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FUNCTIONAL RESPONSE OF *HIPPODAMIA VARIEGATA* (GOEZE) (COLEOPTERA: COCCINELLIDAE) ON *APHIS FABAE* (SCOPOLI) (HOMOPTERA: APHIDIDAE) IN LABORATORY CONDITIONS

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Abstract

Functional response is one of the most important behavioral characteristics that reveal different aspects of prey-predator interactions. In this study, the functional response of the amber ladybird, *Hippodamia variegata* (Goeze), attacking the black bean aphid, *Aphis fabae* (Scopoli), was investigated. Different levels of aphid densities - 20, 40, 60, 80, 100, 120, 140, 160 and 180 - were used. Each density was placed in a test cage (6 x 11 x 23 cm^3), and then exposed to an adult 24 hours old. The experiments were carried out at 25 ± 1 °C, 60 ± 5 % of relative humidity and 16 : 8 (light : darkness) hours photoperiod. Logistic regression was used to distinguish the shape of the functional response (type II or III). Nonlinear least-square regression was used to estimate the attack rate (a) and handling time (T_h). The Nicholson model was used to determine per capita searching efficiency. Logistic regression suggested a type II response on *A. fabae* adults. Searching efficiency, handling time and estimated maximum percent of consumed prey were 0.00078, 0.1774 and 135.29, respectively.

Key words: Functional response, *Hippodamia variegata*, *Aphis fabae*

Introduction

Occurring in various parts of the world, the black bean aphid *Aphis fabae* (Scopoli) is a pest of many plants,. The aphid causes direct and indirect damage by sucking the sap of plants and transmitting plant viruses (BLACKMAN & EASTOP, 2000). *A. fabae* prefers feeding on younger plant tissues, which makes it an important aphid on beta and bean as it renders the head as unmarketable (VOLKL & STECHMANN, 1998). Control of the aphids is commonly achieved by repeated application of insecticides. The development of resistance by the pest to insecticides and their adverse effects on natural enemies highlight the need for fewer insecticide-dependent methods of pest control. One control measure which can be used for the beta aphids is biological control (HASAN & WAPSHERE, 1973, VAN DRIESCHE & BELLOWS, 1996). These aphids are attacked by ladybirds.

Hippodamia variegata (Goeze) is the most abundant and important natural enemy of *A. fabae* in Iran and plays a major role in reducing the population density of its prey. In addition to *H. variegata,* there are some other ladybirds in Iran, such as *Coccinella* spp. and *Adalia* spp., which are less abundant and less important. They are from the same family (Coccinellidae) that consumed black bean aphids (RAJABI, 1998). Among the natural enemies of black bean aphids, *H. variegata* serves as a strong candidate for natural support, mass rearing and release for controlling this aphid because of high population densities and high rates of consumed prey (FRANZMAN, 2002). In this regard, the study of foraging behavior and demographic parameters of *H. variegata* in a prey-predator system is essential. In this study, different densities of prey and predator were selected according to the reference. The main purpose of the selection of these densities was to identify the role of different densities of the prey and predator on the foraging behavior of the predator and on the prey-predator interactions. The selected densities may not be completely compatible with those of the prey and predator in natural populations.

Before using a predator in a biological control program, it is essential to know about the efficiency of the predator. One of the most important methods to assess the efficacy of natural enemies is studying the behavioral characteristics, including foraging behavior. Studying predator behavior is an important key to understanding how the insects live, and how they influence the population dynamics of their prey (DIXON, 2000). It is thus a necessary prerequisite for the selection of natural enemies for biological control programmers and for the evaluation of their performance after their release (VAN DRIESCHE & BELLOWS, 1996).

