Research Article

Functional Responses of *Nephus arcuatus* Kapur (Coleoptera: Coccinellidae), the Most Important Predator of Spherical Mealybug *Nipaecoccus viridis* (Newstead)

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Nephus arcuatus Kapur is an important predator of *Nipaecoccus viridis* (Newstead), in citrus orchards of southwestern Iran. This study examined the feeding efficiency of all stages of *N. arcuatus* at different densities of *N. viridis* eggs by estimating their functional responses. First and 2nd instar larvae as well as adult males exhibited a type II functional response. Attack rate and handling time were estimated to be $0.2749\,h^{-1}$ and $5.4252\,h$, respectively, for 1st instars, $0.5142\,h^{-1}$ and $1.1995\,h$ for 2nd instars, and $0.4726\,h^{-1}$ and $0.7765\,h$ for adult males. In contrast, 3rd and 4th instar larvae and adult females of *N. arcuatus* exhibited a type III functional response. Constant *b* and handling time were estimated to be 0.0142 and $0.4064\,h$ for 3rd instars, respectively, 0.00660 and $0.1492\,h$ for 4th instars, and 0.00859 and $0.2850\,h$ for adult females. The functional response of these six developmental stages differed in handling time. Based on maximum predation rate, 4th instar larvae were the most predatory (160.9 eggs/d) followed by adult females (84.2 eggs/d). These findings suggest that *N. arcuatus* is a promising biocontrol agent of *N. viridis* eggs especially for 4th instar larvae and adult females.

1. Introduction

The spherical mealybug, *Nipaecoccus viridis* (Newstead) (Hemiptera: Pseudococcidae), is one of the most important citrus pests in southern and southwestern Iran [1]. This polyphagous pest attacks over 193 plant species throughout tropical and subtropical regions and a large part of the Pacific Basin [2–4]. Chemical control of *N. viridis*, as with other mealybugs, often becomes ineffective due to their cryptic life style in protected locations as well as the presence of a mealy wax that covers its eggs and body [5]. Therefore, biological control using natural enemies has the potential to be an effective alternative method to manage this pest [6–8].

The coccidophagous coccinellid, *Nephus arcuatus* Kapur (Coleoptera: Coccinellidae), is a newly recorded predatory beetle indigenous to the warmer regions of Iran [9]. Until recently, it had only been reported in Yemen and Saudi Arabia [10]. This small coccinellid occurs widely and abundantly in citrus orchards in Dezful, southwestern Iran (personal observation). Recent investigations on the biology and consumption capacity of this predator confirm its potential for the control of *N. viridis* in the citrus orchards [11, 12]. However, more studies are needed to develop this predator within a successful biological management programme.

Prior to using a natural enemy in a biological control programme, it is essential to evaluate its predatory capacity. One of the criteria for determining the efficiency of a predator is the ability of the predator to change its feeding behaviour in response to changes in prey density, that is, its functional response, defined as the number of prey eaten per predator as a function of prey density [13, 14]. Several types of functional response curve have been described, including a linear increase (type I), an increase decelerating to a plateau (type II), or a sigmoidal increase (type III) in which predators cause a constant (I), negative (II), or positive (III) density-dependent mortality of their prey [13, 15, 16].

The functional response curve can be described by evaluating two parameters, the coefficient of attack rate (a) and the handling time (T_h). The coefficient of attack rate estimates the steepness of the increase in predation with increasing prey density and the handling time helps estimate the satiation threshold [16]. Information on these variables can provide insights into the efficiency of a predator in regulating prey populations, clarifying evolutionary relationships, and predicting the predator's effectiveness as a biological control agent [16–18].

This study aimed to determine the relative efficiency of different larval instars and of both female and male adults of *N. arcuatus* as biological control agents of *N. viridis*. We achieved this by evaluating the effect of *N. viridis* density on the number of prey consumed by each life stage of *N. arcuatus* to determine the shape of their functional response to prey density, their attack rate coefficients, and handling times.

