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Functional and Numerical Responses of *Cydnoseius negevi* (Swirskii & Amitai) on *Aceria melongenus* (Zaher & Abou-Awad) (Acari: Phytoseiidae: Eriophyidae) Infesting Eggplant

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ABSTRACT

Life table parameters, functional and numerical responses of the phytoseiid predator *Cydnoseius negevi* (Swirski & Amitai) (Acari: Phytoseiidae) on densities of its prey *Aceria melongenus* (Zaher & Abou-Awad) (Acari: Eriophyidae) were studied under controlled temperature (31 ˚C), relative humidity (45%) and photoperiod (16:8 L & D). Prey is one of the major species of pest mites on the eggplant cultivations in Egypt. This study evaluated the predatory abilities fed on moving stages of eriophyid prey at densities 10, 20, 40, 60, and 80 individuals. The results declared that the prey significantly affected development, female longevity, sex ratio, fecundity and predatory efficiency of *C. negevi.* At densities 60 and 80 individuals of prey, higher fecundities were reported (2.58 and 2.62 eggs/daily rate, respectively). At the same conditions, population of the predator could multiply 35.33 and 35.93, (Ro=35.33 and 35.93) in a generation time of 17.01 and 17.04 days (T= 17.01 and 17.04) when the predator fed on the prey, respectively. The attack rate (a)/the handing time (Th) or (a/Th) values indicate that *C. negevi* was effective against eriophyid prey. Prey as well, is a better diet for the predator in terms r_m, e^{rm}, GRR, DT and ARI. Therefore, we consider that the potential of *C. negevi* could confirmed as a biological control agent of the harmful eriophyid prey *A. melongenus* on eggplant cultivars.

Keywords: biology, *Cydnoseius negevi*, Phytoseiidae, *Aceria melongenus*, Eriophyidae, eggplant.

1. Introduction

Eggplant (*Solanum melongena* L.) is an economically important vegetable crop in Egypt. It is susceptible to a number of pathogens, insects, and mites, with bacterial and fungal wilts being the most devastating (Van Eck and Snyder, 2006). Eriophyid rust mite *Aceria melongenus* (Zaher & Abou-Awad) (Zaher and Abou-Awad, 1979) has reported on eggplant leaves in Egypt. Since 1978, the mite frequently found infesting new and well-developed leaves preferring the lower surface, but during high infestation, it was noticed on both surfaces and around the leaf petiole, causing yellowish color in distorted leaves and reduced development. More recently, the predatory phytoseiid mite, *Cydnoseius negevi* (Swirski & Amitai) was related to eggplant cultivations on different varieties. It's usually seen wandering on the leaves, preferring the lower surface around mid-rib, with or without prey (Farahat 2020). In addition, it can successfully develop and reproduce on different preys of phytophagous mites, small insects and on pollen grains (Abou-Awad *et al.,* 1989 and 1998a; Momen *et al.,* 2009; Negm *et al.,* 2014; Hussein *et al.,* 2016; Abdel-Khalek *et al.,* 2019). However, the predatory mite achieves high reproduction rates and short generation cycles especially under warm conditions. Therefore, the objective of this study was to evaluate how prey at different densities affected each other the control efficiency of the predator through the study of the life table parameters, functional and numerical responses.

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2. Materials and Methods

2.1 Experimental procedure

Individuals of *C. negevi* were collected from abandoned eggplant leaves at Tahrir Province (El-Behera Governorate) and transferred to rearing substrates consisting of clean succulent eggplant leaves, supplied with small discs of eggplant leaves heavily infested with the eriophyid eggplant rust mite, *A. melongenus*. Gravid females were left for 24h to lay eggs. Eggs were then isolated for the different biological tests. Clean eggplant succulent leaf discs, free of infestation 1.5 cm, in diameter, used as rearing substrates. The discs were placed in Petri dishes where the upper surfaces were in contact with water-saturated cotton. Discs were then encircled with a thin layer of wet cotton as a barrier to confine the mites. Each disc was supplied with newly hatched predator larva (40 for every test), and each predator was supplied daily with eriophyid prey at densities of 10, 20, 40, 60 and 80 individuals. Each density treatment replicated 40 times. The prey was replaced daily and the development, food consumption and reproduction were recorded twice a day. Arenas, as a control, maintained with the same densities of prey but without predator to record the normal mortality of eriophyid prey.

