Biological aspects, life table parameters, predation capacity and release of the predatory mite, *Kleemannia kosi* El-Badry, Nasr & Hafez (Mesostigmata: Ameroseiidae) for controlling three garlic (*Allium sativum* L.) pests

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ABSTRACT

Biological aspects and life table parameters of the mesostigmatid mite, *Kleemannia kosi* El-Badry, Nasr & Hafez (Family: Ameroseiidae) were investigated at 25±2°C and 70±5% RH on three prey types (*Rhizoglyphus echinopus* (Fumouze & Robin), *Tyrophagus putrescentiae* (Schrank) and *Delia antiqua* (Meigen)). The bulb mite, *Rhizoglyphus echinopus* was the most favorable food for this predator females as it gave the highest reproduction rate of 128 eggs/female followed by *T. putrescentiae* (119.5 eggs/female) and *D. antiqua* (88.8 eggs/female). The maximum net reproductive rate (R_o) occurred on *R. echinopus* recorded 92.15 individuals/generation, followed by 82.08 individuals/ generation on *T. putrescentiae*, while the lowest value was for *D. antique* (45.19 individuals/generation). Gross reproduction rate (GRR) was higher on *R. echinopus* (106 eggs/female/generation) and lower (58.6 eggs/female/generation) on *D. antiqua*. Females and males consumed a higher number of *R. echinopus* (342.0 and 265.5) individuals during life span than other diets. This is the first report revealing mass production and release of Ameroseiidae. Early release of the predator, *K. kosi* for controlling mite and insect pests on garlic (*Allium sativum* L., Amaryllidaceae) in field trial resulted in reducing the three pests significantly. Evaluation of crop loss due to infestation with those pests revealed a yield loss of 27.89 to 29.56% in unreleased plots compared with released one (40.58 and 41.55 kg/10 m^2) for 50 and 100 predators/m^2, respectively. The release of the predatory mite decreases the garlic pests that resulting in crop production increases.

Keywords: Mite predator, biology, mass rearing, biological control, garlic crop, yield loss.

INTRODUCTION

Much attention has been given recently to garlic, *Allium sativum* L. (Amaryllidaceae) as an important bulb crop along with onion which both considered the richest sources of most powerful antioxidant compounds. Both consumption and topical application can provide numerous benefits to our skin and high content of vitamins, enzymes and bactericidal effect. Garlic is adapted to tropical and sub-tropical conditions and attacked by several insect and mite pests and pathogens as well during vegetation and storage periods. These pests include: onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae); onion maggot, *Delia antiqua* Meigen (Diptera: Anthomyiidae); bulb mite, *Rhizoglyphus* spp. (Acaridae); eriophyid mite, *Aceria tulipae* (Keifer) (Eriophyidae) and two-spotted spider mite, *Tetranychus urticae* Koch (Tetranychidae) (Diaz-Montano et al. 2011; El Basheir et al. 2016; Soumia and Karuppaiah 2017). Vegetative propagation results in additional diseases and pest problems throughout garlic developmental stages, causing considerable losses in yield. Acarid bulb mites occurred all over the world causing serious losses every year and are one of the most significant and widespread *Allium* pests. Consequently, *Tyrophagus* and *Rhizoglyphus* were economically important pests of bulbs in fields and storage (Wang 1983; El Basheir et al. 2016). They reduced plant stands, stunt plant growth and promote rot of bulbs in storage (Fan and Zhang 2003). The onion maggot fly, *D. antiqua* is economically serious pest of *Allium* crops globally affects the yield and quality of onion and garlic. Larvae feed on developing epicotyls and roots of young onion plants often resulting in seedling mortality (Wilson et al. 2015); occasionally, the larvae can drill into the bulb and cause bulb rot (Sefrova 2008). Maggots damaged all plantations of onion and garlic crops in Egypt (Salman 2000) and considered as a major pest of garlic.

Pest management on garlic by natural enemies is preferred. Predacious mites are among the natural enemies considered for use in agricultural areas, mainly for the control of insect and mite pests. Mites of family Ameroseiidae Evans is relatively poorly known in comparison with other groups of Mesostigmata, even they have economic importance. This mite family include about 138 species in 12 genera (Mašán 2017). Members of this family are found in cultivated soil, meadows and forest soil, mainly in the superficial litter and humus layers, and in stored food, where they probably feed on fungi and mites of the genus *Tyrophagus* (Karg 1971). Mites of genus *Kleemannia* feeds on eggs, larvae and pupae of onion maggot reducing their numbers. Rare literature is available concerning information on biology of members of family Ameroseiidae (Fletchmann 1985). Some studies have been conducted in Egypt on the biology of this family (Mohamed et al. 1988; Moustafa and El-Hady 2006; El-Naggar et al. 2008).

