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The soil mite *Cunaxa capreolus* (Acari: Cunaxidae) as a predator of the root-knot nematode, *Meloidogyne incognita* and the citrus Nematode, *Tylenchulus semipenetrans*: Implications for biological control

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Original research

ABSTRACT

Plant-parasitic nematodes (PPNs) are dangerous pests, causing serious losses to the world's agricultural crops. As soil-dwelling predaceous mites are known as potential biological control agents against many pests, we investigated the interactions between the cunaxid mite, *Cunaxa capreolus* (Berlese), and two plant parasites (root-knot nematode, *Meloidogyne incognita* (Kofoid and White) and the citrus Nematode, *Tylenchulus semipenetrans* Cobb under laboratory conditions. The predatory mite *C. capreolus* completed its life-span when fed on egg masses EM and second-stage juveniles J2 of *M. incognita* and J2 juveniles of *T. semipenetrans* as food sources in the laboratory in sealed arenas at 32ºC, 60% relative humidity in the dark. Males developed slightly faster than females irrespective of different prey. Adult females lived longer than males and showed a higher rate of food consumption. Life table parameters indicated that feeding *C. capreolus* on J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans* led to the highest reproduction rate (r_m= 0.185 and 0.167 females/female/day), while feeding on EM of *M. incognita* gave the lowest reproduction rate (r_m= 0.085). The results show that *C. capreolus* multiplied rapidly when juveniles of *M. incognita* and *T. semipenetrans* were offered as prey, indicating the mite's potential for regulating population densities of these two pests. Future research should focus on understanding the crop and soil management applications required to enable this cunaxid mite and other predatory species to thrive. The implications of these results on biological control of plant parasitic nematodes are discussed.

Introduction

Plant-parasitic nematodes (PPNs) are important pests causing economically high yield losses in plants cultivated worldwide, turning horticultural areas into poor land, unviable for crop production (Szabó *et al.* 2012). It is estimated that the annual losses are up to 80 billion dollars a year (Jones *et al.* 2013). Consequently, the integrated management of major nematode pests is essential to improve world crop production. In Saudi Arabia, damages and losses are caused

