



The Potential of Araneae as Biological Control Agents against Honey-wax Pests (Pyralidae)

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ABSTRACT

A diverse array of spider species inhabits agroecosystems and wild mountainsides, where beekeeping boxes are temporarily installed for natural feeding. Over the past decade, the wax moths *Achroia grisella* and *Galleria mellonella* have become widespread pests in bee colonies within Armenian agrosystems and have also caused damage to stored honeybee combs. Spiders, as predators, employ various strategies to eliminate pests in nature and beekeeping boxes, acting as effective biological control agents. This study aimed to evaluate the functional responses of several Aranea species to these pests, providing viable options for biological control technologies without pesticide use. In this research, eleven spider species were tested, and different functional responses were observed against wax moth larvae and adults. The findings highlighted that *Steatoda paykulliana* was the most significant natural enemy and *Thanatus pictus* was the least effective predator. In addition, intraspecific interference among the eleven spider species demonstrated that increased spider density led to a decreased predation ratio. The results further signified a positive correlation between predator density and the intensity of scrambling competition.

Keywords: Araneae, Biocontrol, Functional response, Pyralidae.

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INTRODUCTION

The wax moth species greater *Galleria mellonella* and lesser *Achroia grisella* (Lepidoptera: Pyralidae) are pests of honeybee (*Apis mellifera*) colonies that are distributed worldwide. Their larvae can cause extensive damage to stored wax combs when the bee colony is weak, especially in stressed colonies (Ellis et al. 2013), and transmit incurable and noneliminated viral pathogens (Kwadha et al. 2017). Strong colonies are more preferred by female moths (Williams, 1997). The wax moth is efficient at degrading polyethylene, the most common form of plastic (Bombelli et al. 2017), and can inspire the development of technologies to avoid plastic pollution.

Natural ecosystem and agrosystem pests have been controlled by the indiscriminate use of chemical insecticides for decades. The immense reliance on

pesticides has resulted in biodiversity loss, toxicity issues, and widespread environmental pollution (Brühl & Zaller, 2019). The circulation of natural predators to control pest dynamics is one of the various efforts that have been made recently to combine or even substitute insecticides in the management of integrated or invasive pests (Miller et al. 2006; Di et al. 2021).

Spiders (Araneae) are one of the diverse groups of animals in the world and include 50,105 species according to the World Spider Catalog (World Spider Catalog, 2024). Hence, members of this group are now being used as predators in agrosystem to decrease the use of chemical pesticides, thereby contributing to ecological sustainability.

Several advanced studies have used Spider populations to control pests (Fagan & Hurd, 1991; Hayes & Lockley, 1990). Nyffeler et al. were pioneers in studying the ability of Lycosidae spiders to manage cotton field pests of

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the Noctuidae family and the potential of black widow spiders in tackling wheat field pests (Nyffeler & Benz, 1988; Nyffeler et al. 1992). Young and Edwards studied a few spider species in the USA as predators of crop pests (Young & Edwards, 1990). Furthermore, researchers have revealed the positive effects of spiders in controlling various pests (Marc et al. 1999; Snyder & Wise, 1999) and many investigations have reported encouraging results (Huang et al. 2018; Matteson, 2000). All the previous studies have attempted to represent their outcome around the predator and pest numbers that would be tantamount to the processes in the field or nature (Rodrigues et al. 2013).

This research aimed to evaluate the role of spiders as generalist predators in the biological control of wax moths in beekeeping equipment and to quantify their predation efficiency. In addition, this study intended to identify specific spider species with the highest potential for effective pest management and to understand the behavioral interactions between spiders and wax moths. Furthermore, this investigation sought to evaluate the impact of spider predation on the overall health and productivity of beekeeping operations and to explore the potential for integrating spider-based biocontrol methods with other pest management strategies. This attempt could provide beekeepers with novel approaches for the biological control of pests and aid in healthy product management.