Two species of family Ameroseiidae: *Kleemannia kosi* El-Badry, Nasr & Hafez and *Kleemannia plumosa* (Oudemans) are associated in rare numbers on corn, onion and garlic (Metwally 2016). *Kleemannia kosi* has been mentioned as potentially useful for the biological control of *Rhizoctonia solani* J.G. Kühn and *Sclerotium bataticola* Taubenh (Moustafa and El-Hady 2006).

A wide range of ameroseiid mites have the potential to be exploited as biological control agents against pests of bulb crops and could be mass reared and released during the critical periods of pest infestation which consider as other safe control methods in the Integrated Pest Management (IPM) approaches (Diaz et al. 2000).

Therefore, the present study investigates biological aspects of *K. kosi* on three diets in the laboratory. Also evaluates the control potential of this predator on some garlic pests and measures the effect of these pests infestation on yield loss in garlic.

MATERIALS AND METHODS

Biological study

The experiment was conducted at Laboratory of Acarology, Cotton and Field Crop Mites Department, Plant Protection Research Institute, Agriculture Research Centre, Sharkia Branch, Sharkia governorate, Egypt during 2020–2021 season.

Prey source and stock culture

Both acarid mites, *Tyrophagus putrescentiae* (Schrank) and *Rhizoglyphus echinopus* (Fumouze & Robin) (Acaridae) were reared on artificial diet (wheat germ, yeast granules and bran with ratio of 6:2:2), then incubated at 25±2°C and 70±5% RH in big jars filled with a layer of mixture of (cement, clay and charcoal with ratio of 7:2:1) until depth of 0.5 cm. Water drops were added when needed (Mesbah et al. 2016). To avoid fungal infection, nutrition was removed by fine brush under a stereo-microscope and renewed every 2–3 days.

The larvae of maggot fly, *Delia antiqua* (Meigen) (Diptera: Anthomyiidae) were obtained from infested onions and introduced to the predator in the Laboratory of Acarology as food.

Stock culture of the predatory mite, *Kleemannia kosi* El-Badry, Nasr & Hafez

The predatory mite was collected from soil underneath *Allium sativum* L. (Amaryllidaceae) crop at Zagazig, Sharkia governorate, Egypt. The predator was extracted from the soil using modified Tullgren funnels (Krantz and Walter 2009). The stock culture was started by a single adult female reared on all stages of astigmatid mite, *R. echinopus* which reproduced on crushed cereals as food in big jars under controlled conditions (25±2°C and 70±5% RH).

Biological aspects and food consumption

Three groups of 60 newly deposited eggs of the predator, *K. kosi* were singly transferred with a fine brush to plastic cells (3 cm in diameter and 2 cm in depth) filled up to 0.5 cm with a mixture of (cement, clay and charcoal with ratio of 7:2:1). A known number of each prey type was added to each cell. All cells were incubated at 25±2°C and 70±5% RH. The incubators containing saturated solution of NaCl to maintain at 75 % RH according to (Winston and Bates 1960).

Males were introduced to females for mating for seven days then removed. Observations on all biological aspects and food consumption were made twice a day during the predator life span.

Release of predatory mite, *K. kosi* for controlling some garlic pests

To evaluate the control potential of *K. kosi* against some garlic pests: *T. putrescentiae*, *R. echinopus*, and *Delia antiqua* Meigen (Diptera: Anthomyiidae), field experiment was conducted at El Tahra village, Zagazig, Sharkia governorate, Egypt in winter growing season during mid-October, 2020–2021. The experimental area was 1/4 feddan, divided into three equal parts of experimental plots. Each plot was 6 x 7 m² (1/100 fed.), with four replicates. The garlic cloves were sown in the hills (one clove/ hill in three rows) at a plant density of 60 plants/m^2, and 50 cm wide with the distance between cloves of 10 cm. All regular agricultural practices were made in all treatments. The other area was not sprayed with any chemicals to allow for natural infestation.

The predatory mite, *K. kosi* was released using cups with perforated cap (4 cm diameter and 10 cm depth) containing a known number of motile stages of *K. kosi*. Release was conducted by hanging the cups on the plant leaves early in the morning. The predatory mite was released at two rates (50 and 100 predators/m^2) and the control without release (untreated) after four weeks of garlic planting on 12 November, 2020. The number of mite and insect pests was counted before release, then samples were taken after four weeks from release. This is to allow the predator to colonize on garlic. Samples of 20 plants of each treatment (five plants from each replicate) were collected fortnightly. The plants were transferred to the laboratory for direct examination under a stereo-microscope. The number of mite and insect pests and the predator as well were counted for three months after release.

Loss in yield

The plots were harvested on 15 April, 2021. The final harvested garlic bulbs yield was calculated for 10m^2/ plot (3 plots for each treatment). The measure of damage caused directly by mite and insect infestation was estimated based on bulb yield obtained (kg/10 m^2) in plots naturally infested with pests compared with the released plots. Evaluation of the loss in yield due to infestation with pests was calculated using the formula by (Arnemann et al. 2018) as follows:

% Reduction in yield = Control – Release area / Control * 100.