mainly by *Meloidogyne* spp. and the citrus nematode *Tylenchulus semipenetrans* (Al Rehiayani and Fouly, 2005; Al-Yahya, 2018). The citrus nematode causes the disease known as citrus slow decline, which limits citrus production across a range of edaphic and environmental conditions (Campos-Herrera *et al.* 2019). Root knot nematode *Meloidogyne incognita* (Kofoid &White), is one of the most important nematodes associated with reduction in the yield of agricultural crops and their quality in the world (Thongkaewyuan and Chairin 2018). In Saudi Arabia, losses to plants caused by *M. incognita* are more severe and complex than in cold countries since the climate is suitable for the developmental activity and reproduction of nematodes throughout the year (Colagiero and Ciancio 2011). Control of plant parasitic nematodes by nematicides has become less desirable because of increased environmental awareness, public concerns about nematicides residues and contamination of food and water (Athanassiou and Palyvos 2006; Sikora *et al.* 2008). Because of the aforementioned concerns, alternative methods should be developed, such as biological control agents for the management of plant-parasitic nematodes. Common soil predators feed on plant parasitic nematodes and may have potential in biological control (Ekmen *et al.*2010; Heidemann *et al.* 2011). Most of these predators of root-knot nematodes are widely distributed and common in soils, including mites, predatory free-living nematodes, collembolans (springtails) and other organisms (Agbenin, 2011; Stirling *et al.* 2017; Campos-Herrera *et al.* 2019). Soil predatory mites are among the most effective biocontrol agents of several pests (Navarro-Campos *et al.* 2012), and nematodes, as first reported by Linford and Oliveira (1938). Later on, numerous studies have been conducted to investigate nematophagous mites. Muraoka and Ishibasi (1976) identified the predation of *Cephalobus* sp. (Nematoda: Cephalobidae) by 41 species of soil predatory mites. Sharma (1971) indicated that *Hypoaspis aculeifer* (Canestrini) (Acari: Laelapidae) significantly reduced the population of *Tylenchorhynchus dubius* (Bütschli, 1873) (Nematoda: Tylenchida) on potted plants. Imbriani and Mankau (1983) reported the predation of *Aphelenchus avenae* Bastian, 1865 (Nematoda: Aphelenchidae) and eight other nematode species by *Lasioseius scapulatus* Kennett, 1958 (Acari: Ascidae). *Hypoaspis calcuttaensis* (Acari: Laelapidae) showed great capability in consuming saprophagous, plant-parasitic and predaceous nematodes (Bilgrami, 1997). Walter and Kaplan (1991) reported that the cunaxid mite *Coleoscirus simplex* (Ewing, 1917) (Acari: Cunaxidae) fed on colonies of greenhouse cultures of root-knot nematode (Meloidogyne spp.), where it preys on vermiform nematodes and soil arthropods. Oliveira *et al.* (2007) estimated the consumption rate of *Pergalumna* sp. (Acari: Oribatida: Galumnidae) on the root-lesion nematode *Pratylenchus coffeae* (Zimmermann, 1898) (Nematoda: Pratylenchidae) and second-stage of root-knot nematode *M. javanica*. Chen *et al.* (2013) estimated that the predatory mite *Blattisocius dolichus* significantly reduced the density of *Radopholus similis*. Currently, there are more than 400 known species in the family Cunaxidae around the world (Skvarla and Dowling 2019). All members of this family are considered to be free-living predators feeding on nematodes, fungal spores, spider mites, fungus gnats, small insects as well as eggs of other soil-inhabiting micro arthropods (Skvarla *et al.* 2014). Knowledge about Cunaxidae fauna of Saudi Arabia is limited by only two species; *Cunaxa setirostris* (Hermann) and *Cunaxa capreolus* (Berlese) both been reported in debris and top soil layers of eucalyptus trees and date palm, *Phoenix dactylifera* in Qassim region and Sakaka governorate, Kingdom of Saudi Arabia, respectively (Fouly and Rehiayani, 2011 and Elmoghazy, 2016). However; there is no study to date which has examined the potential of *C. capreolus* on *M. incognita* or *T. semipenetrans* in Saudi Arabia or anywhere else. Therefore, the objective of this study is to report on the feeding behavior and life history of a cunaxid mite, *C. capreolus* that colonized root-knot nematode cultures in Saudi Arabia, and discuss biological control of root knot nematode *M. incognita* and citrus Nematode, *T. semipenetrans* within an ecological framework.

Material and methods

Nematodes

The root knot, *Meloidogyne incognita* and the citrus nematode, *Tylenchulus semipenetrans* were collected from greenhouse and citrus orchard field respectively at the Agricultural Experimental Station, College of Agriculture and Veterinary Medicine, Qassim University, Al-Mulida district (26.3489° N, 43.7668° E), Saudi Arabia. Egg masses of root knot nematode for these experiments were obtained from greenhouse cultures of a population of *Meloidogyne incognita* originally isolated from eggplant and were reared on tomato (*Lycopersicon esculentum* Mill. cv. Peterson) under greenhouse condition. For each experiment, *Meloidogyne*- infected roots of tomato were collected from 10-week-old greenhouse cultures and washed free of soil. The roots were cut into 1- to 2-cm long segments, with each segment containing two egg masses. The Citrus nematodes, *Tylenchulus semipenetrans* were collected from soil samples including roots, from lemon trees and the roots were gently washed free of soil and cut into 2- to 3-cm long segments, with each segment containing one or two egg masses. The egg mass and larval stages provides an important tool in studying population dynamics of Meloidogyne spp. and other plant parasitic nematodes having their eggs aggregated in gelatinous matrices (Byrd *et al*. 1972).