Spider Fauna of Armenia

According to WSC (2024), Armenia is home to 229 spider species belonging to 34 families. Various researchers have documented the spider fauna of Armenia and have contributed to our understanding of its arachnofauna (Ovtsharenko, 1994; Tanasevitch, 1990; Dunin, 1992; Marusik, 1989; Logunov, 2015; Logunov & Guseinov, 2002; Rakov & Logunov, 1997; Dunin & Zacharjan, 1991; Mikhailov, 2000, 2013, 2016; Mikhailov & Propistsova, 2017). More recent studies have been conducted by Zarijian et al. (Zarijian, 2020, 2021, 2022; Zarijian & Kalashian, 2021; Zarijian et al., 2022, 2023).

MATERIALS & METHODS

In this study, 11 species of Araneae that represented 9 families and 9 genera were used (Table 1). These were collected by handpicking sweeping from various regions of Armenia during the experimental period (2021–2022). The spiders were identified based on the identification keys of "Spiders of Europe" (Nentwig et al. 2024). They were installed in plastic boxes (58×37×16 cm) (a separate box for each species) in which a single infected wax comb was laid (infected by both moth species arbitrarily). The laboratory conditions were 26±0.5°C and 60±3% relative humidity.

The spiders were starved for 48h, and then, one adult spider of each species (only female spiders were used to avoid cannibalism) was dropped in each box (Fig. 1). Each box contained one spider and larvae (at the third instar stage) of moths at different densities (10, 20, 30, 40, 50,

Table 1: The spiders' species used as biocontrol agents in the experiment.

No.	Family	Species
1	Agelenidae	<i>Tegenaria domestica</i> (Clerck, 1757)
2	Araneidae	** <i>Araneus quadratus</i> Clerck, 1757
3	Dysderidae	** <i>Dysdera crocata</i> C. L. Koch, 1838
4	Lycosidae	<i>Lycosa praegrandis</i> C. L. Koch, 1836
5		** <i>Lycosa singoriensis</i> (Laxmann, 1770)
6	Philodromidae	<i>Thanatus pictus</i> L. Koch, 1881
7	Pisauridae	** <i>Pisaura mirabilis</i> (Clerck, 1757)
8	Salticidae	<i>Philaeus chrysops</i> (Poda, 1761)
9	Scytididae	<i>Scytodes thoracica</i> (Latreille, 1802)
10	Theridiidae	<i>Steatoda paykulliana</i> Walckenaer, 1805
11		** <i>Steatoda dahli</i> (Nosek, 1905)

**First record for Armenian fauna in this paper.



Fig. 1: *Steatoda paykulliana* installed in an experiment box after starving for 48 h

and 60) (Fig. 2). The experiments were repeated with five replicates per density level. The number of preys that survived after 48 h was recorded. The functional responses of each spider species in each family were analyzed according to the Holling II model (Holling, 1959). The same experiment was performed with adult moths too.

Quantities of larvae and adult moths in each box before and after preying by spiders for 2 days were calculated and recorded in Table 2.

The experiment was continued to determine the intensity of scrambling competition of the spiders toward larvae and adult moths. For this study, spiders from each species were placed in 6 boxes in which 40 larvae (followed by the adults) were laid. There were 1, 2, 3, 4, and 5 spiders per box, with the control box having no spiders (Fig. 3).

The spiders underwent a period of starvation that lasted for 2 days prior to the commencement of the experiment. Each density trial was replicated four times. The count of surviving moths within each enclosure was

Table 2: Functional responses of spiders to larvae and adults of moths (a') the spider's attack coefficient, (N) the density of the moths, (Na) the number of moths (larvae or adults) predated by the spider, (r) the fitting coefficient, (Th,) the spider's handling time per moth, and (N max) the maximum number of moths predated by the spider