After last moulting, the male partner put with the females for mating. Males were then transferred to new arenas. This was repeated during oviposition period for several times, with resting period (3-day-intervals). Observations of the development were done twice a day and reproduction, survival and food consumption once a day. Every 5-6 days, the predator gets transferred to new arenas, while the eggs removed daily from the arenas. Experiments were conducted at 31 ˚C and 45% R.H and photoperiod (16:8 h L:D). To test the sex ratio, 40 eggs confined, singly in new arenas and the hatched larvae reared until maturity.

2.2 Statistical analysis

2.2.1 Life tables

Data of the developmental time, survival of the two sexes and female daily fecundity of *C. negevi* individuals were analysed based on the age-stage, female and male life tables (Chi & Liu 1985; Chi 1988) using the computer program TWO SEX-MSChart (Chi 2015). The population parameters (the net reproductive rate (R_o); the intrinsic rate of natural increase (r_m), the finite rate of increase (e^{rm}) and the mean generation time, T) calculated in sequence.

The net reproductive rate is defined as the mean number of offspring that an individual can produce during its lifetime and is calculated as: $R_o = \sum_{\times=0}^{\infty}$ Lxmx The intrinsic rate of natural increase (r_m), was estimated from the Euler – Lotka formula using the method of iterative bio section with the age indexed from 0 (Goodman 1982) as:

$$\sum_{\times=0}^{\infty} e^{-r(x+1)Lxmx=1}$$

Where, age-specific survival rate (Lx), age–specific fecundity (Mx).
The finite rate of increase calculated as:

$$\lambda = e^{rm}$$

The mean generation time is the time length that a population needs to increase to R_o-fold of its size as the population reaches the table age-stage distribution and is calculated as $T = L_n\ R_{o/r}$

The gross reproductive rate (GRR) calculated as: GRR = Σmx (May 1976; Carey 1993). Doubling time (DT): it is defined as the time required the population to double and is calculated as follows: DT= $In2/r_m$ (Birch 1948; Andrewartha and Birch, 1954 and Southwood 1978).

The annual Rate of Increase (ARI). This can calculated from the intrinsic rate of increase (r_m) or finite rate of increase (e^{rm}) or doubling time (DT) or the net reproductive rate (R_o) assuming that the rate of increase is constant throughout the year:

$$ARI = 365 = e^{365r} = 2^{365/DT} = R_o^{365/T}$$

The bootstrap method was used to estimate the standard errors of the population parameters. The differences of bootstrap-values between treatments were compared using the paired bootstrap test based on the confidence interval of difference (Efron and Tibshirani 1993). Means followed by a different letter are significantly different between treatments using the paired bootstrap test at the 5% significance level (Smucker *et al.,* 2007). The bootstrap method is included in the computer program TWOSEX-MSChart (Chi 2015). Data of the developmental times, adult life span, fecundity and daily reproduction were analyzed using one –way ANOVA followed by Tukey's test (P<0.05 (SPSS Inc. 2012).

2.2.2 Functional responses to different prey densities

Data were analyzed in Microsoft Excel (http://www.microsoft.com). The functional responses determining by fitting the data to the Holling disc equation (Holling 1959);

$$\mathrm{Ha} = \frac{\mathrm{a.H.T}}{1 + \mathrm{a.H.Th}}$$

Where, Ha= number of prey items attacked (number of prey consumed), a= attack rate (searching efficiency), H= prey density (number prey density), T= total available searching time and Th= handling time (Day or more). The parameters (a) and (Th) were calculated using a linear regression technique when 1/Ha was regressed on 1/H. (a) is the reciprocal of the slope and Th is the intercept. The (a/Th) value indicates the effectiveness of predator. Maximum predation rate (K) calculated as T/Th.