Statistical analysis

Life table parameters were estimated according to Birch (1948) using the Life48, BASIC Computer Program (Abou-Setta et al. 1986). Data of biological aspects of the predator in laboratory and data of release were analyzed using One-Way analysis of variance (ANOVA) and mean comparison using LSD to test the significant differences between mean values using SAS statistical software (SAS Institute 2003).

The reduction in percentage of pests was estimated by equation of Henderson and Tilton (1955).

RESULTS AND DISCUSSION

Biological aspects

The biology of the ameroseiid mite, *K. kosi* was affected by prey type. Both females and males passed through one larval and two nymphal stages before reaching adulthood. Mating is essential for eggs production. Females deposited their eggs singly or scattered on the substratum. The eggs are white, then become creamy before hatching. The embryo moved to one side which appeared dark in colour. Hatching occur through a longitudinal median slit. The hatched larvae crawl searching for food. The food type no affected the incubation period of both females and males eggs. The incubation period ranged from 2.10 to 2.35 days for male and 2.20 to 2.35 days for female (Tables 1 and 2).

The duration of life cycle for both sexes was affected by the food type, as it averaged (9.90, 9.33 and 8.60 days) for males and (10.90, 9.73 and 8.90 days) for females when *K. kosi* respectively feeds on motile stages of both *Rhizoglyphus Echinopus* (Fumouze & Robin) and *Tyrophagus putrescentiae* (Schrank) (Acaridae) and larvae of *Delia antiqua* Meigen (Diptera: Anthomyiidae) (Tables 1 and 2). Similar results were obtained by El-Naggar et al. (2008) who mentioned that this period averaged (9.83, 9.25, 6.65, 5.89 and 13.68) days for males and (10.90, 10.35, 8.05, 7.13 and 15.85) days for females when *K. kosi* reared on *Lepidoglyphus destructor* Schrank, *Goheria wahabeii* (El-Naggar, Taha & Hoda), *Fuosarium oxysporum* Schlecht, *Asperigulus niger* van Tieghem and larvae of *Musca domesticae* Linnaeus, respectively. Shereef and Soliman (1980) found that incubation period of *Kleemannia plumosa* (Oudemans) averaged two days, while life cycle averaged 5 days at 27°C.

Adult longevity of *K. kosi* highly influenced by type of prey. For female, it lasted 25.95, 23.50 and 14.35 days; while for male, it lasted 25.70, 19.60 and 11.50 days respectively on the same previous foods (Tables 1 and 2).

Kleemannia kosi is oviparous, unmated females could oviposit, but their eggs failed to hatch (Mabrouk 1983; El-Naggar et al. 2008). However, pre-oviposition, oviposition and post-oviposition periods were obviously affected by prey type, whereas the motile stages of *R. echinopus* was the most favorable for *K. kosi* females to give the highest number of eggs (128 eggs/female, with a daily rate of 6.81 eggs/♀/day). On the contrary, larvae of *D. antiqua* gave the lowest number of eggs (88.80 eggs/female, with a daily rate of 8.00 eggs/♀/day) (Table 1). This result is similar to this obtained by Mabrouk (1992) who reported that *Sertitympanum zaheri* (El-Badry, Nasr & Hafez) gave the lowest number of deposited eggs when reared on fungus, *A. niger*. El-Naggar et al. (2008) mentioned that *A. niger* is the most favorable prey for *K. kosi* as it give the highest number of eggs (99.46), while *L. destructor* gave the lowest one (59.00 eggs).

Life table parameters of the ameroseiid mite, *K. kosi*

The mean generation time (T_G) of the predatory mite, *K. kosi* under laboratory conditions was significantly affected by the prey type. The shortest mean generation time (T_G) was observed on *D. antique* (13.15) days, while the longest (17.43) days was recorded on *R. echinopus* at 25ºC. The longest time for population density doubling (DT) was 2.68 days on *R. echinopus*, while the shortest period was 2.4 days on *D. antique*. The maximum net reproductive rate (R_o) occurred on *R. echinopus* (92.15 individuals/ generation), followed by 82.08 individuals/ generation on *T. putrescentiae*, while the lowest value observed on *D. antique* (45.19 individuals/generation) (Table 3).

The maximum intrinsic rate of natural increase (r_m) (the difference between birth rate and death rate) values were 0.259, 0.286 and 0.289 individuals/♀/day respectively on *T. putrescentiae*, *R. echinopus* and *D. antique*. The finite rate of increase (**λ**) was ranged from 1.29 offspring/ individual/day on *T. putrescentiae* to 1.33 on *R. echinopus* and *D. antique*. Gross reproduction rate (GRR) was higher on *R. echinopus* (106 eggs/female/generation) and lower (58.6 individuals/female) on *D. antiqua*. The survival rate of the predator immature stages on the three prey was 0.9, 0.9 and 0.8; while the 50% mortality was 29.5, 26.0 and 19.0 days on the same prey types.