Spider species	Life stage of prey	Equation of functional response	r	Th(h)	a'	Nmax
<i>T. domestica</i>	larva	$1/N_a = 3.233/N + 0.072$	0.905	0.072	0.309	10
	adult	$1/N_a = 7.99/N + 0.078$	0.974	0.078	0.125	6.2
<i>A. quadratus</i>	larva	$1/N_a = 8.951/N + 0.003$	0.994	0.003	0.111	13.6
	adult	$1/N_a = 4.139/N + 0.241$	0.977	0.031	0.241	17.8
<i>D. crocata</i>	larva	$1/N_a = 4.058/N + 0.017$	0.997	0.017	0.246	21.08
	adult	$1/N_a = 22.369/N + 0.102$	0.998	0.102	0.044	12.8
<i>L. praegrans</i>	larva	$1/N_a = 2.407/N + 0.007$	0.994	0.007	0.415	40.2
	adult	$1/N_a = 2.726/N + 0.013$	0.993	0.013	0.439	32.6
<i>L. singoriensis</i>	larva	$1/N_a = 2.298/N + 0.008$	0.988	0.008	0.435	41.8
	adult	$1/N_a = 2.869/N + 0.15$	0.977	0.15	0.348	33.2
<i>Th. pictus</i>	larva	$1/N_a = 41.8/N + 0.525$	0.928	0.525	0.023	1.8
	adult	$1/N_a = 30.78/N + 0.182$	0.970	0.182	0.032	4.2
<i>P. mirabilis</i>	larva	$1/N_a = 4.722/N + 0.024$	0.989	0.024	0.211	19
	adult	$1/N_a = 9.393/N - 0.005$	0.995	0.005	0.106	16.8
<i>Ph. chrysops</i>	larva	$1/N_a = 3.2/N + 0.033$	0.973	0.033	0.312	22.2
	adult	$1/N_a = 2.836/N + 0.33$	0.966	0.33	0.352	23.8
<i>S. thoracica</i>	larva	$1/N_a = 53.265/N - 0.212$	0.997	0.212	0.018	3.8
	adult	-	0	0	0	0
<i>S. paykulliana</i>	larva	$1/N_a = 2.344/N + 0.008$	0.989	0.008	0.426	40.6
	adult	$1/N_a = 1.9016/N + 0.012$	0.969	0.012	0.521	42.2
<i>S. dahli</i>	larva	$1/N_a = 3.724/N + 0.028$	0.956	0.028	0.268	22
	adult	$1/N_a = 5.171/N + 0.013$	0.991	0.013	0.193	20.8



Fig. 2: Graphic explanation of the first part of the experiment

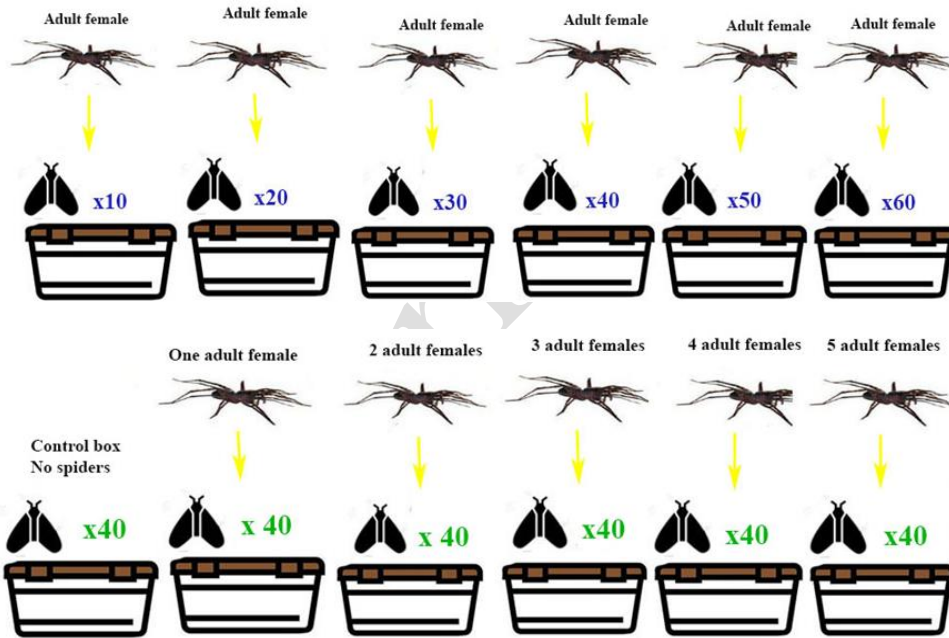


Fig. 3: Graphic explanation of the part of the experiment showing the intensity of spiders' scrambling competition

recorded after 1 day. Intraspecific competition among spiders for predation on both moth larvae and adults was assessed using the Hassell model (Hassell & Varley, 1969).