2.2.3 Numerical responses to different prey densities

After graved virgin female predator introduced onto the arenas eggplant leaf disc, the number of eggs laid by the predator recorded every day through oviposition period. Dead prey replaced with new ones every day. The result of numerical responses and oviposition fitted to regression equations. Different regression curves tested to fit the data presented in this paper. The regression model whose R^2 value was closer to (1) selected to fit the data.

3. Results and Discussion

The predatory phytoseiid mite *C. negevi* was able to develop successfully from egg to adult on the motile stages of eriophyid eggplant rust mite *A. melongenus* at different densities (10, 20, 40, 60 and 80 individuals). Feeding on the eriophyid prey led to the shortest developmental period of predatory immatures at densities 60 and 80 individuals and longest at density 10 individuals. The time elapsed between the egg and adult stages was almost similar for both sexes at densities 60 and 80 individuals (Table 1). Virgin female of predator was able to mate immediately after the final moulting. Mating was essential to induce oviposition, and multiple mating was important for maximum eggs output (Amano and Chant, 1978; Overmeer *et al.,* 1982; Momen, 1997; Rasmy *et al.,* 2003; Abou-Awad *et al.,* 2018).

Preoviposition period was shorter (2.00 days) at densities 60 or 80 individuals and longer (4.53 days) at density 10 individuals. The same thing also occurred with the generation period of the predator. Oviposition period was shorter (16.46 days) at density 10 individuals compared to (19.00 days) at high densities (Significant at 5% level). Longevity was almost the same with the five different densities. Development of the predatory males was faster (Table 1).

No feeding observed during larval stage. The consumption rate increased through the developmental stages (Table 2).

At density 80, immature stages of females and males devoured a daily average of 25.55 and 24.32 individuals of *A. melongenus,* respectively, while adult female consumed a daily average of 31.16 individuals of prey at the same density. On the other hand, the highest egg production of *C. negevi* was 49.85 eggs, with daily rate 2.62 eggs at density 80 individuals of prey (Table 1). This was dissimilar that reported by Abdel-Khalek *et al.,* (2019) who recorded that the total fecundity of *C. negevi* ranged from 36.75 to 41.67 eggs/female, when the same predator fed on the two –spotted spider mite *Tetranychus urticae* Koch at 27 ˚C . Abou-Awad *et al.,* (1989) cited that the fecundity of *C. negevi* was 25.64 eggs / female at 27 ˚C when fed on *T. urticae* and the oviposition rate was 1.4 egg / female / day. Momen (1997) as well, demonstrated that the total fecundity of *C. negevi* fed on *T. urticae* at 28 ˚C was 39.70 eggs/female and the oviposition rate was 1.4 egg/female/day.

Table 1: Developmental times (days) of the predatory phytoseiid mite *Cydnoseius negevi* reared on different densities of *Aceria melongenus* at 31 ˚C and 45% RH.