Data on life table parameters of ameoseiid mites are not available in the literature. However, for similar result of other mesostigmatids, Mesbah (2013) mentioned that the blattisociid mite, *Blattisocius dentriticus* (Berlese) can double itself every 2.34 days with a single generation when feeds on *R. robini*. Also, Nasr et al. (1990) determined that the intrinsic rate of increase (r_m) of the *B. dentriticus* female was maximized on *T. putrescentiae* and *R. robini* Claparède nymphs. Tawfik et al. (2017) reported the net reproductive rate (R_o) of the blattisociid mite, *Lasioseius queenslandicus* (Womersley) [mentioned as *Lasioseius athiasae* Nawar & Nasr] female was (40.21, 46.73, 25.84 and 8.92 eggs) in a generation time (T) of 17.92, 23.44, 22.26 and 27 days, when feeds respectively on *T. putrescentiae*, *R. robini*, *Tetranychus urticae* Koch, and root-knot nematode, *Meloidoyne incognita* (Kofoid & White).

Predation capacity of the ameroseiid mite, *K. kosi*

Kleemannia kosi successfully fed on the tested prey. The number of devoured bulb mite, *R. echinopus* was significantly higher than other prey. The male devoured during longevity (195.5, 131.0 and 129.5) individuals of *R. echinopus*, *T. putrescentiae* and *D. antique*, respectively; meanwhile the female consumed (239, 171.2 and 150.0) individuals, respectively of the same previous prey. Females during life span consumed a significantly higher number of prey than males. Females and males consumed a higher number of *R. echinopus* (342.0 and 265.5) individuals during life span than other diets (Tables 4 and 5).

El-Naggar et al. (2008) had a similar result for *K. kosi* during its life span for both males and females when fed respectively on immature stages of both *L. destructor* and *G. wahabeii* and housefly larvae (82.6 & 91.1, 55.7 & 74.5 and 99.4 & 112.8) individuals.

Biological control of the acarid mites, *T. putrescentiae* and *R. echinopus* and larvae of onion maggots fly, *D. antique*

The mean number of *T. putrescentiae* individuals infested garlic crops after release of the predatory mite, *K. kosi* under field conditions in season 2020–2021 is varied over time, as it was 20.60 individuals/ plant at the start of the experiment on 12 November, 2020, and gradually increased to 81.70 individuals/ plant on 18 March, 2021 (Figure 1).

Table 1. Mean *Kleemannia kosi* female biological aspects fed on different prey kept at 25±2ºC and 75±5% RH.

Biological aspects	Mean duration (days) ±SD			F– value	P– value	LSD at 0.05
	R. echinopus	***T. putrescentiae***	***D. antiqua***			
Egg	2.35 ± 0.41 a	2.30 ± 0.35 a	2.20 ± 0.42 a	0.37	0.6923	0.36
Larva	3.15 ± 0.41 a	2.20 ± 0.35 b	2.30 ± 0.42 b	17.41	0.0001	0.36
Protonymph	2.25 ± 0.35 a	1.95 ± 0.28 a	2.20 ± 0.35 a	2.36	0.1132	0.30
Deutonymph	3.15 ± 0.24 a	3.28 ± 0.30 a	2.20 ± 0.26 b	48.32	0.0001	0.24
Immature stages	8.55 ± 0.37 a	7.43 ± 0.55 b	6.70 ± 0.89 c	21.17	0.0001	0.58
life cycle	10.90 ± 0.39 a	9.73 ± 0.67 b	8.90 ± 1.05 c	17.76	0.0001	0.69
Generation	14.10 ± 0.46 a	12.38 ± 1.09 b	10.65 ± 1.13 c	33.36	0.0001	0.86
Pre-oviposition	3.20 ± 0.54 a	2.65 ± 0.53 b	1.75 ± 0.26 c	25.16	0.0001	0.42
Oviposition	18.80 ± 0.79 a	17.30 ± 1.77 b	11.10 ± 0.88 c	110.80	0.0001	1.12
Post-oviposition	3.95 ± 0.64 a	3.55 ± 0.44 a	1.50 ± 0.33 b	72.31	0.0001	0.44
Longevity	25.95 ± 0.80 a	23.50 ± 2.13 b	14.35 ± 0.88 c	187.70	0.0001	1.29
Fecundity	128.00 ± 2.6 a	119.50 ± 3.7 b	88.80 ± 6.0 c	226.80	0.0001	3.97
Daily rate	6.81 ± 0.23 b	6.91 ± 0.84 b	8.00 ± 6.58 a	11.85	0.0002	0.55
Life span	36.85 ± 0.94 a	33.23 ± 2.59 b	23.25 ± 1.53 c	149.20	0.0001	1.67

Means within rows followed by the same letter were not significantly different at 5%.

Table 2. Mean *Kleemannia kosi* male biological aspects fed on different prey kept at 25±2ºC and 75±5% RH.