The spiders utilized in this study were taxonomically identified and preserved as vouchers in the collections of the Scientific Center of Zoology and Hydroecology at the Institute of the National Academy of Sciences of the Republic of Armenia.

Data Analyses

The Holling type II formula was used to calculate the predatory functional response, as follows:

$$N_a = a'TN / (1 + a'ThN) \tag{1}$$

Where, N represents the prey density, N_a denotes the number of preys consumed, T indicates the time required for the predator to locate the prey ($T = 2$ days or 48 h), a' signifies the instantaneous attack rate, and Th represents the time required by the predator to handle one individual, considering a box area of 0.2146 m². The parameters a' and Th were measured using a nonlinear least-squares method. Initially, starting values for a' and Th required for the nonlinear regression (NLR) procedure were determined via linear regression of $1/N_a$ against $1/N$. The resulting y-

intercept served as the initial estimate for T_h , whereas the reciprocal regression coefficient provided an estimate for a' . N_a and N were determined experimentally; on the contrary, a' and T_h were derived computationally. Equation (2)

All experimental data regarding the intraspecific disturbance of spider predation on moth larvae and adults were analyzed using the Hassell model, as expressed below:

$$E = QP^{-m} \quad (2)$$

Where, E represents the predation ratio of the spiders, P denotes the spider density, Q signifies the searching constant, and m represents the interference constant. Q and m were estimated using the following equation:

$$E = \frac{N_a}{N \times P} \quad (3)$$

Where, N_a represents the aggregate number of moths consumed by all spiders, N denotes the density of moths, and P indicates the density of spiders.

The predation competition among spiders for the prey was characterized using scrambling competition. Hence, the intensity of scrambling competition (I) among spiders was quantified using the following equation:

$$I = \frac{E_1 - E_p}{E_1} \quad (4)$$

Where, E_1 represents the predation ratio of a single spider and E_p signifies the predation ratio with a density of spiders denoted by P . The correlation between the intensity of scrambling competition (I) and spider density (P) was derived using the following equation:

$$I = a \lg P + b \quad (5)$$

According to the values of I , the parameters a and b were estimated. All collected data were analyzed using MS Excel 2007 and IBM SPSS statistic 20.

RESULTS

The functional response of the spiders used in this research toward moth larvae and adults was determined. The functional response equations of each species are presented in Table 2 for the 11 species studied. The results indicated that spiders from the same species exhibited varying functional responses to the pest larvae and adults. The fitting coefficients of the 22 equations ranged from 0.905 to 0.998, which implied that these equations were a good fit for all the examined species, with the exception of *Scytodes thoracica*. *Steatoda paykulliana* demonstrated the highest ability toward the adults of moths, followed by *Lycosa singoriensis* toward the larvae. Both *S. paykulliana* and *Lycosa praegrandis* exhibited a high reaction toward the larvae, and the highest attack coefficient (0.439) was reached by *L. praegrandis* toward the pest's adults and the shortest T_h (that is, 0.003 h) by *Araneus quadratus* toward the pest's larvae.

This study examined the functional response of spiders to moth larvae and adults. Table 2 presents the functional response equations for each of the 11 species explored. The findings revealed that spiders belonging to the same species exhibited varying functional responses to

pest larvae and adults. The fitting coefficients of the 22 equations ranged from 0.905 to 0.998, which suggested a good fit for all species, except *S. thoracica*. Notably, *S. paykulliana* displayed the highest predation ability against moth adults, followed by *L. singoriensis*, which targeted the larvae. In addition, both *S. paykulliana* and *L. praegrandis* showed strong reactions to larvae. Of these, *L. praegrandis* presented the highest attack coefficient (0.439) against pest adults, and the shortest handling time (0.003 h) was observed for *A. quadratus* when preying upon pest larvae. Thus, *S. paykulliana* was the most important natural enemy, while *Thanathus pictus* had insufficient predatory abilities toward wax moths.