One of the important behaviors of a predator is functional response. Functional response refers to the number of prey attacked successfully per predator as a function of prey density (SOLOMON, 1949). It describes the way a natural enemy responds to the changing density of its prey, by killing more or fewer individuals, and it is a commonly measured attribute of natural enemies of pests (HASSELL, 1978; IVES *et al*., 1993). HOLLING (1959, 1966) considered three types of functional response. In type I, there is a linear relation between prey density and the number of prey killed, while in type II it is curvilinear and the saturation level is reached in a gradual way. Type III is described by a sigmoid relation and considered to be a regulating factor in the population dynamics of the pest and the natural enemy. The functional response of a predator is a crucial factor in the population dynamics of prey-predator systems. This behavior can determine if a predator is able to regulate the density of its prey (LIVDAHL & STIVEN, 1983). Functional response models help to evaluate two vital parameters, handling time (i.e. the time that it takes a predator to encounter and consume a single prey), and attack rate (i.e. the rate at which a predator searches). Several studies (FAN & ZAHO*,* 1988; IVES *et al*., 1993) have been carried out on the functional response of *H. variegata* to different densities of other aphids such as *Aphis gossypii* Glover and *Diuruphis noxia* Mordvilko. The type of functional response and the value of its parameters (attack value and handling time) are influenced by different factors such as natural enemy, host species, physical conditions in the laboratory, and the variety of the host plant (MESSINA & HANKS, 1998).

Materials and Methods

Insect cultures

H. variegata used in this study was originally collected from *A. fabae* in an infested beta field at the College of Agriculture of Borojerd University (Lorestan) Iran in May, 2007. The *A. fabae* culture was originally started from individuals collected from the above beta field and kept in a growth chamber on beta plants. Both ladybird and aphid individuals were kept in a growth chamber at 25 ± 1 °C, 60 ± 5 % of relative humidity and a photoperiod of 16 : 8 (light : darkness) hours.

Functional response

The experimental arena consisted of a Plexiglas cage (6 x 11 x 23 cm^3) with a micromesh screen on the lid for ventilation. Adults of A. *fabae* were randomly placed on the beta leaves inside the cages at densities of 20, 40, 60, 80, 100, 120, 140, 160 and 180 per cage. A single female predator (maximum 24 hours old) was introduced into each cage. Each prey density was replicated 10 times. After 24 hours, the ladybirds were removed and the number of consumed prey was counted. The experiment was conducted under the above-mentioned controlled conditions.

Two principal steps underlie the statistical analysis of the functional response: first, model selection, and secondly, hypothesis testing (Juliano, 1993). In the first step, a logistic regression analysis was made of the proportion of prey privatized as a function of initial density. The proportion of prey consumed declines monotonically with prey density in the type II response, but is positively density-dependent over some region of prey density in the type III response (Trexler *et al*., 1988). The sign of the linear coefficient estimated by the logistic regression (negative or positive) can be used to distinguish the shape of the functional response curve (type II or type III, respectively) (Juliano, 1993; Messina & Hanks, 1998). In the second step, both the disc equation (Holling, 1959, 1966) (Equation 1) and the random predator equation (Royama, 1971; Rogers, 1972) (Equation 2) were used to obtain estimates for handling time (T_h) and searching efficiency or attack rate (*a*).

For the type II response, the equations are as follows:

$$(1) \qquad N_a = aTN_t / 1 + aT_hN_t$$

$$(2) \qquad N_a = Nt\,\{1 - \exp\,[a(T_hN_t - T)]\}$$

where N_a is the number of consumed prey, and N_t is the number of prey offered, T is the total time available for the predator, a is the attack rate (searching efficiency) and T_h is the handling time.

Statistical analysis was performed using the SAS package (SAS Institute, 1989). In order to estimate the handling time and searching efficiency, nonlinear regression, using the least square method with DUD initialization, was used.

Results

Functional response and percentage of consumed prey curves are depicted in Fig. 1. The logistic regression analysis (Table I) indicated a type II functional response. The estimate of the linear coefficient was significantly different from 0 ($p < 0.01$) and its value was - 0.3637 S.E.