The second stage juveniles of *Meloidogyne incognita* were extracted from tomato root while *Tylenchulus semipenetrans* from soil mixed with lemon roots. The juveniles of nematodes were extracted by sieving and sucrose centrifugation method (Jenkins, 1964). The pore size of sieve used was 38 micrometers. Sieve size (38 micrometer opening) or 400-mesh. The juvenile's numbers were adjusted to 100 J2/ml for experiments by taking one ml of nematode solution to nematode counting slide and counted using a 40x magnification dissecting microscope. The centrifugal flotation method used in this study is one of the best methods that allows isolation of active as well as slow-moving and inactive nematodes (Bezooijen, 2006)

Predatory mite

The mite *C. capreolus* was originally extracted from tomato greenhouse soil at the Experimental Research Station, Qassim University, Buraidah, Al-Qassim, Saudi Arabia. Quantitative samples were composed of three equidistant cores, 30 mm in diameter and 80 mm in depth, from each pot culture. The subsamples were combined and extracted in a Berlese-Tullgren funnels, using 20-cm-diameter powder funnels (Krantz, 1978) with a rheostat controlled light source for 24 h, by which time > 99% of the active mites had been extracted and was maintained in darkness at 32 ± 1°C, 60 ± 5% RH, with second-stage juveniles of *Meloidogyne incognita* (Kofoid &White) (Tylenchida: Meloidogynidae) supplied as food resource in the Laboratory of Acarology, Qassim University.

Experimental arenas

All experiments were conducted in rearing cells (2 cm in diameter and 0.8 cm deep) filled with a mixture of activated charcoal and plaster of Paris at a 1:7 ratio to a depth of 0.5 cm and covered by a glass slide to prevent mites from escaping, and the two parts were held together by a binder clip.

Prey

Three different preys were evaluated for their effect on development, oviposition, fecundity, life table parameters and predation rate of *C. capreolus*.

- 1. Second-stage juveniles (J2) of *M. incognita*.
- 2. Second-stage juveniles (J2) of *T. semipenetrans*.
- 3. Egg mass (EM) of *M. incognita*.

Continuous predation of *C. capreolus* on J2 juveniles of *M. incognita*, J2 juveniles of *T. semipenetrans* and EM of *M. incognita*

Gravid females were transferred into rearing cells with a moistened brush with second-stage juveniles of *M. incognita* and allowed to lay eggs for one day and resultant eggs were then isolated for the different biological experiments. Eggs were placed singly on individual rearing cells, and the newly hatched larvae (50 for every test) were supplied with the food resource to be evaluated (one of the three preys). After the deutonymph stage, males were put with the females for mating. Males were then transferred into new arenas and individually reared until their death. Three experiments were designed to quantify the amount of predation of J2 juveniles of *M. incognita*, of *T. semipenetrans* and EM of *M. incognita*. In the first experiment, 100 J2 juveniles of *M. incognita* were added daily to each rearing cell. In the second experiment, 100 J2 juveniles of *T. semipenetrans* were added daily to each rearing cell. In the third experiment, two *M. incognita* egg masses and drop of water were added daily to each rearing cell, and each rearing cell was sealed and put into an incubator at $32 \pm 1°C$, $60 \pm 5\%$ RH in darkness. Replacement of the prey was carried out daily and records of developmental rate, predation rate, reproduction and behavior observation were reported twice a day under a standard binocular microscope, and predators were transferred to new arenas every 2-3 days, to keep a constant prey supply. The eggs of mites and prey residue were removed daily from the rearing cells. The necessity of mating was determined by adding adult males to independent arenas with virgin females of various ages and scoring for subsequent production of eggs. The developmental time and survival to adult stage of the females used in the experiments of the progeny ($N = 50$) of each female in each treatment were observed to calculate life-table parameters, following (Hulting *et al.* 1990).

Statistical analysis

The life history data, the number of eggs deposited and number of preys consumed of all individuals by *C. capreolus* on three type of prey were analyzed according to Analysis of variance (ANOVA) and simple correlation using SAS program (SAS Institute, 2005). Also, the difference between means was conducted at the 5% level by Duncan's Multiple Range Test (DMRT). The life table parameters of the cunaxid mite, *C. capreolus* were calculated according to (Hulting *et al.*1990).

Results

Life-history of *C. capreolus*

Cunaxa capreolus was able to complete its life cycle, including egg, larva, protonymph, deutonymph, tritonymph and adult, when using egg masses and J2 juveniles of *M. incognita* and J2 juveniles *T. semipenetrans* as food resource. Life history of *C. capreolus* females pass through one larval and three nymphal stages before reaching adulthood, while male has one larval and two nymphal stages (protonymph and deutonymph). Each motile stage is proceeded by a quiescent one. The development times of immature stages of *C. capreolus* fed on EM of *M. incognita*, J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans* are presented in (Table 1).