2. Materials and Methods

2.1. Prey and Predator Cultures. *N. viridis* mealybugs were collected from *Citrus sinensis* L. trees in an orchard in Dezful (48°30′E, 32°20′N), Khuzestan Province, southwestern Iran, in the autumn of 2011. They were then mass-reared on sprouting potato (*Solanum tuberosum* L.) shoots, in rearing boxes (24 × 16 × 10 cm) that were tightly covered by a fine mesh net. *N. arcuatus* adults were collected from the same orchard and reared on sprouted potatoes infested with *N. viridis* for two generations before being used in experiments. The stock colonies of both *N. arcuatus* and *N. viridis* were maintained in an incubator at 30 ± 1°C, 65 ± 5% RH, and 14L : 10D photoperiod.

2.2. Functional Response Assessments. To obtain a cohort of *N. arcuatus* for experiments, 50 pairs of adult *N. arcuatus* were transferred from the stock culture into a colony of *N. viridis* (mixed developmental stages on 10–12 sprouted potato plants) in a plastic box (20 × 13 × 8 cm) covered with a fine mesh net for ventilation; predator oviposition was allowed to proceed for 12 h after which time the adult predators were removed. Developing predator larvae were observed every 12 h and, over time, developed into cohorts of 1st, 2nd, 3rd, and 4th instar larvae and mated adults males and females (10-day-olds) for use in experiments. Before each developmental stage was evaluated, replicate individuals were kept without food for 12 h in a micro tube (1.5 mL) in order to standardize their hunger level. Thereafter, each predator was introduced into a plastic container (9 × 7 × 3 cm) containing different densities of eggs of *N. viridis* which were the preferred prey for the developmental stage of *N. arcuatus* [19]. Each container had a 20 mm diameter hole in the middle of the lid, which was covered by a piece of fine net to provide ventilation. The densities of *N. viridis* eggs were as follows: 2, 4, 6, 8, 10, 14, and 18 eggs for 1st instar larvae; 2, 4, 8, 16, 20, 30, 40, and 50 eggs for 2nd instar larvae; 2, 4, 8, 16, 20, 40, 60, 80, 100, and 120 eggs for 3rd instar larvae; 2, 4, 8, 16, 32, 60, 100, 140, 180, and 220 eggs for 4th instar larvae; 2, 4, 8, 16, 40, 65, 90, and 115 eggs for adult females; and 2, 4, 8, 16, 20, 35, 50,

60, and 80 eggs for adult males. These densities were selected based on preliminary tests of the consumption capacity of different stages of *N. arcuatus*. After 24 h, predators were removed and the number of eggs consumed was recorded. There were between 10 and 21 replicates for each treatment; greater replication was used for some prey densities to achieve precise information. Experimental conditions were based on optimal temperature for *N. arcuatus* activity: 30 ± 1°C, 65 ± 5% RH, and 14L : 10D photoperiod [11].

2.3. Statistical Analysis. The functional responses of *N. arcuatus* were analyzed in two steps [20]. In the first step, the type (shape) of functional response was described by determining how well the data fitted to a type I, II, or III functional response, using a polynomial logistic regression of the proportion of prey consumed (N_a/N_0) as follows:

$$\frac{N_a}{N_0} = \frac{\exp\left(P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3\right)}{1 + \exp\left(P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3\right)}, \quad (1)$$

where N_a is the number of prey consumed, N_0 is the initial prey density, and the parameters P_0, P_1, P_2, and P_3 are the constant, linear, quadratic, and cubic parameters related to the slope of the curve. The above parameters were estimated using the CATMOD procedure in SAS software [20, 21]. The data sets for each developmental stage of *N. arcuatus* were fitted individually to (1) and the types of functional response were determined by examining the signs of P_1 and P_2. If P_1 was positive and P_2 was negative, a type III functional response was evident. However, if P_1 was negative the functional response type was a type II [20].

In the second step, a nonlinear least squares regression (PROC NLIN [21]) was used to estimate the functional response parameters (T_h and either a for type II functional response or b, c, and d for type III functional response) using Rogers's random predator equation which is the most appropriate type II functional response in situations with prey depletion [22]:

$$N_a = N_0 \left\{1 - \exp\left[a\left(T_h N_0 - T\right)\right]\right\}, \quad (2)$$

where T is the total time that predator and prey are exposed to each other (24 h); a is the attack rate; and T_h is the handling time in hours [20, 23].