Biological aspects	Mean duration (days) ±SD			F– value	P– value	LSD at 0.05
	R. echinopus	***T. putrescentiae***	***D. antiqua***			
Egg	2.35 ± 0.34 a	2.25 ± 0.35 a	2.10 ± 0.46 a	1.06	0.3619	0.35
Larva	2.60 ± 0.57 a	2.00 ± 0.41 b	2.15 ± 0.34 b	4.85	0.0158	0.41
Protonymph	1.80 ± 0.26 b	1.80 ± 0.26 b	2.15 ± 0.34 a	4.96	0.0147	0.26
Deutonymph	3.15 ± 0.24 a	3.28 ± 0.30 a	2.20 ± 0.26 b	48.32	0.0001	0.24
Immature stages	7.55 ± 0.60 a	7.08 ± 0.50 ab	6.50 ± 0.82 b	6.50	0.0050	0.59
life cycle	9.90 ± 0.66 a	9.33 ± 0.65 a	8.60 ± 0.99 b	6.92	0.0037	0.71
Longevity	25.70 ± 2.90 a	19.60 ± 1.90 b	11.50 ± 1.65 c	48.57	0.0001	2.08
Life span	35.60 ± 2.90 a	28.93 ± 1.80 b	20.10 ± 1.54 c	123.60	0.0001	2.02

Means within rows followed by the same letter were not significantly different at 5%**.**

Table 3. Life table parameters of *Kleemannia kosi.*

Parameter	*R. echinopus*	*T. putrescentiae*	*D. antiqua*
Mean generation time (T_G)[a]	17.43	15.40	13.15
Gross reproduction rate (GRR)[d]	106	98.5	58.6
Survival rate %	0.9	0.9	0.8
50% mortality	29.5	26	19
Sex ratio (females/ total)	0.8	0.8	0.7
Net reproductive rate (R_o)[b]	92.15	82.08	45.19
Intrinsic rate of increase (r_m)[c]	0.259	0.286	0.289
Finite rate of increase (λ)	1.29	1.33	1.33
Doubling generation (DT)[a]	2.68	2.42	2.4

[a] Day, [b] per generation, [c] individuals/female/day, [d] eggs/ female/ generation

$R_o = \Sigma(lx \times mx)$; $T = \Sigma(x \times l_x \times mx) / \Sigma(lx \times mx)$; $r_m = \ln(R_o)/T$; $DT = \ln(2)/r_m$ and $\lambda = \exp(r_m)$

Table 4. Mean numbers of prey consumed (±SD) of *Kleemannia kosi* female reared on different prey.

Developmental stages	*R. echinopus*	*T. putrescentiae*	*D. antique*	F– value	P– value	L.S.D at $_{0.05}$
Larva	25.0 ± 2.36 a	19.1 ± 0.88 b	15.5 ± 0.71 c	233.8	0.0001	1.38
Protonymph	36.5 ± 2.42 a	23.9 ± 1.10 b	18.2 ± 0.42 c	565.0	0.0001	1.42
Deutonymph	41.5 ± 3.37a	28.6 ± 1.26 b	19.6 ± 0.52 c	409.6	0.0001	1.92
Immature stages	103.0 ± 3.50a	71.6 ± 1.90 b	53.3 ± 1.06 c	1853.4	0.0001	2.18
Longevity	239.0 ± 7.75 a	171.2 ± 10.38b	150.0 ± 2.45 c	615.3	0.0001	6.98
Life span	342.0 ± 10.33a	242.8 ± 11.51b	203.3 ± 2.67 c	1030.2	0.0001	8.31

Means within rows followed by the same letter were not significantly different at 5%.

Table 5. Mean numbers of prey consumed (±SD) of *Kleemannia kosi* male reared on different prey.

Developmental stages	*R. echinopus*	*T. putrescentiae*	*D. antique*	F– value	P– value	L.S.D at $_{0.05}$
Larva	20.0 ± 2.40 a	15.1 ± 0.74 b	13.7 ± 0.48 c	152.1	0.0001	1.33
Protonymph	50.0 ± 4.71 a	20.0 ± 2.36 b	13.6 ± 0.52 c	489.2	0.0001	2.80
Deutonymph	43.5 ± 4.12 a	17.2 ± 0.79 b	15.6 ± 0.52 c	509.6	0.0001	2.23
Immature stages	70.0 ± 7.84 a	35.1 ± 0.74 b	27.3 ± 0.82 c	1082.4	0.0001	4.18
Longevity	195.5 ± 7.62 a	131.0 ± 8.76 b	129.5 ± 3.69 b	603.0	0.0001	6.28
Life span	265.5 ± 9.66 a	166.1 ± 8.77 b	156.8 ± 3.97 c	1675.4	0.0001	7.04

Means within rows followed by the same letter were not significantly different at 5%.

After two release rates of *K. kosi* (50 and 100 predators/m^2), *T. putrescentiae* population during four months after the release was gradually decreased after four weeks of release till the end of the season. The highest reduction was 94.66 and 97.67% in early March, respectively for 50 and 100 predators/m^2, on garlic leaves. All treatments differed statistically from the unreleased (control) (Figure 1).