To mature from egg to adult, the females required 20.65, 15.60, 16.22 days on EM of *M. incognita*, J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans*, respectively (Table 1). Total development time (from egg to adult) of *C. capreolus* was slightly faster in males than in females, which may ensure insemination of females soon after their emergence, a prerequisite for the onset of oviposition. The generation period and adult longevity lasted 25.92 and 22.72 days, 18.65 and 27.62 days and 19.33 and 26.44 days when *C. capreolus* fed on EM of *M. incognita*, J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans*, respectively (Table 2). Female always deposited its eggs singly and at random in protected places.

Mating was necessary for oviposition in *C. capreolus* for the maximum reproduction of the females, as unmated females produced lower numbers of eggs compared to mated ones. The sex-ratio was calculated from the developmental experiment. The value females 80, 70 and 56%, Table 5 when predatory mite fed on J2 juveniles of *M. incognita*, J2 juveniles of *T. semipenetrans* and EM of *M. incognita*, respectively. The longest oviposition period was observed when *C. capreolus* fed on J2 juveniles of *M. incognita* with 22.12 days. The life span period, likewise followed the same trend on the different prey.

Predation rate

Table 3 shows the numbers of J2 juveniles of *M. incognita*, J2 juveniles of *T. semipenetrans* and EM of *M. incognita* prey consumed by predatory females and males. Both immature female and male *C. capreolus* kept preying on J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans* within one week with no significant difference ($F_{female} = 1.61$, $F_{male} = 1.56$,

Table 1 Development of *Cunaxa capreolus* offered egg masses and second-stage juveniles of *M. incognita* and second-stage juveniles of *T. semipenetrans* as prey in sealed arenas at 32°C, 60% relative humidity in the dark.

Parameter	Sex	Mean duration (days) ± SE		
		J2 juveniles of *M. incognita*	J2 juveniles of *T. semipenetrans*	EM of *M. incognita*
Egg	Female	6.54±1.12	6.75± 0.73	8.81±0.96
	Male	6.10± 0.96	6.22±0.82	8.11± 0.81
Larva	Female	3.41±0.24	3.53±0.41	4.75±0.29
	Male	3.25±0.33	3.45±0.24	4.65±0.33
Active	Female	2.90±0.24	3.04±0.22	4.00±0.24
	Male	2.81±0.20	2.98±0.30	4.00±0.30
Quiescent	Female	0.51±0.12	0.49±0.08	0.75±0.11
	Male	0.44±0.10	0.47±0.11	0.65± 0.12
Protonymph	Female	2.30±0.28	2.40±0.33	3.44±0.24
	Male	2.22±0.24	2.32±0.24	3.38±0.30
Active	Female	1.89±0.18	1.95±0.20	3.03±0.21
	Male	1.82±0.20	1.90±0.18	2.98± 0.18
Quiescent	Female	0.41±0.10	0.45±0.08	0.41±0.08
	Male	0.40±0.09	0.42±0.09	0.40±0.08
Deutonymph	Female	2.14±0.20	2.17±0.13	2.20±0.24
	Male	2.11±0.24	2.10±0.31	2.07±0.28
Active	Female	1.44±0.20	1.46±0.21	1.47±0.24
	Male	1.43±0.20	1.45±0.30	1.40±0.20
Quiescent	Female	0.70±0.12	0.71±0.11	0.73±0.12
	Male	0.68±0.13	0.65±0.11	0.67±0.11
Tritonymph	Female	1.30±0.20	1.37±0.24	1.45±0.22
Active	Female	0.90±0.12	0.97±0.12	1.00±0.12
Quiescent	Female	0.40±0.011	0.4±0.09	0.45±0.08
Egg to adult	Female	15.60±0.98 a	16.22±1.09 a	20.65±1.08 b
	Male	13.68±1.05 a	14.09±1.02 a	18.21±1.11 b

The means followed by different letters in each row denote significant differences (F test, P<0.01).

