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# Functional response of the predatory mite, *Typhlodromus bagdasarjani* (Acari: Phytoseiidae) to protonymphs of *Eotetranychus frosti* (Acari: Tetranychidae) on four apple cultivars

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## Original research

### ABSTRACT

The functional response of natural enemies and their interactions may be affected by host plant characters. Functional response of the adult females of the predatory mite, *Typhlodromus bagdasarjani* Wainstein & Arutunjan to protonymphs of *Eotetranychus frosti* (McGregor) on four apple cultivars Imperial Gala, Kohanz Golab, Granny Smith and Lebanon Red was investigated. The protonymphs of *E. frosti* were offered to the adult female of the predator at densities of 2, 4, 8, 16, 32, 64 and 128 on apple leaf discs (4 cm<sup>2</sup>). The number and length of trichomes on the lower surface of each apple cultivar were measured. The highest and lowest number of trichomes were observed in Granny Smith and Kohanz Golab, respectively. *Typhlodromus bagdasarjani* adult females exhibited the type II functional response on *E. frosti* protonymphs regardless of apple cultivars. Also, the values of attack rate ( $a$ ) and handling time ( $T_h$ ) were determined using the Rogers's type II model. Adult females of *T. bagdasarjani* had the highest attack rate ( $a$ ) (0.0747 h<sup>-1</sup>) and the shortest handling time (0.7005 h) on Kohanz Golab, and the lowest attack rate (0.0334 h<sup>-1</sup>) and the longest handling time (1.1189 h) was on Granny Smith. The theoretical maximum predation rate ( $T/T_h$ ) on Kohanz Golab, Imperial Gala, Lebanon Red and Granny Smith were 34.26, 33.79, 26.85 and 21.45 prey/day, respectively. The estimated value of  $a/T_h$  indicated that *T. bagdasarjani* was most effective against *E. frosti* on Kohanz Golab with lowest number of trichomes. The finding of this study shows that the predation and searching activity of the predator was affected by trichome density and length of the apple leaves.

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**Keywords** predatory mite; apple cultivar; attack rate; handling time; biological control

## Introduction

Tetranychid mites are among the important pests of different agricultural crops, including field crops, fruit trees, vegetables and ornamental plants worldwide (Fathipour and Maleknia, 2016). *Eotetranychus frosti* (McGregor) (Tetranychidae) is considered to be one of the most serious pests of apple trees in Iran and maybe in other apple growing areas of the world (Darbemamieh *et al.*, 2007; Khodayari *et al.*, 2010; Jafarian and Jafari 2016 a, b; Jafarian *et al.*, 2020). This species causes serious damages on fruit trees such as apple and citrus in different parts of Iran (Sadeghi-Namaghi, 1995; Darbemamieh *et al.*, 2007; Khodayari *et al.*, 2008, 2010; Darmiani *et al.*, 2011; Jafari *et al.*, 2014). The feeding of this pest with high population density on the lower surface of the leaves usually leads to decrease in the fruit quality, defoliation and losses

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in apple yield in the same and also following seasons (Jafari *et al.*, 2014). The biological traits of this mite, including the irregular dense webs, depositing eggs on the leaf surface under the webs and the defecation on threads of complicated webs are close to CW (Complicated-web type) life type of tetranychid mites and subtype CW-r (Saito, 1983).

Control of spider mites relies heavily on the use of chemical acaricides (Badii *et al.*, 2004). Due to the undesired effects of hazardous pesticides, the interest in biological control and resistant cultivars is growing. Host plant resistance is a main component of integrated pest management (IPM) programs that can potentially contribute to the efficacy of natural enemies (Lorenzen *et al.*, 2001). The physical and the chemical properties of the host plant have different effects on phytophagous pests and their natural enemy's traits like developmental time, survival and fecundity (Madadi *et al.*, 2007). The functional responses or other foraging behaviors of predators may be influenced by host plant in different ways such as the effect on prey size, shelter for prey, restricting the natural enemy movement by plant physical structures or reducing the searching efficiency of predator by sticky secretions (Price *et al.*, 1980; Messina and Hanks, 1998; Sabelis *et al.*, 1999). The physical properties of the plant such as shape and type of trichomes may influence the consumption rate of the predatory mites (Loughner *et al.*, 2008). Since the population growth of a pest species is usually slower on resistant plants, host plant resistance is often assumed to increase the capacity of a biological control agent to keep the pest population under the economic damage threshold (Boethel and Eikenbary, 1986).