Developmental stages	Sex	*C. negevi*				
		10	**20**	**40**	**60**	**80**
Egg	♀	2.00±0.16[a]	2.00±0.16[a]	2.00±0.16[a]	2.00±0.14[a]	2.00±0.14[a]
	♂	2.00±0.31[a]	2.00±0.31[a]	2.00±0.32[a]	1.90±0.16[a]	1.90±0.16[a]
Larva	♀	1.77±0.16[a]	1.35±0.15[a]	1.21±0.15[a]	1.15±0.13[a]	1.15±0.13[a]
	♂	1.47±0.02[a]	1.21±0.02[b]	1.1±0.01[b]	0.8±0.01[c]	0.8±0.01[c]
Protonymph	♀	2.73±0.05[a]	2.20±0.05[b]	2.00±0.09[b]	1.90±0.09[b]	1.90±0.09[b]
	♂	2.2±0.11[a]	1.93±0.10[a]	1.77±0.10[a]	1.5±0.10[a]	1.5±0.010[a]
Deutonymph	♀	2.2±0.13[a]	1.97±0.12[a]	1.97±0.11[a]	1.6±0.11[a]	1.6±0.11[a]
	♂	1.94±0.12[a]	1.67±0.11[a]	1.77±0.11[a]	1.5±0.11[a]	1.5±0.11[a]
Total immature	♀	6.7±0.61[a]	5.52±0.63[b]	5.18±0.58[b]	4.64±0.58[c]	4.65±0.51[c]
	♂	5.61±0.61[a]	4.81±0.62[b]	4.64±0.57[b]	3.8±0.57[c]	3.8±0.52[c]
Life cycle	♀	8.7±0.84[a]	7.52±0.83[b]	7.18±0.75[b]	6.65±0.79[c]	6.65±0.71[c]
	♂	7.61±0.73[a]	6.81±0.72[b]	6.64±0.68[b]	5.7±0.62[c]	5.7±0.61[c]
Preoviposition	♀	4.53±0.53[a]	2.47±0.23[b]	2.35±0.21[b]	2.00±0.21[b]	2.00±0.21[b]
Generation	♀	13.23±1.12[a]	9.99±0.94[b]	9.53±0.91[b]	8.65±0.90[c]	8.65±0.86[c]
Oviposition	♀	16.46±1.11[a]	17.97±1.12[b]	18.21±1.17[b]	19.00±1.18[c]	19.00±1.18[c]
Mean total fecundity	♀	10.92±1.1[a]	24.19±1.9[b]	34.51±2.4[c]	45.08±3.1[d]	49.85 ± 3.6[d]
Mean daily rate	♀	0.57±0.17[a]	1.27±0.17[b]	1.92±0.18[c]	2.58±0.21[d]	2.62± 0.23[d]
Postoviposition	♀	4.14±0.42[a]	4.47±0.46[a]	3.73±0.38[b]	3.50±0.31[b]	3.50±0.31[b]
Longevity	♀	25.13±1.2[a]	24.91±1.3[a]	24.29±1.1[b]	24.5±1.2[b]	25.5±1.2[b]
	♂	11.13±0.97[a]	13.52±0.92[b]	14.13±0.97[c]	14.3±0.95[c]	14.3±0.94[c]
Life span	♀	33.83±2.95[a]	32.43±2.93[b]	31.47±2.91[c]	31.15±2.91[c]	31.15±2.9[c]
	♂	18.94±1.76[a]	20.33±1.79[b]	20.76±1.78[b]	20.00±1.63[b]	20.00±1.61[b]
Sex ratio (Female/total)	♀	29 / 40	29/40	29/40	29/40	29/40
% Surviving	♀	85	89	95	100	100
	♂	86	89	93	100	100
Number of observations	♀	29	29	29	29	29
	♂	11	11	11	11	11

Mean marked with the same letters in a horizontal column are not significantly different (F-test, P < 0.05, < 0.01)

Table 2: Number of preys consumed (daily rats) when *Cydnoseius negevi* was maintained on different densities of *Aceria melongenus* at 31˚C and 45% R.H.

Parameters	Density of *A. melongenus* Mean ± S.D.					
	Sex	**10**	**20**	**40**	**60**	**80**
Protonymph	♀	6.47±0.11	7.94±0.13	8.23±0.13	10.89±0.15	10.92±0.16
	♂	6.42±0.11	7.83±0.13	8.14±0.13	10.54±0.15	10.53±0.15
Deutonymph	♀	10±0.0	12.49±0.16	13.74±0.16	14.54±017	14.63±0.17
	♂	10±0.0	12.43±0.16	13.63±0.16	12.53±0.15	13.79±0.16
Total immature	♀	16.47±0.19	20.43±0.20	21.97±0.20	25.43±0.21	25.55±0.21
	♂	16.42±0.19a	20.26±0.20b	21.77±0.20b	23.07±0.21c	24.32±0.21c
Preoviposition	♀	10±0.0a	17.16±0.18b	18.79±0.18b	19.46±0.19b	21.14±0.19b
Generation	♀	26.47±0.22a	37.59±0.31b	40.76±0.35b	44.89±0.38c	46.69±0.33c
Oviposition	♀	10±0.0a	19.21±0.20b	25.18±0.22c	27.43±0.25c	31.16±0.27d
Postoviposition	♀	10±0.0a	16.72±0.19b	22.32±0.22c	23.19±0.23c	26.67±0.24d
Longevity	♀	30±0.25a	53.09±0.53b	66.29±0.63c	70.08±0.65c	78.97±0.72d
	♂	23±0.23a	48.63±0.51b	61.17±0.62c	62.43±0.61c	66.71±0.65d
Life span	♀	46.47±0.37a	73.52±0.67b	88.26±0.73c	95.51±0.81d	104.52±0.85e
	♂	39.42±0.26a	68.89±0.72b	82.94±0.76c	85.50±0.79c	91.03±0.82d

Different letters in the horizontal row denote significant difference (F-test, P < 0.05, < 0.01).