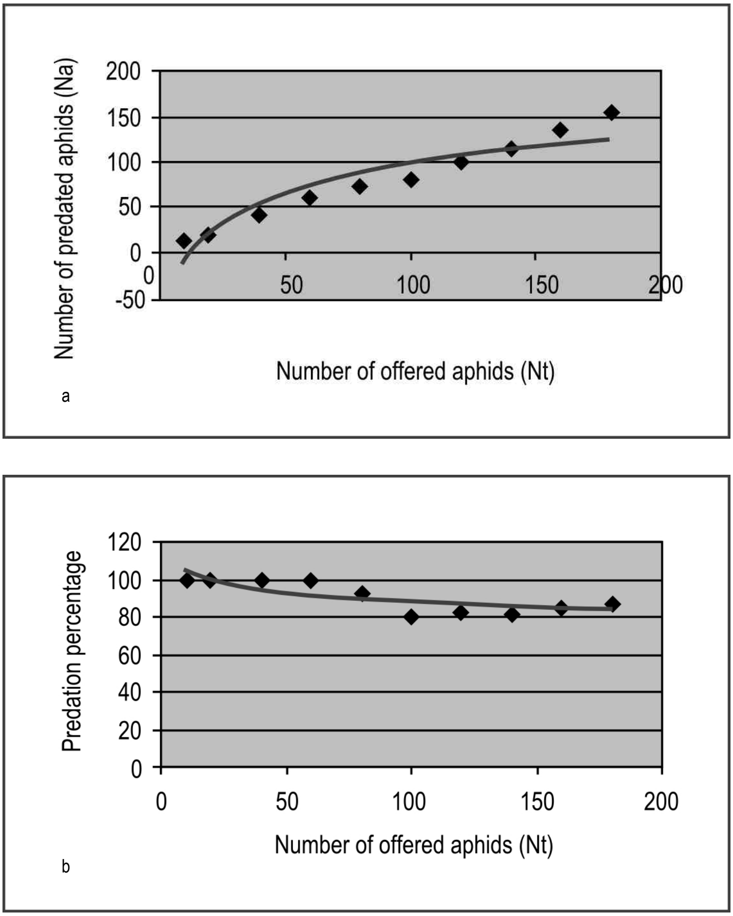

Figure 1. Functional response (a) and percentage predation (b) of *H. variegata* on *A. fabae*. Symbols and lines represent the observed and predicted numbers (Holing disc equation), respectively.

Attack rate and handling time for the disc equation were 0.00078 ± 0.0000111 h^{-1} and 0.1774 ± 0.0004 h, respectively, and for the random predator equation they were 0.00093 ± 0.000201 h^{-1} and 0.1999 ± 0.0094 h, respectively (Table II).

The lower coefficient of determination [R^2 = 1 - (residual sum of squares/corrected total sum of squares)] for the disc equation and the random predator equation were thus 0.62 and 0.61, respectively. The estimated maximum rate of consumed prey (T/T_h) for the disc equation and the random predator equation were determined as 135.29 and 120.07, respectively.

The rates and standard errors of the estimated parameters indicated that both equations (disc equation and random predator equation) adequately describe the functional response of *H. variegata.*

Table I. Results of logistic regression analysis of the proportion of *A. fabae* consumed by *H.* variegata to initial prey numbers.

Parameters	**Estimate**	**S.E.**	**X^2**
Constant	18.4976	1.8159	103.77
Linear	-0.36	0.0442	67.72
Quadratic	0.00242	0.000347	48.85
Cubic	-0.88	1.82	33.83

Table II. Parameters (mean ± S.E.) estimated by disc and random predator equations, evaluating functional response of *H. variegata* to densities of *A. fabae.*

	Disc equation			**Random predator equation**		
Type	***a*** **(h^{-1})**	**T_h (h)**	**R^2**	***a*** **(h^{-1})**	**T_h (h)**	**R^2**
II	0.00078 ± 0.000111	0.1774 ± 0.0004	0.62	0.00093 ± 0.000201	0.1999 ± 0.0094	0.61