df = 7, 11, P > 0.05) among different days. The results showed that deutonymphs of predators consumed significantly more prey of the J2 juveniles of *M. incognita* than of J2 juveniles of *T. semipenetrans* (P = 0.001), while there was not a significant difference between the two prey in the protonymphal stage (P = 0.081). The average daily predation rate was 16.26, 13.86 and 0.38 prey for female adults (P = 0.178), and 13.63, 10.97 and 0.33 prey for male adults (P = 0.220) on J2 juveniles of *M. incognita*, J2 juveniles of *T. semipenetrans* and EM of *M. incognita*, during the immature stages, respectively. The maximum rate was recorded during the oviposition period, with the female consuming an average of 70.18 J2 juveniles of *M. incognita*, 55.75 J2 juveniles of *T. semipenetrans* and 1.97 EM of *M. incognita* respectively.

Fecundity

Results presented in Table 4 showed that *C. capreolus* females fed on J2 juveniles of *M. incognita* exhibited the highest fecundity while feeding on EM of *M. incognita* led to the lowest rate of fecundity and oviposition. The total numbers of deposited eggs by each female mite was significantly higher for female fed J2 juveniles of *M. incognita* and followed by J2 juveniles of *T. semipenetrans* and then EM of *M. incognita*, which occupied the last rank (F = 129.4 and P <0.01). The first laid eggs were observed on 18th day (on J2 juveniles of *M. incognita*), 19th day (on J2 juveniles of *T. semipenetrans*) and 21st day (on EM of *M. incognita*) of life span. The highest daily oviposition was 3.82, 3.11 and 1.02 eggs on J2 juveniles of *M. incognita*, J2 juveniles of *T. semipenetrans* and EM of *M. incognita*, respectively, which was observed in 27th, 29th and 17th days of total life span the females, respectively. The highest fecundity 44.56, and 39.33 eggs per female was recorded when *C. capreolus* fed on J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans*, respectively. While the minimum 9.29 eggs per female was observed when *C. capreolus* fed on EM of *M. incognita*. The post-oviposition period did not significantly differ among the three type of prey.

Table 2 Average duration in days of the predatory mite *Cunaxa capreolus* adults, feeding on egg masses and second-stage juveniles of *M. incognita* and second-stage juveniles of *T. semipenetrans* as prey at in sealed arenas 32°C, 60% relative humidity in the dark.

Parameter	Sex	Mean duration (days) ± SE		
		J2 juveniles of *M. incognita*	J2 juveniles of *T. semipenetrans*	(EM) of *M. incognita*
Pre-oviposition				
mean ± SD	Female	3.05±0.24	3.11± 0.30	5.27±0.45
Generation				
mean ± SD	Female	18.65±0.98 a	19.33±1.36 a	25.92± 1.18 b
Oviposition				
mean ± SD	Female	22.12±1.30 a	20.23±1.25 a	14.20±2.11 b
Post-oviposition				
mean ± SD	Female	2.45±0.24	3.10±0.22	3.25±0.24
Longevity	Female	27.62±1.57 a	26.44±2.08 a	22.72±2.14 b
mean ± SD	Male	22.65±2.22 a	21.76±1.45 a	20.85±1.28 a
Life span	Female	43.22±2.13 a	42.66±2.64 a	43.37±2.78 a
mean ± SD	Male	36.33±1.98 a	35.85±2.93 a	39.06±2.55 a

The means followed by different letters in each column denote significant differences (F test, P<.0.01).

Life table parameters

The effect of different prey species on life table parameters is shown in Table 5. A population of *C. capreolus* could multiply with 28.46, 24.39 and 9.38 net reproduction rate in a generation time of 25.28, 26.39 and 32.30 days when the predator fed on J2 juveniles of *M. incognita,* J2 juveniles of *T. semipenetrans* and EM of *M. incognita*, respectively. It was also found that under those conditions, feeding of *C. capreolus* on J2 juveniles of *M. incognita* led to the highest intrinsic rate of population growth (r_m = 0.185 females/female/day), while feeding on EM of *M. incognita* gave the lowest intrinsic rate of increase (r_m = 0.085). It is worth noting that the sex ratio of the progeny of females fed on J2 juveniles of *M. incognita* or J2 juveniles of *T. semipenetrans* favoured females compared with EM of *M. incognita.* The highest rate of predator females was reported on the second-stage juveniles of *M. incognita* (24/30). Evidently, since females are in excess of males, a high and long-lasting fertility of the males is expected. However, it is always desired in mass rearing to obtain females with high fecundity.