For modeling the type III functional response, attack rate (a) in (2) was substituted in (3) with a function of prey density [16, 24]. In the simplest generalized form, attack rate (3) is a function of the initial number of prey:

$$a = \frac{\left(d + bN_0\right)}{\left(1 + cN_0\right)}, \quad (3)$$

where b, c, and d are constants that must be estimated. The simplest form arises when a is a function of initial density, as in

$$N_a = N_0 \left\{1 - \exp\left[\left(d + bN_0\right)\left(T_h N_a - T\right)\left(1 - cN_0\right)\right]\right\}. \quad (4)$$

The functional response parameters for 1st instar and 2nd instar larvae and adult males were obtained using (2) (for type II). However, the functional response parameters for 3rd instar and 4th instar larvae and adult females were obtained using (3) and (4) (for type III).

Differences in estimates of attack rates and handling were analyzed using (5) (type II) or (6) (type III) with an indicator variable as follows [20]:

$$N_a = \Big\{ 1 \\ - \exp \left[- \left(a + D_a \left(j \right) \right) \left(T - \left(T_h + D_{T_h} \left(j \right) \right) N_a \right) \right] \Big\}, \tag{5}$$

$$N_a = \frac{\exp \left[b + D_b \left(j \right) \right] N_0^2 T}{1 + \exp \left[b + D_b \left(j \right) \right] N_0^2 \left[T_h + D_{T_h} \left(j \right) \right]}, \tag{6}$$

where j is an indicator variable that takes the value 0 for the first data sets and the value 1 for the second data sets. For a type II response (5), the parameters D_a and D_{T_h} estimate the differences between the data sets in the values of the parameters a and T_h, respectively. Specifically, the attack rate for one stage is a, and that for another stage is $a + D_a$. If the parameters D_a and D_{T_h} are significantly different from zero, then a and T_h, for the two data sets, are different. For the type III response (6), the parameters D_b and D_{T_h} estimate the differences between the two data sets being compared with the values of b and T_h, respectively. Specifically, the handling time for one stage is T_h, and that for another stage is $T_h + D_{T_h}$ [20].

The maximum predation rate (T/T_h), which represents the maximum number of prey that can be consumed by an individual during 24 h, was calculated using the estimated T_h [25].

3. Results

The polynomial logistic regression analysis of the proportion of *N. viridis* consumed by 1st and 2nd instar larvae and by adult male *N. arcuatus* yielded estimated parameters that indicate a type II functional response for these predator stages (Table 1). The linear coefficient P_1 was negative for these stages; that is, the proportion of prey consumed declined monotonically with an increase in the initial number of prey offered, which indicates a type II functional response (Figures 1 and 2). Therefore, (2) was used to estimate a and T_h. Estimated parameters showed that the 1st instar larva of *N. arcuatus* had the smallest attack rate and handling time compared with 2nd instar larva and adult males (Table 2). The asymptotic 95% confidence interval for D_a included 0 but that for D_{T_h} did not, which means that there is a significant difference between T_h and $T_h + D_{T_h}$ and that these three groups have a different functional response, with a significant difference in handling time, but not in attack rate (Table 3).

Results of the polynomial logistic regression for 3rd and 4th instar larvae and adult female *N. arcuatus* indicate a type III functional response for these predator stages. The linear coefficient, P_1, was positive, and the quadratic coefficient, P_2, was negative for these stages (Table 1). Thus, the proportion of prey consumed is positively density dependent, which

indicates a type III functional response (Figures 1 and 2). Therefore, (3) was substituted for (2), and the two data sets were fitted to a type III functional response curve. Results of the nonlinear least square regression indicated that parameters c and d were not significantly different from 0 (not shown): therefore, they were removed from the model, and a reduced model was used [20]. Similarity relationships between a and N_0 in these data sets ($a = bN_0$) enabled the use of model (6) for data analysis. Both the estimated b value and T_h were smallest for 4th instar larvae followed by adult females. The asymptotic 95% confidence interval for D_b and D_{T_h} showed that there was a significant difference between T_h and $T_h + D_{T_h}$, while there is no significant difference between b and $b + D_b$ (Table 4). Thus, there is a significant difference between T_h and $T_h + D_{T_h}$ and these three groups also have a different functional response, with a significant difference in handling time, but not in constant b (Table 3). For these three groups the relationships between the attack rate and the initial number of prey were linear ($a = bN_0$), and the rate of successful attack (a) ranged from 0.0284 to 1.704 h^{-1} for 3rd instar larvae; from 0.0132 to 1.452 h^{-1} for 4th instar larvae; and from 0.0172 to 0.6872 h^{-1} for adult females.

