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The functional response of *Aphidius ervi* (Haliday)(Hym.: Braconidae, Aphidiinae) to different densities of *Sitobion avenae* (Fabricius)(Hom.: Aphididae) on two wheat cultivars

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Abstract- The functional response of *Aphidius ervi* to different *Sitobion avenae* densities on two wheat cultivars (Sardary and Alvand) was examined in laboratory conditions. Experiments were carried out in test tubes on an F_2 lab generation without wheat clusters and also on F_2 and F_5 generations in pots using wheat clusters. In the tubes, female wasps were exposed to aphid densities of 2, 4, 7, 14, 28, 32, 42 and 56 for one hour, but on the potted plants, to the same densities of aphids for 24 hours. Results obtained from the logistic regression indicated types II (Holling's model) and III (Roger's model) in all 3 experiments on Alvand as a resistant cultivar and Sardary as a sensitive cultivar, respectively. The type II model of functional response fitted on data obtained on the Alvand cultivar indicates a negative bottom top impact of the resistant cultivar on the parasitoid. The model parameters estimated for F_2 and F_5 wasps were not significantly different for the Sardary cultivar. However, the area of discovery and handling time in the F_5 generation on the Alvand cultivar were higher than that of F_2.

Keywords: ***Aphidius ervi*, Functional response, *Sitobion avenae***

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important cereal used by humans either directly or indirectly. This precious plant has the first ranking of cultivation area and global production as compared to other types of products and uses up approximately 12.5% of global and 70% of Iranian fields. The average annual world production of wheat is 500 million tons 2.8% or 14 million of which is produced in Iran (11).

More than 100 pest species from several insect orders have destructive activity on wheat. The most important order is Homoptera including Aphids.

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Rhopalosiphum padi (L.), *Metopolophium dirhodum* (Wlk.), *Sitobion avenae* (F.), *Schizaphis graminum* (Rondani), and *Diuraphis noxia* (Mordvilka) are among the major wheat pests worldwide (4).

One important approach for controlling insect pests is the use of natural enemies according to IPM which has been done worldwide in the recent decades (10). Various types of natural enemies feed on aphids in wheat fields, among which parasitoids have significant existence (2).

Parasitoid wasps from the Aphidiinae subfamily (family: Braconidae) are known as the most important factor for controlling aphids. *Aphidius ervi* from the above category has a destructive role on *Sitobion avenae*. Until now, the activity of this parasitoid on different cereal aphids and green peach aphid has been recognized (7).

When analyzing the interaction between parasitoid and host by using quantitative models, descriptive parameters of such models can be used for predicting the parasitoid – host relations (3). The basic element in these models is the functional response which was first defined by Solomon (1949) as the relation between the number of attacked hosts by a predator and the host densities (13). The reason for applying the name "functional response" is that the number of attacked hosts by a parasitoid will be a function of the host densities (5). Holling (1959) found 3 types of functional responses and their curves. In the first type the number of attacked hosts increases in a linear manner as do the host densities to reach the maximum level and then remains stable. In this case the percentage of attacked hosts is constant (independent from the densities) and then decreases. In the second type of functional response, the number of attacked hosts increases as the host densities decrease, but not in a linear manner, and the curve grade decreases gradually till it reaches a steady state. In this case, the percentage of attacked hosts decreases gradually (depending on the inverse densities). Van Emden (1987) believes that whenever the natural enemy is dependent on the inverse densities, the percentage of attacked hosts on the resistant genotype increases because this genotype results in the reduction of pest densities on itself and so there will be a positive (synergistic) impact between the resistant genotype and biological control (16). In functional response type III, the number of attacked hosts follows a sigmoid (S shape) curve in which the slope increases at first but then decreases. In this case the percentage of attacked hosts increases (depending on densities) and then decreases. Based on another one of Van Emden's triple theories (16),if the natural enemy is dependent on the hosts' densities, the mutual impact between the resistant genotype and the biological control will be negative (Antagonistic), because the percentage of attacked hosts on the resistant genotype decreases. Various kind of plants can influence the behavior and function of natural enemies by physical and biochemical features and may also act indirectly through artificial diets (8, 9).

The aim of the present research was to study the functional response of the parasitoid wasp *Aphidius ervi* to the various densities of aphid *Sitobion avenae*, and estimating the effects of wheat genotypes on the behavioral features of the parasitoid during various laboratory generations. It results in the evaluation of the mutual influences of a resistant host and the biological control for an integrated management plan of the aphid. At this point not only the influence of physical features but also the indirect effect of the host plant on the parasitoid through an artificial diet was investigated.