Feeding behavior

he soil predatory mite *C. capreolus* searched actively for nematodes around the experimental arena. Once a nematode was found, the predatory mite probed it with its first pair of legs and pedipalps, snatched it with its chelicerae, and devoured it. The chelicerae are the main killing and feeding organs. The first pair of legs are used to hold the prey during attack and feeding. After each predation, the predatory mite cleared its mouthpart with its first pair of legs, and immediately started the next search. *Cunaxa capreolus* took one minute to consume a nematode. Several specimens were observed feeding on the EM of root-knot nematodes *M. incognita*. The possibility that *C. capreolus* fed only on the gelatinous matrix that surrounds the nematode eggs cannot be excluded, though several mite specimens have been observed with the rostrum and the chelicerae penetrated into the gelatinous matrix and fed on the inside of

Table 3 Food consumption of *Cunaxa capreolus* in sealed arenas at 32°C, 60% relative humidity.

| Predator | Sex | No. consumed | | | | | |
		J2 juveniles of *M. incognita* Total average	Daily rate	J2 juveniles of *T. semipenetrans* Total average	Daily rate	EM of *M. incognita* Total average	Daily rate
Larva	Female	33.45±1.05	9.8	29.35±1.35	8.31	2.20±0.09	0.46
	Male	32.19±0.65	8.58	28.28±1.69	8.19	2.11±0.08	0.45
Protonymph	Female	61.77±1.49	26.85	60.99±3.04	25.41	2.45±0.11	0.71
	Male	60.18±1.94	27.1	55.80±3.25	24.05	2.33±0.12	0.68
Deutonymph	Female	97.65±2.67	45.63	75.46±3.66	34.77	1.92±0.08	0.87
	Male	94.21±2.14	44.64	70.62±3.54	33.62	1.75±0.07	0.84
Tritonymph	Female	60.87±2.00	46.82	59.08±2.60	43.12	1.42±0.06	0.98
	Male	-	-	-	-	-	-
Total	Female	253.74±4.99 a	16.26	224.88±4.58 b	13.86	7.99±0.34 c	0.38
	Male	186.58±3.58 a	13.63	154.70±5.28 b	10.97	6.19±0.28 c	0.33
Pre oviposition	Female	187.50±5.36	61.47	151.08±4.75	48.57	6.76±0.41	1.28
Generation	Female	441.24±4.35 a	23.65	375.96±4.23 b	19.44	14.75±0.53 c	0.56
Oviposition	Female	1552.42±9.36 a	70.18	1127.99±8.30 b	55.75	27.99±0.88 c	1.97
Post oviposition	Female	62.58±2.15	25.54	65.09±3.21	20.99	2.65±0.14	0.81
Longevity	Female	1802.5±12.05 a	65.26	1344.16±14.25 b	50.83	37.40±0.88 c	1.64
	Male	1145.20±9.20 a	50.56	854.28±10.91 b	39.25	27.52±0.54 c	1.32
Life span	Female	2056.24±20.11 a	47.57	1569.04±13.35 b	36.78	45.39±1.11 c	1.04
	Male	1331.78±18.25 a	36.65	1008.98±10.09 b	28.14	33.71±1.04 c	0.86

Letters in horizontal columns denote significant differences (F- test, P < 0.01).

Table 4 Fecundity of females of the predatory cunaxid mite, *Cunaxa capreolus* on different prey species in sealed arenas at 32°C, 60% relative humidity.

Fecundity of *C. capreolus* females with different prey species					
J2 juveniles of *M. incognita*		J2 juveniles of *T. semipenetrans*		EM of *M. incognita*	
Average no. of eggs, mean±SD	Daily egg laying rate, mean	Average no. of eggs, mean±SD	Daily egg laying rate, mean	Average no. of eggs, mean±SD	Daily egg laying rate, mean
44.56± 2.18 a	2.01	39.33±3.14 a	1.9	9.29±0.45 b	0.65

Different letters in horizontal rows denote significant difference (F test, P<0.05, P<0.01)

eggs causing cavity hole in egg masses. No cannibalism behavior was observed in *C. capreolus* either in the presence or absence of prey nematodes. *Cunaxa capreolus* colonies with eggs were found in cracks on the roots of tomato plants.