The value of the coefficient of determination ($R^2 = 1$ – residual sum of squares/corrected total sum of squares) indicated that Rogers's random predator equations ((2) and (4)) adequately described the functional responses of all stages of *N. arcuatus* (see values for R^2, Table 2).

The maximum number of *N. viridis* eggs that could be eaten by all stages of *N. arcuatus* increased with larval instar and adult females consumed more *N. viridis* eggs than adult males (Table 2). This parameter was highest for 4th instar larva followed by adult females and 3rd instar larva.

4. Discussion

The warm, dry climate of southwestern Iran provides suitable conditions for activity of the mealybug, *N. viridis*, in orchards [1]. In these regions, as in many countries, *Cryptolaemus montrouzieri* Mulsant is released to control mealybugs in orchards. However, probably due to warm summers and the symbiotic relationship between ants and mealybugs, this predator has not been able to establish permanent populations and must be mass-reared and released on a yearly basis to control *N. viridis* [8]. In contrast, *N. arcuatus* is the most abundant predator in orchards from spring to fall and often controls *N. viridis* in citrus orchards (personal observation). Zarghami et al. [11] studied the effect of temperature on the population growth and life table parameters of *N. arcuatus* as a predator of *N. viridis* and noted that *N. arcuatus* could develop at a wide range of temperatures (20–35°C), with an optimal temperature of 30°C. They reported that when *N. arcuatus* was provided with two prey species (*N. viridis* and *P. citri*), prey stage, prey size, and previous feeding experience had no effect on prey selection by this predator [12]. Moreover, *N. arcuatus* is considered to be the most effective predator of other mealybugs including *Maconellicoccus hirsutus* (Green) and *Phenacoccus solenopsis* Tinsley due to its large populations and extended periods of activity, especially during the hot summer months [26, 27].

TABLE 1: Results of logistic regression analysis of the proportion of *N. viridis* consumed by different stages of *N. arcuatus* as a function of initial prey density.

Stages of predator	Coefficient	Estimate	SE	χ^2	P value
1st instar	Constant	3.4233	1.0793	10.06	0.0015
	Linear	−0.5926	0.3537	2.81	0.0939
	Quadratic	0.0273	0.0351	0.61	0.4359
	Cubic	−0.00048	0.00106	0.21	0.6474
2nd instar	Constant	9.6343	1.9010	25.69	<0.0001
	Linear	−0.6126	0.1849	10.98	0.0009
	Quadratic	0.0131	0.00565	5.39	0.0202
	Cubic	−0.00010	0.000055	3.23	0.0724
3rd instar	Constant	3.1992	0.3966	65.07	<0.0001
	Linear	0.0411	0.0193	4.56	0.0326
	Quadratic	−0.00143	0.000286	24.96	<0.0001
	Cubic	$7.195E-6$	$1.281E-6$	31.55	<0.0001
4th instar	Constant	4.0195	0.6154	42.67	<0.0001
	Linear	0.0686	0.0162	18.04	<0.0001
	Quadratic	−0.00080	0.000129	38.68	<0.0001
	Cubic	$1.927E-6$	$3.044E-7$	40.09	<0.0001
Adult females	Constant	3.1257	0.6513	23.03	<0.0001
	Linear	0.1424	0.0358	15.78	<0.0001
	Quadratic	−0.00311	0.000575	29.35	<0.0001
	Cubic	0.000015	$2.681E-6$	30.64	<0.0001
Adult males	Constant	13.4559	1.9436	47.93	<0.0001
	Linear	−0.6228	0.1122	30.79	<0.0001
	Quadratic	0.00970	0.00206	22.07	<0.0001
	Cubic	−0.00005	0.000012	17.88	<0.0001

TABLE 2: Parameters estimated by Rogers's random predator equation as well as R^2 and maximum predation rate (T/T_h) for six life stages of *N. arcuatus* fed on *N. viridis*.