Intraspecific Disturbance and Intensity of Scrambling Competition on Moth Larvae and Adults

The predation ratio was calculated based on Equation (3) and N_a values (Table 3), as shown in Table 3. N_a and E_p of each spider decreased gradually with the increase in spider density. The searching constant (Q) and the interference constant (m) were calculated with the Hassell model to fit the predator density (Equation 2) using the NLR model (Table 4). In most cases, the fitting coefficients of these equations ranged from 0.797 to 0.990. However, in certain species, this coefficient exceeded 0.990, which alludes that the predation rate of the species was considerably correlated with its density and that the predator density interfered with its predation on moths. This finding denotes that an increase in predator density led to an increase in the interference effect between spider individuals, and as a result, the general predation rate decreased. Significant variations were noted in the Q and m values for both moth larvae and adults. The intensity of scrambling competition, as presented in Table 3, was calculated using Equation (4), whereas the parameters a and b of Equation (5) in Table 5 were estimated using the NLR model. The intensity of scrambling competition was positively correlated with increasing spider density.

DISCUSSION

The wax moths *A. grisella* and *G. mellonella* are the major pests of honey wax, and they attack the honey-producing boxes in most moist areas, especially in territories adjoining forest areas in Armenia. These moths have developed high levels of resistance against pesticides to the extent that using chemical methods is not effective anymore (Cotter et al. 2000). However, the role of natural predators of *A. grisella* and *G. mellonella* as spiders in agricultural ecosystems has not been studied extensively. Spiders are the most prevalent predators in the vicinity of beekeeping equipment, and certain species within this group play a significant role in curbing pest populations. Understanding the dynamics between predators (spiders) and pests is a primary objective in global pest management efforts. To implement environmentally safe strategies, various eco-sustainable control methods and integrated pest management programs have recently been evaluated (Zappala et al. 2012).

Table 3: Predation ratio and intensity of scrambling competition of spiders toward two species of moths and their larvae, (Ep) the predation ratio with P density of spiders, (I) the intensity of the scrambling competition, (Na) the total number of pests preyed on by all of the spiders in the container

Spider	The life stage of prey	Spider density	Na	Ep	I
<i>T. domestica</i>	larva	1	5	0.125	0.000
		2	4.5	0.056	0.552
		3	4	0.033	0.736
		4	4.5	0.028	0.776
		5	4.6	0.023	0.816
	adult	1	4	0.1	0.000
		2	3.5	0.043	0.57
		3	3.6	0.03	0.7
		4	4	0.025	0.75
		5	3.8	0.019	0.81
<i>A. quadratus</i>	larva	1	9	0.225	0.000
		2	7.5	0.093	0.586
		3	7.3	0.06	0.733
		4	7.25	0.045	0.8
		5	6.6	0.033	0.853
	adult	1	10	0.250	0.000
		2	8	0.100	0.6
		3	8	0.066	0.736
		4	7.5	0.046	0.816
		5	6.8	0.034	0.864
<i>D. crocata</i>	larva	1	13	0.325	0.000
		2	9	0.112	0.655
		3	7.6	0.063	0.806
		4	7.7	0.048	0.852
		5	7.2	0.036	0.889
	adult	1	7	0.175	0.000
		2	5	0.062	0.645
		3	5	0.041	0.765
		4	5.2	0.032	0.817
		5	4.8	0.024	0.862
<i>L.praegrans</i>	larva	1	14	0.350	0.000
		2	9.5	0.118	0.662
		3	8	0.066	0.811
		4	8	0.050	0.857
		5	7.6	0.038	0.891
	adult	1	11	0.275	0.000
		2	8.5	0.106	0.614
		3	7.3	0.060	0.781
		4	7	0.043	0.843
		5	6.6	0.033	0.880
<i>L. singoriensis</i>	larva	1	17	0.425	0.000
		2	10.5	0.131	0.691
		3	9	0.075	0.823
		4	7.75	0.048	0.887
		5	8	0.004	0.990
	adult	1	14	0.350	0.000
		2	9.5	0.118	0.662
		3	8.3	0.069	0.802
		4	7.5	0.046	0.868
		5	7.2	0.036	0.897
<i>Th. Pictus</i>	larva	1	2	0.050	0.000
		2	2	0.025	0.500
		3	2.3	0.019	0.620
		4	2.5	0.015	0.700
		5	2.8	0.014	0.720
	adult	1	3	0.075	0.000
		2	3	0.037	0.506
		3	4	0.033	0.560
		4	4.25	0.026	0.653
		5	4.4	0.022	0.706
<i>P. mirabilis</i>	larva	1	8	0.200	0.000
		2	5.5	0.068	0.660
		3	6.6	0.055	0.725
		4	6.5	0.040	0.800
		5	5.8	0.029	0.855
	adult	1	6	0.150	0.000
		2	4.5	0.056	0.626
		3	6.6	0.055	0.633
		4	5.75	0.035	0.766
		5	5.4	0.027	0.820
<i>Ph.Chrysops</i>	larva	1	12	0.300	0.000
		2	9.5	0.118	0.606