Discussion

Few studies have been carried out on the life history of predatory cunaxid mite, *C. capreolus* being fed on different prey. Zaher *et al.* (1975) reported that *C. capreolus* preying on booklice completed development in 16.5 days, and had an oviposition rate of 43.5 eggs/female/ at 30 ± 1°C, which agrees closely with the current findings. When feeding on free-living nematodes, *C. capreolus* reached maturity in 17.35 days at a temperature of 35°C ± 2 and 75 ± 5% R.H. (Mostafa *et al.* 2016). *C. capreolus* when fed on booklice (Psocoptera), at 15°C had extremely prolonged nymphal stages and a low oviposition rate of 0.41 egg/day/female (Soliman *et al.* 1975). In comparison with *C. capreolus*, the development time of *Cunaxatricha tarsospinosa* Castro & Den Heyer *et al.* fed on *Tenuipalpus heveae* Baker was 33.2 days, and oviposition rate was 1.36 eggs/female/day at 25.4 ± 0.2°C, 83 ± 5% RH and 12:12 h L: D photophase (Castro and Moraes 2010). Males developed faster than females in this study, which agrees with Mostafa *et al.* (2016) when *C. capreolus* was fed on Collembola and free-living nematodes. Duration of the whole life span of *C. capreolus* at 32°C was slightly longer than reported by Zaher *et al.* (1975) at 30°C and Mostafa *et al.* (2016) at 35°C for *C. capreolus* fed on various diets. The differences encountered in the cited literature may be due to the differences in foods and experimental conditions. Omar and Mohamed (2014) also determined the duration of the various adult stages of *Cunaxa setirostris* (Hermann) which were longer than in the present study, except for being close in the pre-oviposition period when fed on *Tetranychus urticae*

Table 5 Effect of different prey species on the life table parameters of the predatory cunaxid mite, *Cunaxa capreolus* in sealed arenas at 32°C, 60% relative humidity.

Parameters	Prey type		
	J2 juveniles of *M. incognita*	J2 juveniles of *T. semipenetrans*	EM of *M. incognita*
Net reproduction rate (R_o)	28.46	24.39	9.38
Mean generation time (T)	25.28	26.39	32.3
Intrinsic rate of increase (r_m)	0.185	0.167	0.085
Finite rate of increase (λ)	1.498	1.325	0.58
50% mortality (in day)	40	41	31
Sex ratio (Female/total)	24/30	21/30	17/30

Koch, *Tydeus californicus* (Banks) and *Eutetranychus africanus* (Tucker). These differences could be reflecting different foods. In the same study, total fecundity ranged between 18 and 73 eggs. Total fecundity when fed on *T. californicus* approximated the current result. On the other hand, Zhang (2003) reported that the generation time of Cunaxid mite, *Coleoscirus simplex* lasted 14 days, with the daily rate of deposited eggs 4.35 egg/ female. Among the data presented for nine species of cunaxidae fed on various diets, mean oviposition rates ranged between 0.4 and 2.60 eggs/day (Zaher *et al.* 1975; Soliman *et al.* 1975; Walter and Kaplan 1991; Arbabi and Singh 2000; Castro and Moraes 2010 and Mostafa *et al.* 2016).