However, the highest number of eggs/female/day at highest densities of prey also observed for the allied phytoseiid species (Canlas *et al.,* 2006; Reichert *et al.,* 2017; Neto *et al.,* 2019). The production of eggs by the phytoseiid predators depends greatly on their feeding, not only because of the quantity of eggs they will produce, but also because of the amount of resources invested per egg (Sabelis 1985 a & b).

At densities 60 and 80 individuals of prey, population of the predator could multiply 35.33 and 35.93 (Ro= 35.33 and 35.93) in a generation time of 17.01 and 17.04 days (T= 17.01 and 17.04) when the predator fed on the eriophyid prey, respectively. At the same conditions, the intrinsic rate of increase (r_m) was 0.21 individuals/female/day for both previous densities, and the finite rate of increase (e^{rm}) was 1.23 female daughters/female/day, respectively. At aforementioned densities of prey as well, the gross reproductive rate (GRR) was the highest (35.59 and 36.14 eggs) respectively; while the doubling time (DT) and the annual rate of increase (ARI) were (3.30 and 3.29 days) and (1.67 X 10^{33} and 2.11 X 10^{33} at the same prey densities, respectively (Table 3).

Table 3: Effect of prey density of *Aceria melongenus* on the life table parameters of the *Cydnoseius negevi* at 31˚C and at 45 % R. H.

Life table parameters	***C. negevi* fed on *A. melongenus***				
	10	**20**	**40**	**60**	**80**
Net repr. rate (R_o)	7.50±0.48^a	17.28±0.74^b	24.59±1.01c	35.33±2.11^d	35.93±2.14^d
Mean generation time (T.)	16.27±0.7^a	16.37±0.7^a	17.29±0.8b	17.01±0.8^b	17.04 ± 0.8^b
Intrinsic rate of increase(r_m)	0.124±0.01^a	0.174±0.01^b	0.185±0.01^b	0.21±0.01^c	0.21 ± 0.01^c
Finite rate of increase (e^{rm})	1.132±0.10^a	1.190±0.11^b	1.203±0.11^b	1.233±0.11^c	1.234±0.11c
Gross reproductive rate (GRR)	7.91±0.61^a	17.54±0.9^b	25.02±1.8^c	35.59±2.1^d	36.14±2.21^d
Doubling time (DT)	5.595	3.981	3.744	3.307	3.297
Annual rate of increase (ARI)	4.36X10^{19}	3.97X10^{27}	2.23X10^{29}	1.67X10^{33}	2.11X10^{33}
50 % mortality (in days)	31	31	30	30	30

Mean marked with the same letters in a horizontal column are not significantly different (F-test, $P < 0.05, < 0.01$).

Thus, the higher fecundity, net reproduction rate, short generation time and the gross reproductive rate of *C. negevi*, when reared on the eriophyid prey with high densities, indicated significant potential as an effective biological control agent. Similar studies demonstrated several phytoseiid mites as major predators of eriophyids (Rasmy and El-Banhawy, 1974; Easterbrook, 1982; Abou-Awad, 1983; Momen and El-Sawy, 1993; Abou-Awad *et al.,* 1998b; Rasmy *et al.,* 2003; Abou-Awad *et al.,* 2018).

Solomon (1949) mentioned that the functional response is the change in prey number killed per individual predator per unit of time. It is one of the most important aspects in the dynamics of a predator-prey relationship, and is a major component of population models, to improve the practical predictive potential of predator candidates for biological control (Berryamen 1992; Sepiulveda and Carrillo 2008). The type II functional response in this study, was indicated by two parameters, prey consumed (1/Ha) to the predator *C. negevi* and different densities of its eriophyid prey (H). Daily predator rate gradually increased when predator were provided at increasing prey densities (Fig. 1). Attacking of predator rate determines the ability of the predator to catch prey within a given area; while the handling time indicates the time a predator spends to identify, subjugate, attack, and consume a particular prey (Holling, 1959).