adult	3	6.6	0.055	0.816	
	4	7.5	0.046	0.846	
	5	6.6	0.033	0.890	
	1	13	0.325	0.000	
	2	10.5	0.131	0.596	
<i>S. thoracica</i>	larva	3	9	0.075	0.769
		4	7.75	0.048	0.852
		5	6.6	0.033	0.898
		1	1	0.025	0.000
		2	1.5	0.018	0.280
adult	3	1.3	0.010	0.600	
	4	1.75	0.010	0.600	
	5	2	0.010	0.600	
	1	0	00	0.000	
	2	0	00	0.000	
<i>S. paykulliana</i>	larva	3	0	00	0.000
		4	0	00	0.000
		5	0	00	0.000
		1	22	0.550	0.000
		2	13.5	0.168	0.694
adult	3	11.3	0.094	0.829	
	4	10	0.062	0.887	
	5	8	0.040	0.927	
	1	27	0.675	0.000	
	2	15	0.187	0.722	
<i>S. dahli</i>	larva	3	13	0.108	0.840
		4	10	0.062	0.908
		5	8	0.040	0.940
		1	11	0.275	0.000
		2	8.5	0.106	0.614
adult	3	7.6	0.063	0.770	
	4	6.75	0.042	0.847	
	5	6	0.030	0.890	
	1	9	0.225	0.000	
	2	7.5	0.093	0.586	
adult	3	7	0.058	0.742	
	4	6.25	0.039	0.826	
	5	5.6	0.028	0.875	

Table 4: The intraspecific disturbance equations of the spiders: searching constant Q and interference constant m.

Spider species	Life stage of prey	Searching constant Q	Interference Constant m	Fitting coefficient
<i>T. domestica</i>	larva	0.120	1.065	0.989
	adult	0.095	1.005	0.989
<i>A. quadratus</i>	larva	0.220	1.173	0.998
	adult	0.245	1.221	0.998
<i>D. crocata</i>	larva	0.307	1.365	0.994
	adult	0.162	1.210	0.989
<i>L. praegrans</i>	larva	0.329	1.380	0.993
	adult	0.269	1.325	0.999
<i>L. singoriensis</i>	larva	0.613	2.421	0.797
	adult	0.335	1.420	0.997
<i>Th. pictus</i>	larva	0.047	0.804	0.984
	adult	0.071	0.732	0.972
<i>P. mirabilis</i>	larva	0.183	1.143	0.975
	adult	0.140	1.005	0.952
<i>Ph. chrysops</i>	larva	0.295	1.384	0.990
	adult	0.337	1.410	0.998
<i>S. thoracica</i>	larva	0.025	0.639	0.901
	adult	0.000	0.000	0.000
<i>S. paykulliana</i>	larva	0.538	1.597	0.998
	adult	0.665	1.724	0.997
<i>S. dahli</i>	larva	0.276	1.366	1.000
	adult	0.227	1.280	0.999

Numerous studies employing the Holling II model have attempted to elucidate the functional response of spiders, yielding results similar to those observed in the current investigation (Maloney et al. 2003; Rao and Kanaujia, 2023). These studies have indicated that as the moth density increases, the spider predation initially rises before reaching a plateau (Lin et al., 2006; Huang et al., 2018). Functional response curves for these spiders typically exhibit the characteristics of type II, wherein prey

Table 5: The equation of intensity of the scrambling-competition for spider's larvae and adults.