Only 2 of 9 results are higher than the current finding. When *C. capreolus* fed on (EM) of *M. incognita*, there was a significant increase in development and pre-oviposition period, and a reduction in oviposition period and fecundity, subsequently, predators performance was poor. Although females of *C. capreolus* could feed on EM of *M. incognita*, their oviposition rate was lower than that on J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans*. J2 juveniles of *M. incognita* is thought to be a profitable prey species for *C. capreolus*, while EM of *M. incognita* are only subsidiary, or alternative, prey. The maximum reproduction (2.01 and 1.90 eggs/♀/day) was recorded when *C. capreolus* fed on J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans*, while the minimum reproduction (0.65 eggs/♀/day) was observed when *C. capreolus* fed on EM of *M. incognita*. It seems that individuals of J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans* are more suitable as main prey than EM of *M. incognita*. It is of interest to note that Zaher *et al.* (1975) revealed that the Citrus brown mite *Eutetranychus orientalis* gave the highest reproductive rate compared with booklice (*Psocoptera*). Similar results were recorded by Zaher (1975), Walter and Kaplan (1991) and Mostafa *et al.* (2016). Based on studies with stigmaeids and phytoseiids the general picture arises that food quality has influence on developmental time duration and much influence on fecundity and immature viability (Al-Azzazy 2002; Gnanvossou *et al.* 2003; Al-Azzazy 2005; Al-Azzazy 2018). On the other hand, several authors (Momen and Hussein 1999; Castro and Moraes 2010) have stated that the presence of alternative food should help predatory mites to survive periods of prey scarcity and thus prevent severe declines in the soil-dwelling predatory mite populations during shortages of primary foods. To reduce dominance of plant parasitic nematodes within the plant community, effective biocontrol agents must focus their actions upon the target plant without harming other vegetation.

Our experiments in laboratory arenas clearly show that the predatory mite *C. capreolus* has the capacity to kill or damage large numbers of plant parasitic nematodes. All active development stages of the predatory mite preyed on nematodes. Mite tritonymphs were most voracious and consumed many more nematodes than larvae, protonymphs and deutonymphs did. Daily consumption increased significantly in the adult. The consumption rate increased from pre-oviposition to oviposition periods and reduced in the post-oviposition period. In this study, the number of consumed (EM) of *M. incognita* by female and male *C. capreolus* were not less than 0.38 and 0.336, average 1.04 and 0.86 per day at 32°C, 60% relative humidity during 42 days, respectively, which showed that *C. capreolus* possesses the continuous and stable preying ability on EM of *M. incognita*. Al Rehiayani and Fouly (2005) reported that, when 200 individuals of *Cosmolaelaps simplex* were released to the rhizosphere soil of potted citrus seedlings two weeks after inoculating 1,000 juveniles of *T. semipenetrans*, the number juveniles decreased by 65% compared to the nematode alone control 75 days after predatory mites were released.

Life table parameters indicated that *C. capreolus* had high biotic potential when preying upon J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans*, while *C. capreolus* had low biotic potential when fed on EM of *M. incognita*. The population growth parameters were more favorable for *C. capreolus* fed on J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans* compared to EM of *M. incognita*. This is confirmed by the intrinsic rate of natural increase (r_m) which was 0.185, 0.167 on J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans* while was 0.085 on EM of *M. incognita*. It is certain that the observed low potential is not an intrinsic characteristic of *C. capreolus*, but rather the result of the

unsuitability of EM of *M. incognita* as prey. This statement reflects the high fertility of *C. capreolus* when fed on J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans*. These results indicate that J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans* provides *C. capreolus* with higher reproductive capability than does EM of *M. incognita*. Suggesting that J2 juveniles of *M. incognita* and J2 juveniles of *T. semipenetrans* could be evaluated in future studies as prey for mass production of *C. capreolus*. The gelatinous matrix of egg masses of *M. incognita* may serve as a barrier to the invasion of some soil predatory mites, small arthropods and microbial antagonists in the soil (Orion *et al.* 2001). This may be one of the reasons why this species (as well as cunaxids in general) are often found in very low numbers on (EM) of *M. incognita*, compared to Blattisociidae, Oribatidae and Ascidae (Al Rehiayani and Fouly 2005; Chunling Xu *et al.* 2014). Our results confirmed that the predatory mite *C. capreolus* has an inherent potential for the control of *M. incognita* and *T. semipenetrans*. and the presented information will be important in the management of these pests. It appears that this mite, as well as other possible biological agents, may be important in balancing these pest nematode populations in field ecosystems. Finally, the findings discussed above would help to gain a better understanding of the efficacy and utilization techniques of predatory Cunaxid mite, *C. capreolus*, as a facultative predator, in biological control programs of plant parasitic nematodes. Further work needs to be done in the presence of nematodes in soil in pots and micro plots.

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