The linear regression of the predatory mite *C. negevi* can be represented by the equation Y=0.0904X +0.0516 for the eriophyid rust mite *A. melongenus* (Fig. 2). From the coefficients of the linear regression, the attack rate (a) was estimated to be 1.11 sq.m, the handling time (Th) as well, was 1.2384 hours for the prey; a/Th values indicate that the predator was effective against the mobile stages of its prey.

The oviposition of *C. negevi* significantly increased with prey density increase until reaching a maximum at the highest densities (60 and 80 individuals, with 2.58 and 2.62 eggs/ female) (Table 1). The regression model whose R^2 value ($R^2 = 0.9913$) was closer to 1 was selected to fit the data (Fig. 3). However, the number of eggs/female/day at the highest densities can considered high for the other predatory phytoseiid species studied (Canlas *et al.,* 2006; Reichert *et al.,* 2017; Neto *et al.,* 2019). Thus, the potential of *C. negevi* could be confirmed as a biological control agent of the eriophyid eggplant mite.

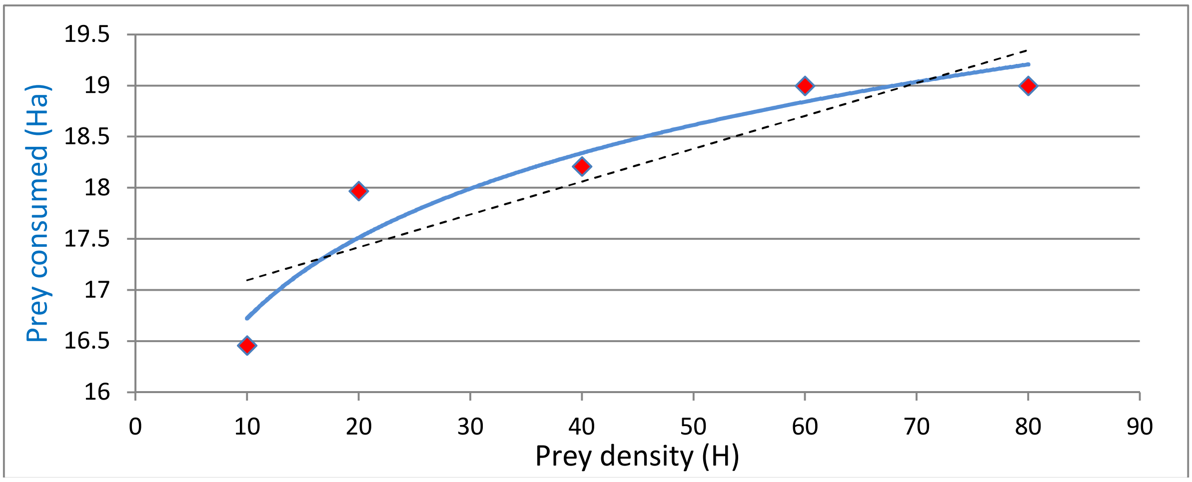

Fig. 1: Type II functional response of the predatory mite *Cydnoseius negevi* feeding on different densities of the eggplant eriophyid mite *Aceria melongenus.*