Stages of predator	Parameter	Estimate	Approximate SE	Approximate 95% confidence		T/T_h	R^2
				Lower	Upper		
1st instar	a	0.2749	0.1132	0.0493	0.5004	4.4	0.999
	T_h	5.4252	0.2844	4.8583	5.9921		
2nd instar	a	0.5142	0.1662	0.1841	0.8443	20	0.982
	T_h	1.1995	0.0375	1.1249	1.2740		
3rd instar	b	0.0142	0.00344	0.00739	0.0210	59.2	0.989
	T_h	0.4064	0.00604	0.3945	0.4184		
4th instar	b	0.00660	0.00244	0.00177	0.0114	160.9	0.986
	T_h	0.1492	0.00403	0.1412	0.1572		
Adult females	b	0.00859	0.00265	0.00333	0.0138	84.2	0.978
	T_h	0.2850	0.00978	0.2656	0.3044		
Adult males	a	0.4726	0.2252	0.0254	0.9199	30.9	0.976
	T_h	0.7765	0.0318	0.7133	0.8398		

The current study is the first to assess the efficiency of all stages of *N. arcuatus* as a predator of *N. viridis*. We found that different developmental stages of *N. arcuatus* had different types of functional responses. The 1st and 2nd instar larvae as well as adult males exhibited a type II functional response. In contrast, the 3rd and 4th instar larvae and adult females exhibited a type III functional response. This is in accordance with observations for other insects species where the type of functional response and its parameters are affected by developmental stage [28–30]. For example, Bayoumy [28] found that the functional responses of 2nd instar larvae (type II), 4th instar larvae (type III), and adult females (type III) of *Nephus includens* (Kirsch) to *Aphis gossypii* Glover were markedly different. However, Tang et al. [31] and Milonas

TABLE 3: Parameters estimated by an equation with an indicator variable for comparing type II functional response parameters of 1st and 2nd instar larvae and males of *N. arcuatus*.

Comparison stage	Estimate	Approximate SE	Approximate 95% confidence	
			Lower	Upper
1st instar-2nd instar				
D_a	0.2393	0.2465	−0.2473	0.7260
D_{T_h}	**−4.2258***	**0.5222**	**−5.2567**	**−3.1948**
1st instar-male adult				
D_a	0.1978	0.3869	−05661	0.9616
D_{T_h}	**−4.6687**	**0.8715**	**−6.3694**	**−2.9280**
2nd instar-male adult				
D_a	−0.0416	0.2994	−0.6323	0.5492
D_{T_h}	**−0.4229**	**0.0595**	**−0.5402**	**−0.3222**

*Significant difference parameters shown in bold face.

TABLE 4: Parameters estimated by an equation with indicator variable for comparing type III functional response parameters of 3rd and 4th instar larvae and females of *N. arcuatus*.

Comparison stage	Estimate	Approximate SE	Approximate 95% confidence	
			Lower	Upper
3rd instar-4th instar				
D_a	−0.00760	0.00763	−0.0226	0.00743
D_{T_h}	**−0.2572***	**0.0134**	**−0.2835**	**−0.2309**
3rd instar-female				
D_a	−0.00562	0.00545	−0.0164	0.00512
D_{T_h}	**−0.1214**	**0.0116**	**−0.1443**	**−0.0985**
4th instar-female				
D_a	0.00198	0.00407	−0.00604	0.0100
D_{T_h}	**0.1358**	**0.0133**	**0.1095**	**0.1621**

*Significant difference parameters shown in bold face.

et al. [32] reported that functional responses of *Nephus ryuguus* (Kamiya) feeding on *Oracella acuta* (Lobdell) and *N. includens* feeding on *Planococcus citri* (Risso) or *Planococcus ficus* (Signoret), respectively, did not differ depending on developmental stage.