The population density of acarid mites, *R. echinopus* in the unreleased (control) plot was recorded with moderate numbers on garlic (26.25 individuals/bulb), the population gradually increased and peaked in the third week of February (46.80 individuals/bulb), then gradually declined thereafter. Whereas, a significant difference was noticed between the both release levels and the unreleased plot. A rapid decline in bulb mite population was occurred after four weeks of release until the end of the trial. The reduction percentage of bulb mite gradually increased and reached maximum of 84.96% at end of the trial after four months of release when the predator was with a rate of 50 predators/ m^2. Similar result was observed for the other release rate (100 predators/m^2). The reduction percentage gradually increased and peaked on 3 March, 2021 (95.84%) with no significant differences between both release levels (Figure 2).

The mean numbers of *D. antique* was 8.65 larvae/ garlic bulb at the start of the experiment and gradually increased and reached a peak in early February (15.20/plant) (Table 9). While, in the two released plots with *K. kosi*, the population of insect larvae was gradually decreased until the end of the season. There is a significant difference between the two levels of release compared with the unreleased plot, as the highest reduction was 93.94 and 98.49% after four months of release for respectively 50 and 100 predators/ m^2 on garlic bulbs (Figure 3).

Sabra and Abdel Wareth (2012) concluded that garlic crop in Egypt is usually attacked by *D. antiqua* in the field. Its population fluctuations reached 1.3–6.0 larvae/100 plant at Fayoum governorate. The highest infestation percentage with this pest was 9.3 and 11.4% in 2008–2009 and 2009–2010 seasons at the same governorate (Abd El-Halim 1998).

Population of the ameroseiid mite, *K. kosi*

This is the first reported study demonstrating mass production of the ameroseiid mite, *K. kosi* and the impact of its release in controlling some pests on garlic.

After the release of *K. kosi* on garlic plants, this predator was found on the leaves and bulbs where it was released and was not detected in the control plot (unreleased). The largest number of individuals was recorded after nine weeks on 18 February, 2021 (3.00 and 3.40 predators/ plant) respectively at rates of 50 and 100 predators/ m^2 (Figure 4). Finally, the results showed that all treatments reduced populations of mite and insect pests compared to control.

The efficiency of the predator increase was synchronized with the increase in the release rate. However, results showed the possibility of controlling mite and insect pests on garlic using ameroseiid mite predators as bio-control candidates at low level of infestation in order to achieve good results in a shorter time.

Effect of garlic infestation with mite and insect pests on yield loss

Several factors including insect pests are harmful to garlic bulbs during harvest, post-harvest and market processes resulting in lower quality of garlic and significant economic losses (MR et al. 2014). Crop loss due to pests infestation revealed a loss in yield ranged between 27.89 to 29.56% compared with that of the released plots (40.58 and 41.55kg/10m^2), respectively for 50 and 100 predators/ m^2.

Delia antiqua is one of the most pests attacks garlic plants (Taylor et al. 2000). It is a key pest of Alliaceous crops worldwide including onion, garlic and leeks that cause yield losses ranging from 20 to 60% (Becherescu 2009).

Conclusion

The ameroseiid mite, *K. kosi* successfully controlled bulb mites and maggot insect. Also, it is a fungivorous mite that control fungi infected garlic crop and can be used for fungi management. Therefore, augmentative early release of this predator for controlling mite and insect pests in the field is necessary to decrease garlic yield loss due to pest's infestation.