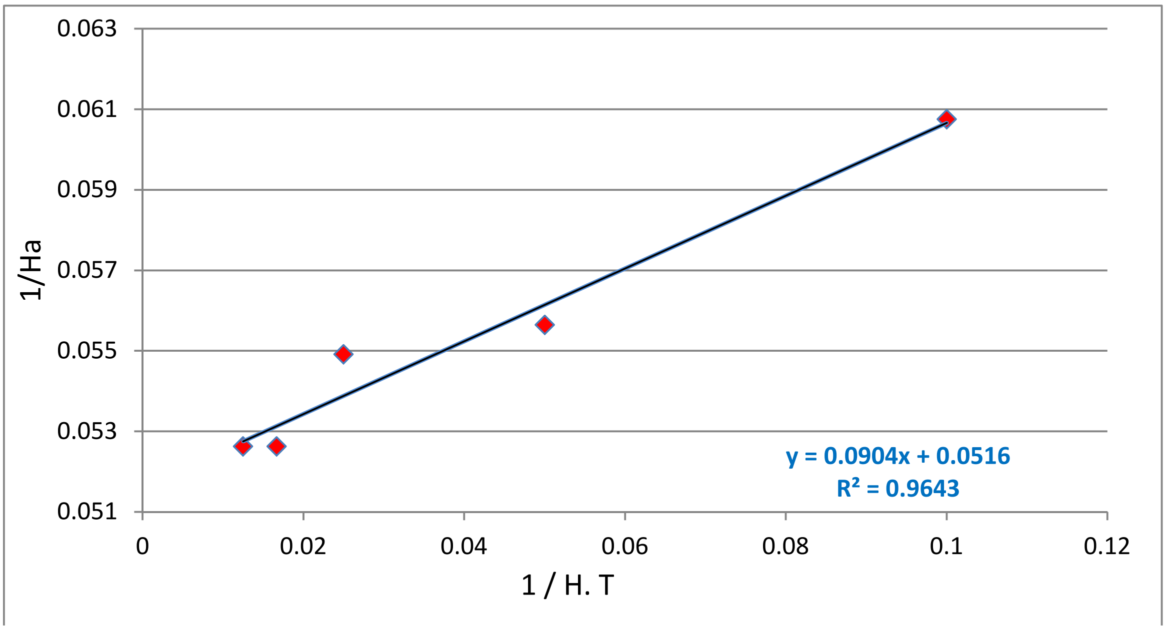

Fig. 2: The linear regression for parameters estimation of the predatory phytoseiid mite *Cydnoseius negevi* feeding on the eggplant *Aceria melongenus* (Y= 0.0904X + 0.0516)Th= 1.2384 hours , a= 1.11 sq.m

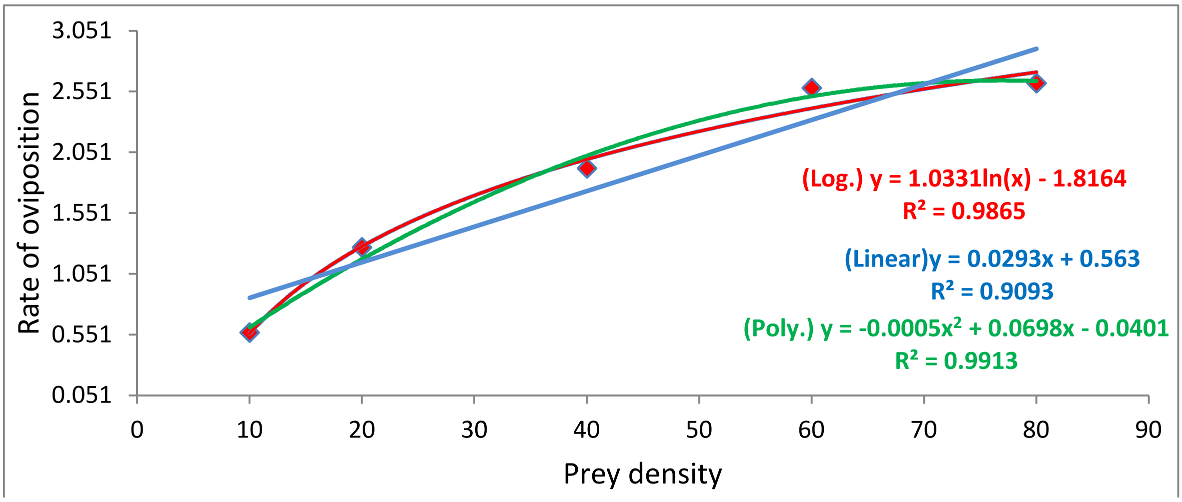

Fig. 3: Regression models for the relationship between density of *A. melongenus* and rate of oviposition of predatory mite *C. negevi.*

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