The most common functional response for coccinellids is type II and has been found in many studies: larvae and adults of *N. ryuguus* feeding on *O. acuta* [31]; larvae of *Propylea dissecta* (Mulsant) feeding on *Aphis gossypii* Glover [33]; all four larval instars and adults of *Hippodamia variegata* (Goeze) feeding on *Aphis fabae* Scopoli [34]; and 2nd instar and 4th instar larvae of *N. includens* feeding on *P. ficus* and *P. citri* [32]. In contrast, a type III functional response appears to be relatively rare among coccinellids [18, 28, 30, 35]. A predator with a type II functional response has the potential to destabilize the prey-predatory population because it causes inverse density-dependent mortality in the prey population. In contrast, a predator with a type III functional response could contribute more to regulating the density of the prey population than a predator with a type II response and is, theoretically, more capable of suppressing prey populations compared to stages exhibiting a type II response [13, 36, 37]. The three postulated mechanisms for type III functional

responses in predators are as follows: (1) the concentration of a predator's hunting efforts in a high-density patch [38]; (2) switching in a multiple prey system [36]; and (3) learning [37, 39]. Our experiment with *N. arcuatus* was a short-term, single species test and so the first mechanism is most likely to be responsible for the type III functional response we observed. It is probable that these stages, by showing a type III response, have the ability to regulate prey population during outbreaks of *N. viridis* in citrus orchards.

Our results indicate that estimated attack rates did not change significantly among the different developmental stages of *N. arcuatus* with similar functional response curves observed for all stages. The attack rate determines how steeply the functional response curve rises with increasing prey density. Thus, the results revealed that the steepness did not differ among different developmental stages of *N. arcuatus* and that the different developmental stages had similar abilities to respond to increasing prey densities. In contrast, the prey handling times increased as the larval age of this predator increased, and also females had longer handling times than adult males. In other words, the 1st instar larva of *N. arcuatus* spent more time and 4th instar larvae and adult females spent less time to consume *N.*
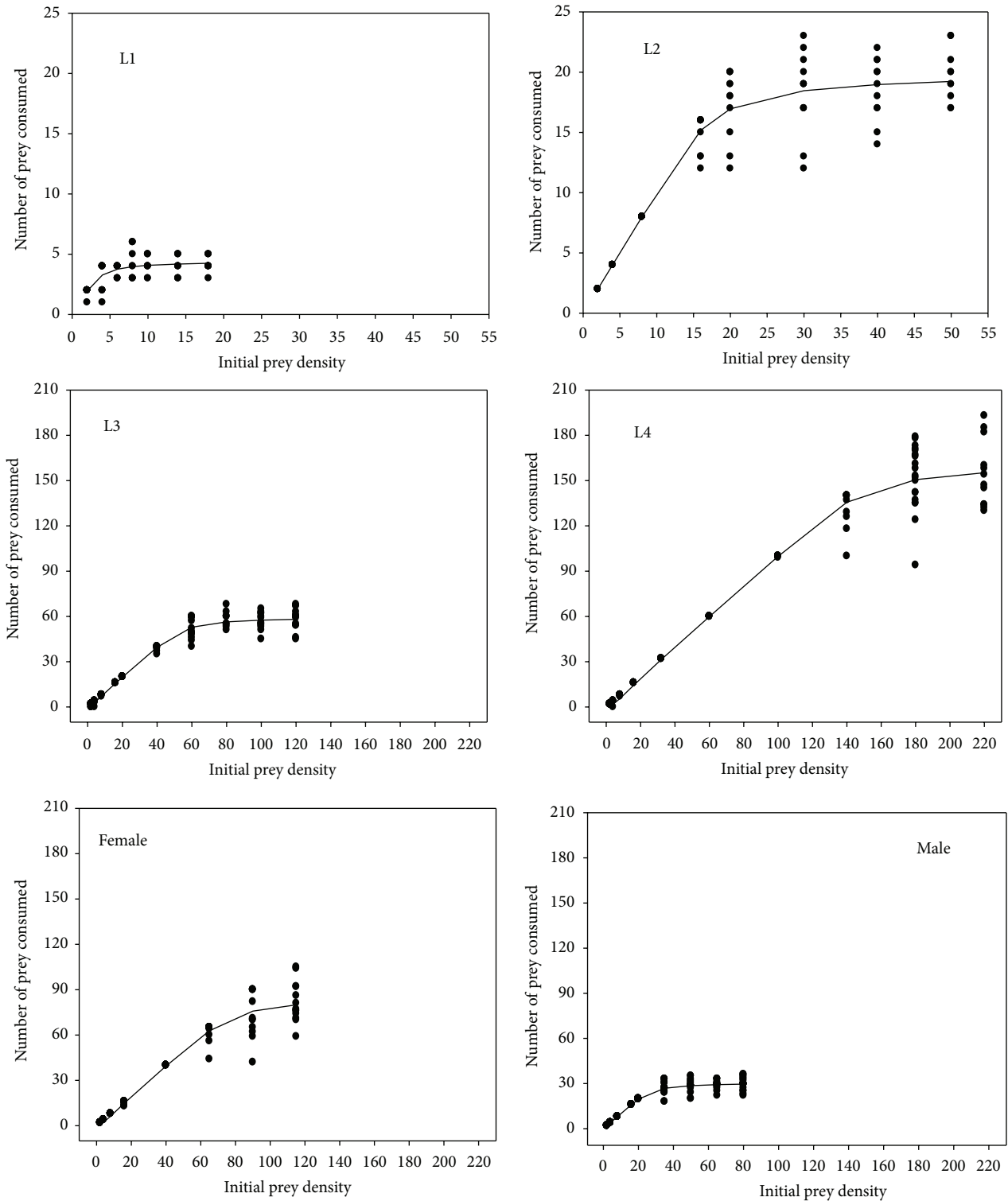
FIGURE 1: Functional responses of *N. arcuatus* to different densities of *N. viridis*. L1: 1st instar larva, L2: 2nd instar larva, L3: 3rd instar larva, L4: 4th instar larva: M: male, and F: female. Symbols are observed data and lines were predicted by model.