MATERIALS AND METHODS

Experiment Designing

Densities 2, 4, 7, 14, 28, 32, 42, 56 of *Sitobion avenae* were used for investigating *Aphidius ervi* functional response. The aphids were obtained from parthenogenetic stocks which had grown on 2 wheat genotypes in pots containing Sardary and Alvand genotypes under greenhouse conditions. The 2 genotypes were screened from 8 genotypes of wheat during two experiments. Consequently, Sadary and Alvand were determined as sensitive and resistant respectively. In order to prove this, two different methods, the index of relative growth average and the length of aphids growth period, were used.

Parasitoids were obtained from the Agricultural Research Center in Fars province. The F_2 and F_5 generations of the wasps were reared on aphids which were feeding on the two selected wheat genotypes. The wasps were starved for 24 hours after emergence and developed in an incubator under certain conditions: temperature of 25±1^{oc}, relative humidity of 50±5 percent and the photoperiod of 16:8 hours (light: darkness).

Functional response of the parasitoid was studied in three situations, in an incubator under the mentioned conditions and in a completely random plan with 6 replicates. In the first situation, test tubes with the length of 14.5cm and the diameter 2cm were used. The various density of aphids grown on two genotypes of wheat, were put on the leaves in an experimental tube with a 24-hour old female parasitoid from the F_2 generation. After 1 hour, the wasps were expelled from the experimental tube and the tubes were put in the incubator. After a new generation emerged from mummies, the number of parasitized aphids were counted.

The second experiment was done in potted plants. In this case, parasitic wasps from the F_2 generation were used for 24 hours. After seeding in the pots, 25 tillers from each genotype were selected. Various densities of aphids were put on top of one tiller in the pot, each pot covered with a transparent cylindrical polythene cage. After 24 hours, the wasps were expelled from the cage and aphids were put in glass tubes until the emergence of wasps.

In the third situation, the experiments were similar to the second; the only difference being the use of F_5 generation parasitoids obtained from aphids on Sardari and Alvand genotypes.

Data Analysis

The functional response data was analyzed in two steps by using SAS software. In order to estimate the type of functional response, first, the logistic regression was performed on the proportion of parasitized aphids (Na) to initial density (N). This regression demonstrates the slope rate and the negative or positive slope of the three main parts of the cubic equation i.e. the linear, quadratic, and cubic parts. By considering this in type II functional responses, the increasing host density leads to a decreasing rate of parasitized hosts (inverse density dependent). Consequently, the first part of this curve, i.e. the linear part, has a negative slope, hence its estimated number will be negative as well, concluding that the reaction is a second type functional response.

In the third type functional response, with increased host density, the proportion of parasitized hosts increases at first (direct relationship to the host density), and then decreases. The estimated number is positive for the linear part and indicates that the curve slope is positive. Hence, the positive or negative mark of the part Na/N in the linear curve represents second or third type functional responses regardless of the other parts. In the second step, after determining the type of functional response, by using nonlinear regression (least square method and DUD technique), the parameters of area of discovery or attacking factor (a) and the handling time (Th) were estimated. The parameter (a) shows the searching power of the parasitoid (6) and is sometimes defined as the proportion of the whole area that one parasitoid searches during the time of testing (for example, one hour in the test tube and 24 hours in the pot).

Hassell (1978) argued that searching power determines the speed with which the functional response curve reaches its highest part (3). The "handling time" is the time that one parasitoid spends finding and parasitizing a host, cleaning itself and relaxation.

In a functional response curve, the highest part of the curve (maximum parasitization) is determined by "Handling time". The parameters a (or b) and Th have a comparative aspect for evaluating the affection of different genotypes of host plants on the parasitic behavior of parasitoids.

In the performed experiments with the affection of the resistant Alvand genotype, the second type of Holling's model (model number 1), and with the affection of the sensitive Sardari genotype, the third type of Rogers' model (model number 2) were used. The mentioned models have already been used for both predators and parasitoids.