Discussion

The type II functional response displayed by *H. variegata* to different densities of *A. fabae* adults is characteristic of many aphid predators, though the type III responses have also been reported (Lanzoni *et al*., 2004). In most related literature, the functional response of *H. variegata* to different densities of Aphids (Dixon, 2000; Kontadimas & Statha, 2005), *Brevicoryne brassica* (El Hag & Zaitoon, 1996) and *A. goosypii* (Fan & Zhao, 1988) has been determined to be type II. However, in studies reported by Lanzoni *et al*. (2000), *H. variegata* displayed a type III functional response to *A*. *goosypii*.

The rates of searching efficiency (*a*) and handling time (T_h) were reported to be 0.09624 h^{-1} and 0.852 h, respectively (Kontadimas & Statha, 2005) and 0.12421 h^{-1} and 0.421 h, respectively (Fan & Zhao, 1988). The cited rates of *a* are greater and T_h are smaller than those obtained in our study. However, the differences among the experimental conditions such as prey species and physical conditions between different studies were substantial. For the type II response, consumed prey is not density dependent: that is, the intensity of consumed prey does not increase with prey density (HASSELL, 1978). Several authors have tried to explain why the type III response is less common than the type II.

In laboratory tests, predators are forced to remain in the patch, whereas under natural field conditions they probably leave the patch because of the very low prey density or because most prey are already consumed (O'NEIL, 1990; IVES *et al.,* 1993).

FAN & ZHAO (1988) pointed out that the relation between functional responses observed in the laboratory and field performance of natural enemies is not clear, but some studies showed a significant difference between the responses observed in laboratory and field environments. It is recognized that functional responses derived from laboratory studies may bear little resemblance to those that could be measured in the field (Wang *et al*., 2004). FAN & ZHAO (1988) pointed out, however, that studies of functional response in the laboratory could be used to infer basic mechanisms underlying natural enemy-prey interactions. Such studies provide valuable information for biological control programs. EL HAG & ZAITOON (1996) observed that during biological control evaluation processes, comparisons of parameter values of two or more predators may be more meaningful and convenient than similar comparisons involving functional response curves. In most available literature, as in this study, the functional response of *H. variegata* to different densities of aphids has been determined to be type II.

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ФУНКЦИОНАЛНИ ОДГОВОР *HIPPODAMIA VARIEGATA* (COLEOPTERA: COCCINELLIDAE) НА *APHIS FABAE* (SCOPOLI) (HOMOPTERA: APHIDIDAE) У ЛАБОРАТОРИЈСКИМ УСЛОВИМА

РЕЗА ЈАФАРИ и ШИЛА ГОЛДАСТЕХ

Извод

Функционални одговор је једна од најважнијих карактеристика у понашању и открива различите аспекте интеракције између предатора и плена. У овом истраживању је проучаван функционални одговор ћилибарске бубамаре *Hippodamia variegata* (Goeze) која напада црну репину ваш *Aphis fabae* (Scopoli). Коришћене су различите вредности густине популације лисних ваши: 20, 40, 60, 80, 100, 120, 140, 160 и 180. Популација сваке густине је постављена у тест кавез (6 x 11 x 23 cm^3) у који је онда стављен и адулт предатора, стар 24 h. Експеримент се одвијао на температури од 25 ± 1 °C, при вредностима од 60 ± 5 % релативне влажности и фотопериода 16 : 8 (светло : тама). Помоћу логистичке регресије одређен је облик функционалног одговора (тип II или III). За процену учесталости напада (*a*) и времена конзумирања једне репине ваши (T_h) коришћена је нелинеарна регресија најмањих квадрата. Ефикасност претраге по јединки одређена је по Николсоновом моделу. Судећи по логистичкој регресији, постоји II тип одговора на адулте *A. fabae.* Ефикасност претраге, време конзумирања и процењени максимални проценат конзумације плена били су 0,00078; 0,1774 и 135,29.

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