viridis eggs than other developmental stages. Handling time is a general term that reflects the cumulative effect of time taken during capturing, killing, subduing, and digesting prey [40]. Thus, being larger is an advantage to 4th instar larvae

and adult females in subduing, consuming, and digesting more prey. Farhadi et al. [34] observed similar results for *H. variegata* feeding on *A. fabae*. Moreover, Bayoumy [28] reported that the functional response of 4th instar larvae
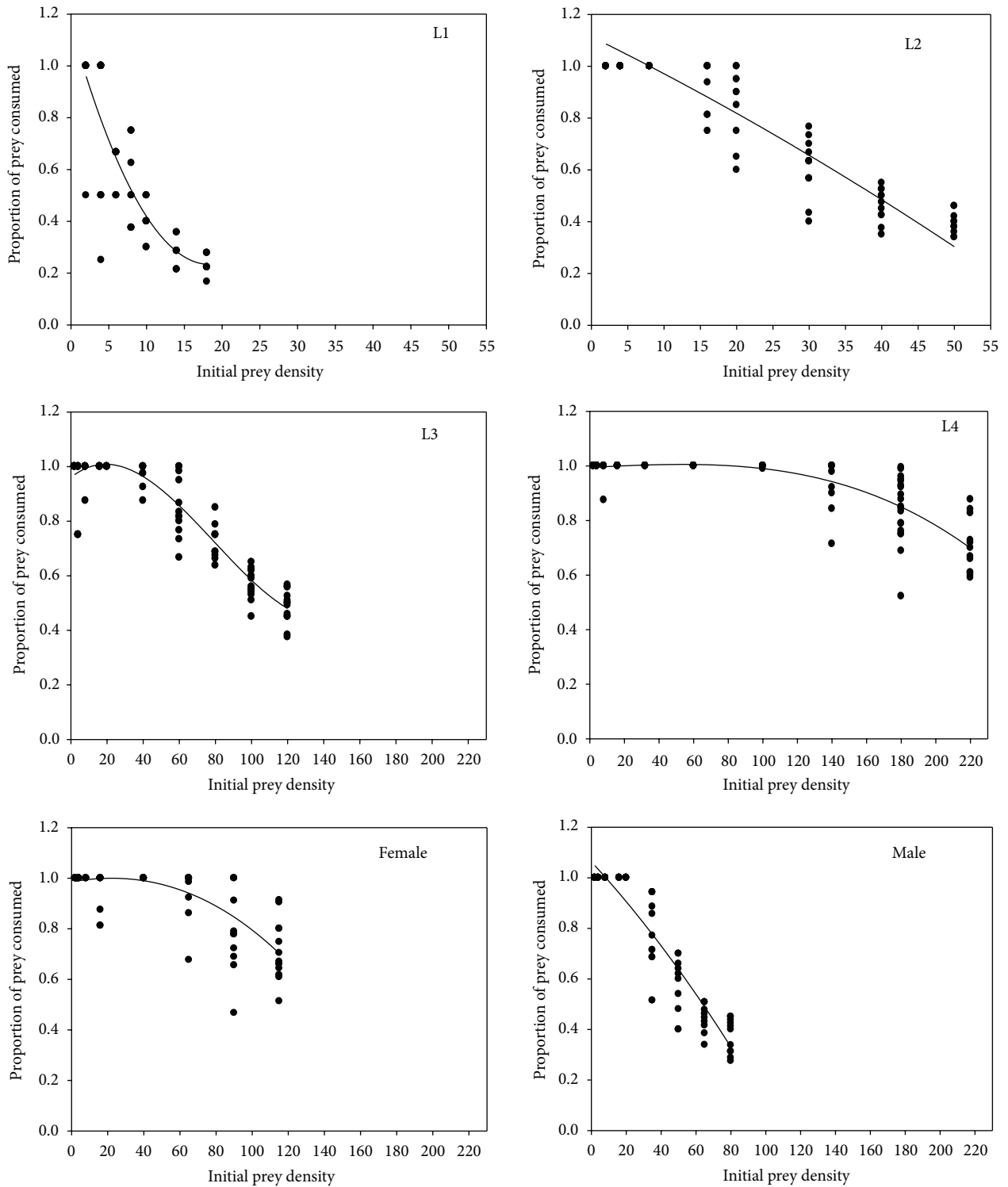
FIGURE 2: Proportion of *N. viridis* consumed by *N. arcuatus* in relation to prey density. L1: 1st instar larva, L2: 2nd instar larva, L3: 3rd instar larva, L4: 4th instar larva, M: male, and F: female. Symbols are observed data and lines were predicted by model.