1) Na = a T N/1 + a Th N
2) Na = N [1 – exp (a (Th Na – T))]
3) a = (d + bN) / (1+ cN) (Full model)
4) a = d + bN c = 0 (Reduced model 1)
5) a = bN c = 0 , d = 0 (Reduced model 2)

Na = the number of parasitized hosts
N= the primary density of host
T= the time of experiment (test)
a= area of discovery
exp= the natural logarithm
b,c,d= fixed numbers
Th = handling time

Rogers' model, with the complete equation (replacing 3 for 2) and all 3 parameters d, c, b, was used for estimating searching power and handling time in several tests on the third type of functional response (using Sardari genotype).The parameter c in the second step and the factors c and d in the third step were set to zero necessarily (with the replacement of factors 4 and 5 in equation 2 respectively). Finally, the decreased model was used. Whenever the complete model for estimating the parameters of functional response type III was used, the confidence level of each parameter was zero. This means that the related parameter is not significantly difference from zero. In this situation, parameter c should be set to zero. This was repeated in the next step with both c and d until the estimation of b and Th parameters. In this situation, a=bN. The main point is that in estimating the parameters of functional response, factor b must be greater than zero.

In all experiments, the maximum parasitism calculated by the models of functional response through the proportion of total time of test to handling time (T/Th) and the comparisons between different experimental situations were done from this viewpoint.

RESULTS AND DISCUSSION

The outcome of the logistic regression and estimated figures are shown in table 1. The acquired numbers for the regression indicate that in all 3 experiments (F_2 in tubes and pots, F_5 in pots), the functional response with the affection of the Sardari sensitive genotype was type III but in the case of the resistant genotype Alvand, the type II model was fitted. It also showed that, the estimated figures for the linear part of the curves was positive for Sardari and negative for Alvand in all 3 experimental situations. The curves of the *Aphidius ervi* functional responses to different densities of *Sitobion avenae* on the sensitive and resistant wheat cultivars, Sardary and Alvand, are shown in figures 1 and 2 respectively.

Table 1. Result of logistic regression analysis, indicating estimates of linear, quadratic and cubic coefficients for proportion of aphids parasitized by *Aphidius ervi* at different experiments

Estimate for Alvand	Estimate for Sardari	Parameter	Type of experiment
3.8765	1.4236	Constant	
-0.2410	0.1288	Linear	Gen. F_5 in vase
0.00637	-0.00526	Quadratic	
-0.00006	0.00005	Cubic	
1.6948	1.9103	Constant	
-0.0503	0.0408	Linear	Gen. F_2 in vase
0.00410	0.000335	Quadratic	
-0.00006	-0.00002	Cubic	
3.1587	2.5331	Constant	
-0.0453	0.00405	Linear	Gen. F_2 in tube
-0.0272	-0.00407	Quadratic	
0.00004	0.00005	Cubic	

Using Holling's model, in the second type functional response, on Alvand genotype, the estimated parameters of searching power (a in type II, b in type III), handling time (Th), the correlation index (R^2), and the maximum amount of estimated parasitism (T/Th) for different generations of *Aphidius ervi* on *Alwand genotype* were respectively as follows:

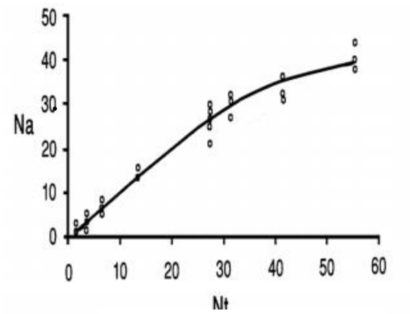
- F_5 in the pots : 0.167, 0.083, 0.97, 72.29
- F_2 in the pots : 0.185, 0.047, 0.90, 127.66
- F_5 in the test tubes : 1.584, 0.040, 0.93, 25.25

The same parameters on Sardari genotype (the 3rd type) were also as follows:

- F_5 in the pots : 0.035, 0.149, 0.97, 40.27
- F_2 in the pots : 0.059, 0.139, 0.98, 43.16
- F_5 in the test tubes : 0.820, 0.057, 0.95, 17.54

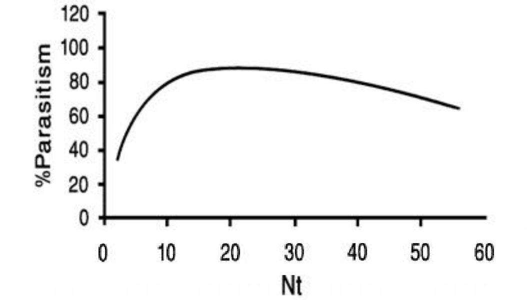
In experiments on the affection of the Alvand genotype (second type of functional response) the data of functional response fitted with both Rogers' and Holling's models. The Holling's model presented better estimation for the parameters searching power (a) and handling time (Th). In the experiment on the affection of the Sardari genotype (third type of functional response) Rogers' model reasonably described the functional response data and parameters b, and Th with a low standard error (SE) and appropriate coefficient of confidence.