Spider species	Life stage of prey	Equation of Intensity of scrambling-competition	r
<i>T. domestica</i>	larva	$I = 0.509 \lg P + 0.088$	0.920
	adult	$I = 0.494 \lg P + 0.093$	0.913
<i>A. quadratus</i>	larva	$I = 0.525 \lg P + 0.092$	0.923
	adult	$I = 0.531 \lg P + 0.094$	0.922
<i>D. crocata</i>	larva	$I = 0.548 \lg P + 0.116$	0.892
	adult	$I = 0.526 \lg P + 0.114$	0.888
<i>L. praegrans</i>	larva	$I = 0.550 \lg P + 0.118$	0.888
<i>L. singoriensis</i>	adult	$I = 0.547 \lg P + 0.100$	0.915
	larva	$I = 0.594 \lg P + 0.110$	0.916
<i>Th. pictus</i>	adult	$I = 0.554 \lg P + 0.115$	0.895
	larva	$I = 0.449 \lg P + 0.078$	0.923
<i>P. mirabilis</i>	adult	$I = 0.424 \lg P + 0.079$	0.914
	larva	$I = 0.513 \lg P + 0.117$	0.878
<i>Ph. chrysope</i>	adult	$I = 0.487 \lg P + 0.103$	0.885
	larva	$I = 0.556 \lg P + 0.099$	0.914
<i>S. thoracica</i>	adult	$I = 0.558 \lg P + 0.089$	0.935
	larva	$I = 0.408 \lg P + 0.025$	0.917
<i>S. paykulliana</i>	adult	-	-
	larva	$I = 0.568 \lg P + 0.123$	0.888
<i>S. dahli</i>	adult	$I = 0.576 \lg P + 0.131$	0.878
	larva	$I = 0.551 \lg P + 0.097$	0.992
	adult	$I = 0.541 \lg P + 0.088$	0.934

consumption peaks with escalating pest density (Mansour & Heimbach, 1993). A plausible explanation lies in the saturation of predation demands once food requirements are met, thus curtailing further predation activity.

Predation escalates with an increase in prey numbers but diminishes with heightened prey density, and a positive correlation exists between I and P (Wu & Wang, 1987). Moreover, predators exhibit reduced predation rates in high-density environments when compared with individual spiders (Pérez-Guerrero et al., 2013).

Intraspecific interference among the 11 spider species under study was assessed using the Hassell model. As the spider density increased, predation ratios declined. Nonetheless, a positive correlation emerged between the intensity of scrambling competition and predator density, which signified a surge in scrambling competition intensity with increasing spider density (Chen et al. 2010).

Conclusion

This research was focused on 11 abundant spiders and investigated their potential to control wax moths. The findings revealed that certain spider species are effective biocontrol agents in wax moth pest management. *S. paykulliana*, *L. singoriensis*, and *L. praegrans* were highly fierce and exhibited a high predatory rate toward moths; hence, these can be used as pest control agents after evaluating the pest density in the honey-keeping boxes. On the contrary, *T. pictus* and *S. thoracica* exhibited the least predatory effects. Intraspecific interactions among the studied spider species were evident. When five spiders were confined to a single enclosure, no aggressive behavior was observed. Nonetheless, an increase in interference among individual spiders led to prolonged prey-searching times and reduced the predation efficiency for each spider.

To validate the applicability of the laboratory findings, the experiment was replicated under natural field conditions, accounting for variables such as activity space, niche overlap, developmental stages, bee community

structure, and predator-prey interactions, all of which can impact predator behavior. Laboratory-reared spider populations were introduced into beekeeping environments, where certain colonies were afflicted by the same pest. The field observations closely paralleled those obtained under controlled laboratory settings, albeit with some noticeable variations. These findings will be elaborated upon in a forthcoming publication.

Data Availability Statement

The data presented in this study are available on request from the corresponding author. The voucher material was deposited in the invertebrate collection of NAS RA Scientific Centre of Zoology and Hydro-ecology Institute.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Author's Contribution

Conceptualization, R.P.; methodology, L.H.; formal analysis, M.V.; investigation M.R.; writing & reviewing N.Z.; editing, K.A.; visualization, R.P., and R.H.; data collection, M.M., and Z.D. All authors have read and agreed to the published version of the manuscript.

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