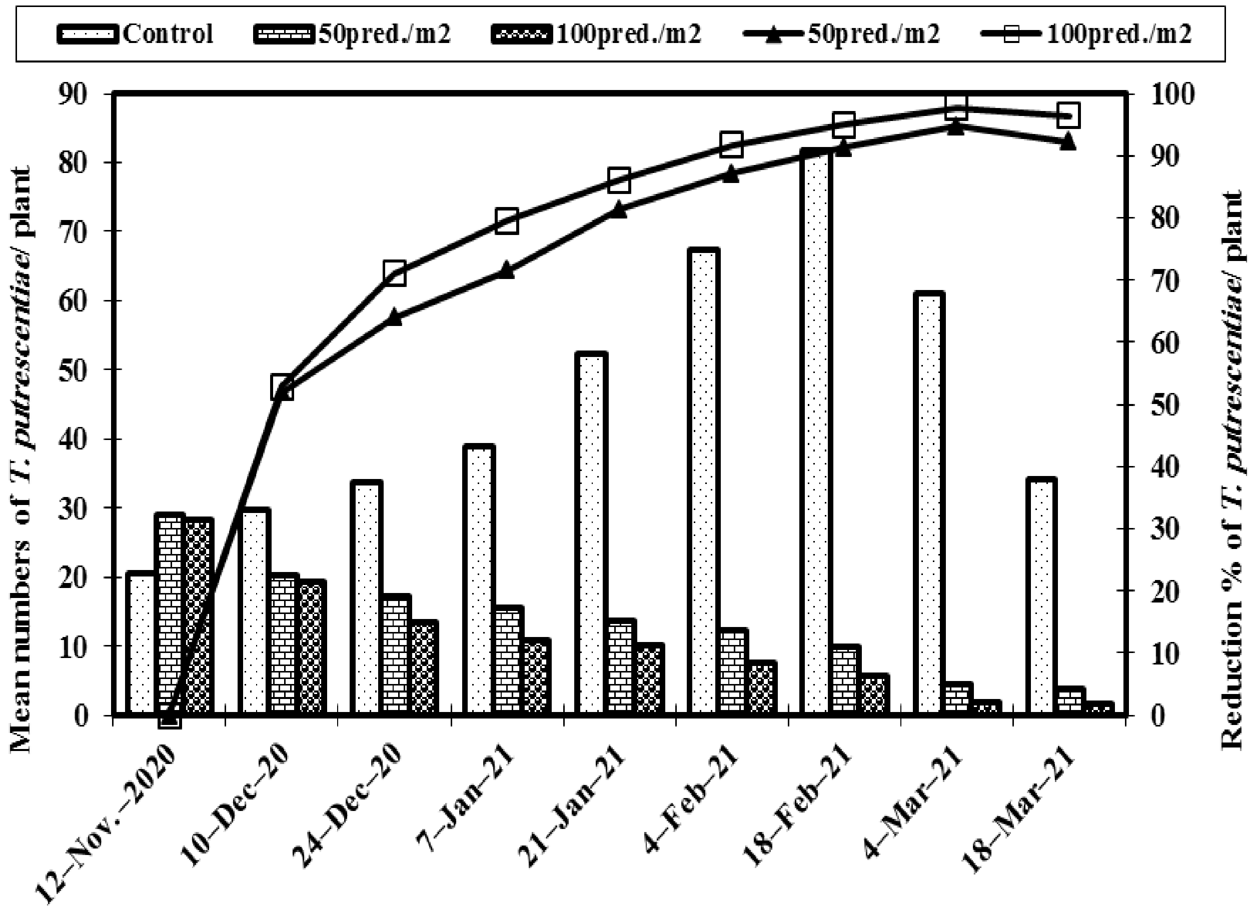

Figure 1. Mean numbers and reduction percentage of the acarid mite, *Tyrophagus putrescentiae* individuals infesting garlic crops after release of the predatory mite, *Kleemannia kosi* under field conditions during 2020–2021 seasons.

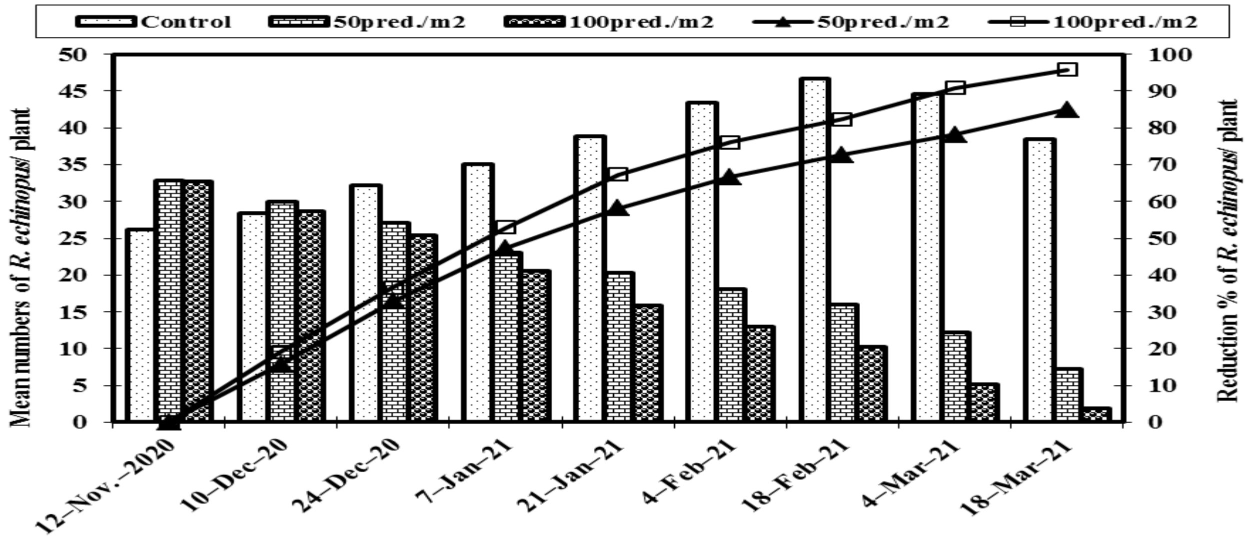

Figure 2. Mean numbers and reduction percentage of the acarid mite, *Rhizoglyphus echinopus* individuals infesting garlic crops after release of the predatory mite, *Kleemannia kosi* under field conditions during 2020–2021 seasons.