A



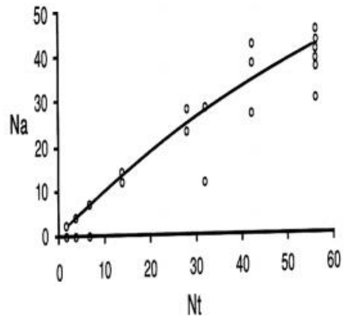
Sardari F5 in Pots
Rogers type (III)

D



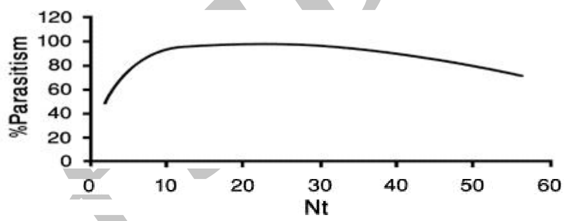
Sardari F5 in Pots
Rogers type (III)

B



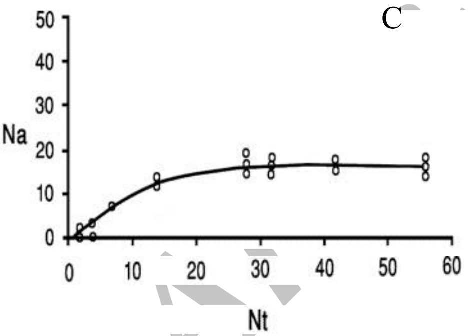
Sardari F2 Pot Rogers (III)

E



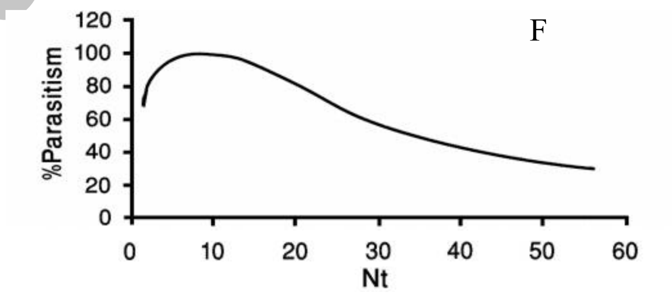
Sardari F2 Pot Rogers (III)

C



Sardari F2 Tube Rogers (III)

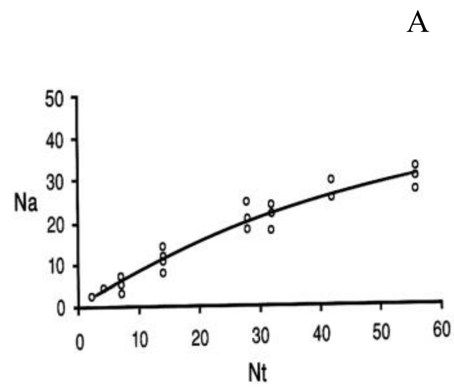
F



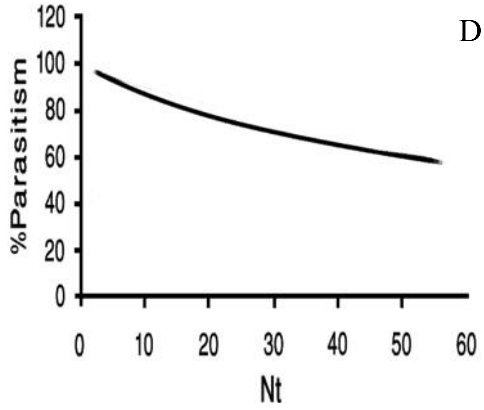
Sardari F2 Tube Rogers (III)

Fig. 1. The curve of functional response (A, B, C) and proportion of parasitized aphids by *Aphidius ervi* (D, E, F) for different experiments on susceptible wheat genotype, Sardari

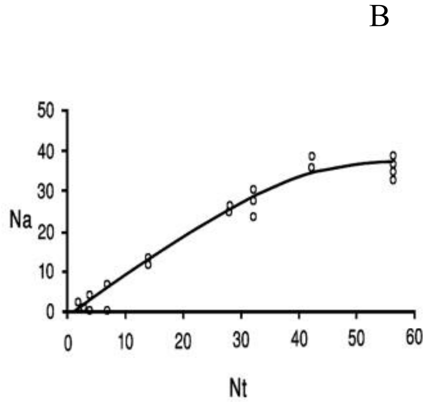
The assessed amount of a, b and Th by both models and also the amount of data fitting with correlation coefficients and the maximum amount of parasitism (T/Th) are shown in table 2.