and adult females of *N. includens* to *A. gossypii* differed in handling time.

The maximum predation rate per day (T/T_h) was highest for 4th instar larvae due to their greater requirements for food and energy to grow and attain the critical weight for pupation

[41] or to achieve a higher search rate [28]. The second highest predation rate was for 3rd instar larvae and the third highest for adult females. These three developmental stages can, therefore, be considered as the most efficient predatory stages of *N. arcuatus*. The voracity of females may be as much as 2.6

times that of adult males. This difference may be correlated with their larger size and high nutrient requirement for egg production and oviposition [42]. The greater voracity of 4th instar larvae compared with adults is also frequently observed in other coccinellid species, for example, *P. dissecta* [33], *H. variegata* [34], and *N. includens* [28]. However, Tang et al. [31] observed that adults of *N. ryuguus* had higher predation rates than 4th instar larvae when preying on *O. acuta*.

Our results also clearly confirm that all stages of *N. arcuatus* show a high predation rate when feeding on *N. viridis* eggs. Muştu and Kilinçer [43] reported that the 4th instar larvae and adults of the related species *N. kreissli* consumed 23.5 and 47.3 eggs of *P. ficus* in 24 h, respectively. Zarghami et al. [19] observed that the males and females of *N. arcuatus* consumed 32.6 and 76.7 eggs of *P. citri* in 24 h. Thus, based on this voracity and the ability of *N. arcuatus* to survive and reproduce at temperatures around 30°C [11], this species could be efficient in controlling mealybugs in warm regions.

5. Conclusion

In conclusion, with respect to type of functional response observed and parameter estimated for all developmental stages of *N. arcuatus*, the most effective predators are, in descending order, 4th instar larvae, adult females, and then 3rd instar larvae. This laboratory study indicates that *N. arcuatus* could be an effective biocontrol agent. Specifically, a mass release of the abovementioned stages of *N. arcuatus* might provide efficient pest management especially in initial field infestations with *N. viridis* eggs. Clearly, empirical data obtained under laboratory conditions cannot be directly extrapolated to field conditions; thus further studies especially on the effect of prey age, prey size, and prey species on functional response, numerical response, long-term predation capacity, and mealybug population suppression under field conditions are needed to evaluate the possibilities for using *N. arcuatus* in inoculative/inundative biological control strategies.

Competing Interests

The authors declare that they have no competing interests.

Acknowledgments

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