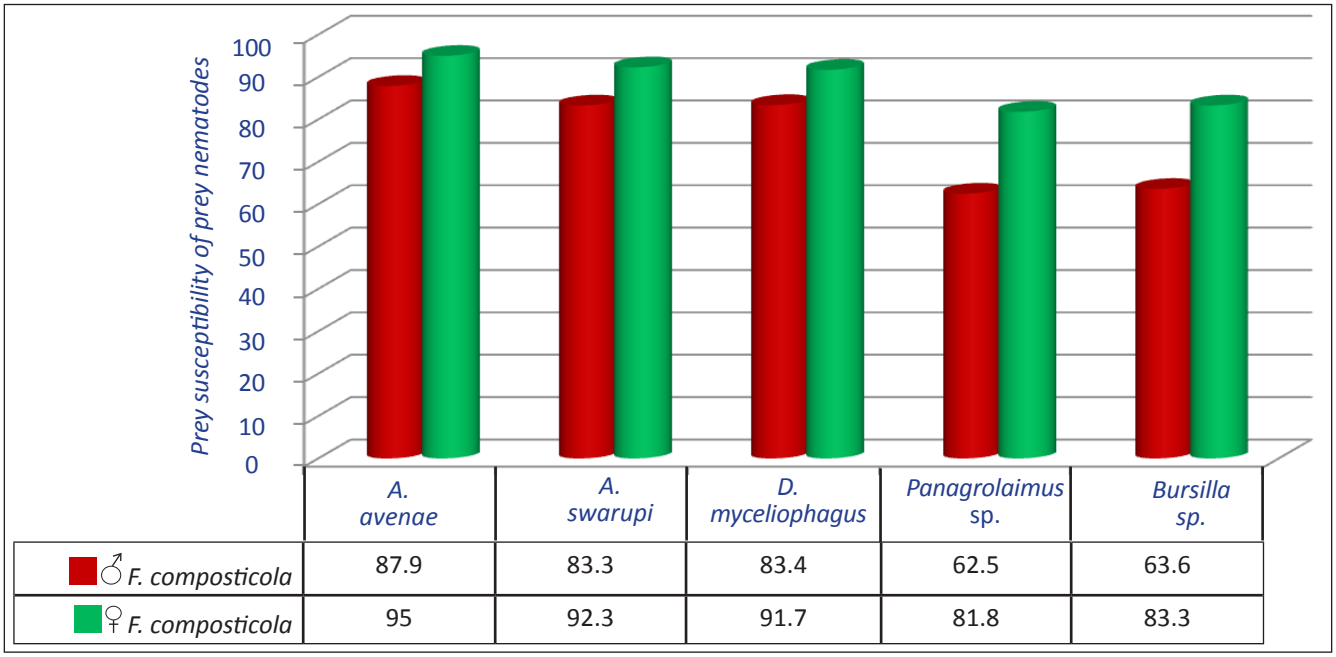
Male *F. composticola* had more encounters on the prey nematode species than the females. It may be because the males did not feed continuously on one prey but they roamed here and there and left many prey without wounding them but females mostly fed on the first encountered prey (70%) continuously. 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 a 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 percent of injured prey nematodes in the case of female predators was less than the male predator. The males encountered more prey species but in most of the cases, the prey 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 1 and 2). The feeding time required to consume an individual depended upon the size of the prey. Probing before the attack was seen in the 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's body. A wounded prey loses the pressure of the hydrostatic skeleton and hence, locomotion is seriously affected. The lower strike rate in the case of *Bursilla* sp. and *Panagrolaimus* sp. (Figure 1) 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.

The strike rate of male and female *F. composticola* on mycophagous nematodes was higher than on the microbivorous nematodes (Figure 1). Similar results were obtained by Bilgrami (1992) in the dorylaimid predator, *Mesodorylaimus bastiani* which had a higher strike rate on endoparasitic nematodes than the ectoparasitic, saprophagous and predaceous nematodes. The female *F. composticola* showed a higher strike rate than the male *F. composticola*, on all the prey nematode species. This may be due to more energy/food requirements by the female for the reproduction process.

The prey susceptibility of mycophagous nematodes to *F. composticola* was higher than the free living nematodes (Figure 2). The high susceptibility may be due to their slow rate of movement 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.*



	A. avenae	*A. swarupi*	*D. myceliophagus*	*Panagrolaimus* sp.	*Bursilla sp.*
♂ *F. composticola*	87.9	83.3	83.4	62.5	63.6
♀ *F. composticola*	95	92.3	91.7	81.8	83.3

Figure 2: Prey susceptibility of different preys to *Fictor composticola*

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). Because of this predatory behaviour, *F. composticola* managed the myceliophagous nematodes significantly when inoculated at spawning resulted in good spawn run and maximum yield.

4. Conclusion

Fictor composticola has a high potential for predation efficiency, the females are more voracious feeder than males. The females fed on the whole prey body whereas male fed the prey for a shorter time on many preys. Thus, the feeding duration of females was more than the males. It can be concluded that females were more potential feeder than males. This character can be used for the further studies in biological control of mushroom nematodes for eco- friendly management.

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