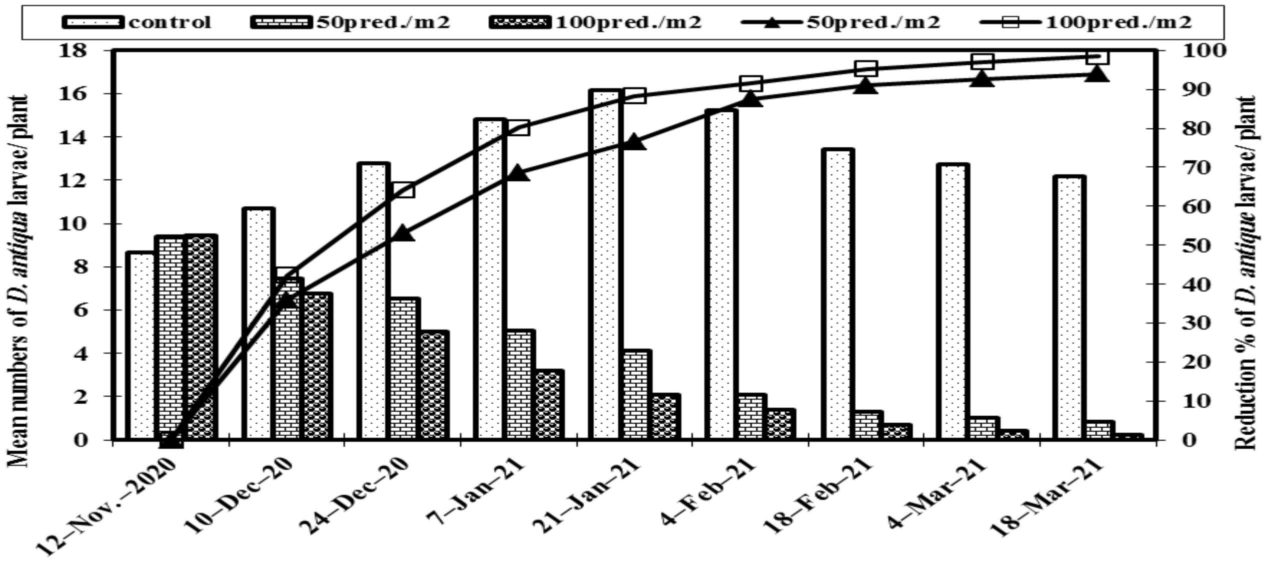

Figure 3. Mean numbers and reduction percentage of onion maggots fly, *Delia antiqua* larvae infesting garlic crops after release of the predatory mite, *Kleemannia kosi* under field conditions during 2020–2021 seasons.

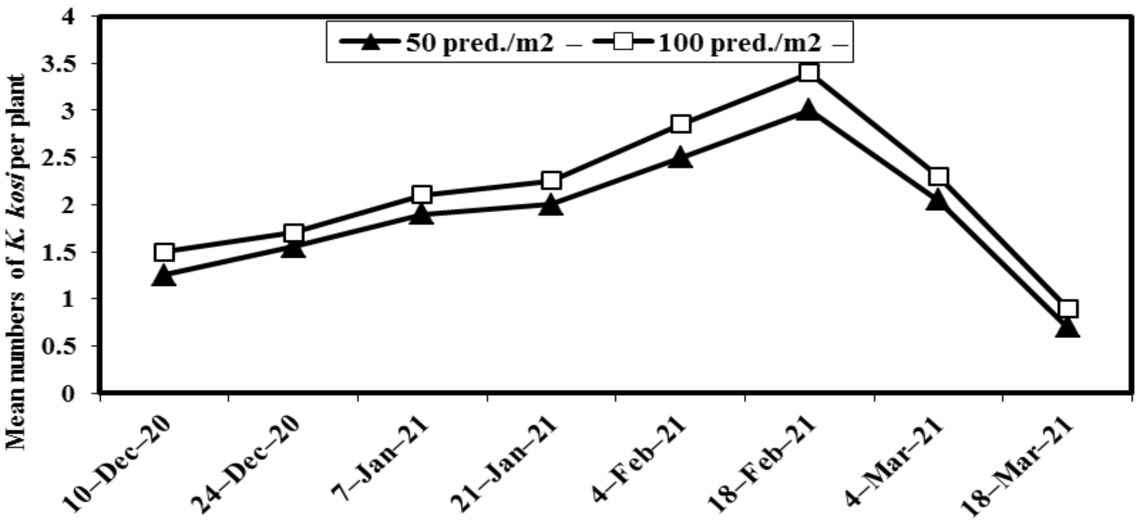

Figure 4. Mean numbers of *Kleemannia kosi/* plant for each sampling date on garlic infested with *Tyrophagus putrescentiae*, *Rhizoglyphus echinopus* and *Delia antiqua* during 2020–2021 seasons.

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