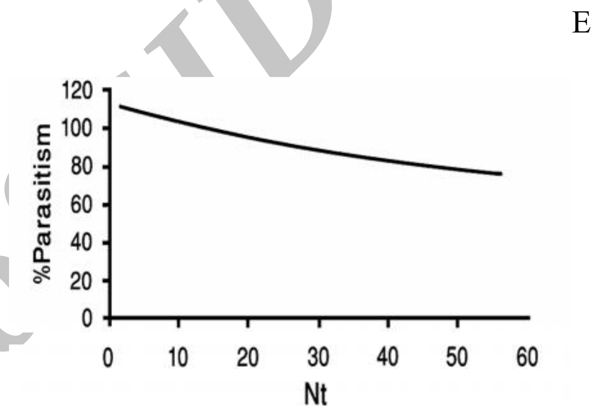
Alvand F5 Pot Holling (II)



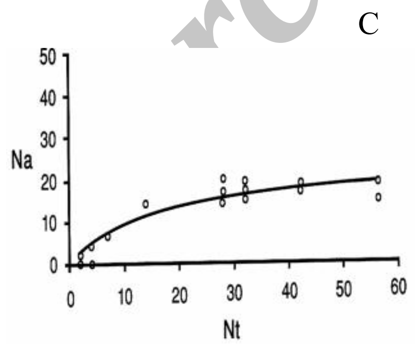
Alvand F5 Pot Holling (II)



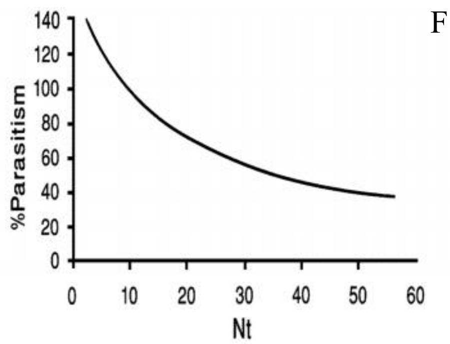
Alvand F2 Pot Holling (II)



Alvand F2 Pot Holling (II)



Alvand F2 Tube Holling (II)



Alvand F2 Tube Holling (II)

Fig. 2. The curve of functional response (A, B, C) and proportion of parasitized aphids by *Aphidius ervi* (D, E, F) at different experiments on resistant wheat genotype, Alvand

In all experiments the amount of R^2 was above 90%, completely fitted to the aforementioned models. Equation number 3 was used for the estimation of parameters related to the third type of functional response (with the effect of genotype Sardari), while the confidence level of 95% included the number zero. So, in the assessment of parameters, c was considered in the first phase while c and d were set to zero in the second. The third type of functional response equation was then obtained by substituting the equation a=bN in Rogers' equation (equation number 2).

Comparing the assessed parameters for each of the experiments in the different situations on two wheat genotypes, the search power of the parasitoid in the experimental tubes was found to be higher while handling time was lower than those in the pots. This was because the wasps did not spend much time in the experimental tubes to search for the hosts and parasitized more hosts in a short period as compared to the pots. Although the searching power of the F_2 parasitoids was more than F_5 for the pots with on two genotypes of wheat, it is concluded that no difference exists between F_2 and F_5 because of overlapping coefficients of confidence for the assessed parameter. A comparison between the handling time and the maximum amount of assessed parasitism by the model (T/Th) that this amount in the F_2 and F_5 parasitoids on sensitive Sardari genotype was not significant, but was noticeable with the increasing negative effect of the resistant Alvand genotype through several generations (table 2). This conclusion is in close agreement with Van Emden's Hypothesis (1987, 1995) about the mutual effect of resistant genotypes on biological control. But the point is that a sensitive genotype may apply its effect through increased feeding of host aphids, leading to their higher suitability for the parasitoid.

Table 2. Parameters (mean±1SE) estimated by Holling and Rogers' equations, indicating the functional response of *Aphidius ervi* at different experiments

T/Th	R^2	Th (h)	b (a=bN)	a(h^{-1})	Type of F. R.	Type of experiment
			Sardari			
40.27	0.97	0.149±0.0052	0.035±0.0049	-	III Rogers	Gen. F_5 in vase
43.16	0.98	0.139±0.0045	0.059±0.0112	-	III Rogers	Gen. F_2 in vase
17.54	0.95	0.057±0.0012	0.820±0.2814	-	III Rogers	Gen. F_2 in tube
			Alvand			
72.29	0.97	0.083±0.009	-	0.167±0.011	II Holling	Gen. F_5 in vase
127.66	0.90	0.047±0.015	-	0.185±0.022	II Holling	Gen. F_2 in vase
25.25	0.93	0.040±0.002	-	1.584±0.148	II Holling	Gen. F_2 in tube

Several studies have been carried out on the role of host plant of pests affecting the behavior of natural enemies specially their functional reaction in a tritrophic system, some of which have led to interesting results.These studies mostly correlated with predators and there have been few representatives of parasitoids. The effect of host plant on the behavior of pest natural enemies may have resulted in changing the type of functional reaction. The functional response of *Propylea guatuordecimpunctata* toward different densities of Russian wheat aphid on some plants was of the second type and of the third type in some others (6).

Taylor (1998) studied the effect of host size in the functional response of *Bracon hebetor* Say. Although he did not find significant differences between the host size and rate of parasitism, he claimed that there was a tendency in the wasp to parasitize larger sized hosts. The difference in the size of the host may be the result of the different host species or the variability in the maternal food plants. Recent researchers use Holling's disk equation to fit data. Most researchers who studied the functional response of parasitoids showed that the reactions were of the second type, and in these cases Holling's disk equation has been used for goodness of fit (1, 12).

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واکنش تابعی زنبور پارازیتوئید *Aphidius ervi* (Haliday) (Hym.: Braconidae, Aphidiinae) نسبت به تراکم های مختلف شته *Sitobion avenae* (Fabricius) (Hom.: Aphididae) روی دو رقم گندم

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چکیده- واکنش تابعی زنبور پارازیتوئید *Aphidius ervi* به تراکم های مختلف شته *Sitobion avenae* تحت شرایط آزمایشگاهی مورد بررسی قرار گرفت. در این تحقیق اثرات دو رقم گندم سرداری و الوند بر روی واکنش تابعی زنبور پارازیتوئید به عنوان یکی از روش های ارزیابی اثرات متقابل ارقام مقاوم و زنبورهای پارازیتوئید نیز بررسی شد. آزمایشات، در داخل لوله آزمایش با نسل F_2 آزمایشگاهی بدون استفاده از بوته های گندم و در داخل گلدان با نسل های F_2 و F_5 با استفاده از بوته های گندم انجام شد. زنبورها از نسل F_1 به بعد از شته هایی خارج شده بودند که از دو رقم گندم سرداری و الوند تغذیه کرده بودند. در لوله آزمایش، زنبور ماده به مدت یک ساعت و در هر دو آزمایش انجام شده در داخل گلدان به مدت ۲۴ ساعت در معرض تراکم های ۲، ۴، ۷، ۱۴، ۲۸، ۳۲، ۴۲ و ۵۶ عدد شته قرار داده شد. تجزیه داده های واکنش تابعی در دو مرحله و با استفاده از نرم افزار SAS انجام گردید. در مرحله اول برای تعیین نوع واکنش تابعی از رگرسیون لجستیک نسبت به شته های پارازیته شده توسط زنبور پارازیتوئید و در مرحله دوم برای تعیین پارامترهای قدرت جستجو (a یا b) و زمان دستیابی به میزبان (Th) از رگرسیون غیر خطی (روش Least Square) استفاده شد. نتایج حاصل از رگرسیون لجستیک نشان داد که در هر سه وضعیت آزمایشی (نسل F_2 داخل لوله و گلدان و F_5داخل گلدان) واکنش تابعی با تأثیر رقم مقاوم الوند از نوع دوم و با تأثیر رقم حساس سرداری از نوع سوم می باشد.

واژه های کلیدی: واکنش تابعی، زنبور *Aphidius ervi*، شته *Sitobion avenae*

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