*Typhlodromus bagdasarjani* Wainstein and Arutunjan is a generalist predator (type III-a lifestyle) (McMurtry *et al.*, 2013) that has relatively high population densities, especially on trees such as apple and it is a potential natural enemy of *E. frosti* in some regions of Iran (Kamali *et al.*, 2001; Hajizadeh *et al.*, 2002; Jafari, 2010). In addition, it can feed on mites belonging to the families Eriophyidae, Tenuipalpidae, Tetranychidae and Tydeidae as well as insect pests such as thrips and whiteflies (Hajizadeh *et al.*, 2002; Jafari, 2010; Rahmani *et al.*, 2010; Ganjisaffar *et al.*, 2011). The preference of this predator to the protonymphal stage of *E. frosti* was reported (Bazgir *et al.*, 2020b). *Typhlodromus bagdasarjani* is a widespread species in the Middle East and was reported from Armenia, Azerbaijan, Turkey, Turkmenistan and Lebanon (Demite *et al.*, 2014).

The functional response parameters of natural enemies are considered to determine the efficiency and ability in regulating pest populations (Fantinou *et al.*, 2012). Functional response in predators describes the relationship between consumption rate of a predator and different prey densities. Holling (1959) proposed three types of functional response, in type I the number of prey consumed linearly increased to reach a maximum, then remains constant with increasing the prey density, in type II the prey consumption increases at a decelerating rate towards an asymptote as prey density increases, and in type III the number of prey eaten approaches an asymptote as a sigmoid function. In functional response experiments searching ability and consumption potential of a predator are determined as two important factors in its efficiency (Holling, 1966). Understanding how various factors affect foraging behavior can provide better understanding of the selection of best conditions in pest control programs. The effect of host plant characters on functional response parameters of some natural enemies has been reported (Madadi *et al.*, 2007; Ahn *et al.*, 2010; Marafel *et al.*, 2011; Rezaie *et al.*, 2017). The significant effect of Lebanon Red, Kohanz Golab, Imperial Gala, Gala Royal, Fuji, Granny Smith and Golden cultivars of apple on life history performance of phytophagous mite *E. frosti* was detected in a previous study (Jafarian *et al.*, 2020). In this regard, with the aim of completing the study of the tritrophic effects of some apple cultivars on the biological activities of *E. frosti* and its predator, the current study was designed and conducted. In this study, we evaluated the effect of four apple cultivars (Imperial Gala, Kohanz Golab, Granny Smith and Lebanon Red) on the functional response of adult females of the predatory mite, *T. bagdasarjani* to different densities of *E. frosti* protonymphs. Also, the leaf characteristics of different apple cultivars in terms of density and length of trichome effects on functional response of *T. bagdasarjani* was addressed.

## Material and methods

### Host plant and prey colony

The apple cultivars were provided from a complex of orchards in Tajareh region, Khorramabad, Western Iran. Four apple cultivars ten years old (planted in 2011) were evaluated, including Imperial Gala, Kohanz Golab, Granny Smith and Lebanon Red, with no pesticide applications conducted during and three years prior to the study. All cultivars were grown in outside with similar environmental conditions and had the same phenological stage. Fresh leaves of each apple cultivar were cut, transferred to the laboratory and used for the experiments. To prepare the colony of prey, the apple leaves infested by the tetranychid mite, *E. frosti*, were collected from apple trees at the vicinity of Khorramabad, Lorestan Province, Western Iran, during 2020. They were maintained at  $27\pm 1^\circ\text{C}$ ,  $60\pm 10\%$  RH and a photoperiod of 16L: 8D h. The collected tetranychid mites were divided into four groups and reared separately on detached leaves of each apple cultivar for three generations before provisioning them as prey in the experiments described below.

### Apple leaf characters

To investigate the role of leaf characters of four apple cultivars on the functional response of the predator, 20 leaves of each cultivar were randomly picked and the number of trichomes on the underside of the leaf in  $1\text{ cm}^2$ , as well as the length of each trichome, were accurately recorded and measured by means of a stereomicroscope (Olympus SZ-1145) equipped with a calibrated lens, respectively.

### Predatory mite colony

The initial population of *T. bagdasarjani* was originally collected from leaves of apple trees located in Khorramabad, Iran during 2020. Laboratory colonies of *T. bagdasarjani* were reared on *E. frosti* on apple leaves in the laboratory. Before their use in the experiments, the predators were separately reared for two generations on the different apple cultivars, using immature stages of *E. frosti* as the sole food source.

### Functional response experiments

According to our observations in apple orchards, around Khorramabad County, Iran, *E. frosti* were mostly found on the underside of apple leaves. The experimental arena for functional response experiments consisted of a piece of apple leaf from the above-mentioned cultivars ( $4\times 4\text{ cm}$ ) placed upside down on a wet cotton layer in a Petri dish (6 cm diameter) with a 0.5 cm hole drilled in the center. This Petri dish was placed in the middle of a larger Petri dish (9 cm in diameter) containing water to keep the leaves fresh. To prevent escaping of the predator and prey, a water-saturated cotton strip was placed around the leaf margin.

To standardize the age of female *T. bagdasarjani* used in experiments, approximately 100 gravid females were randomly selected from the colony and transferred to apple leaf disc arenas supplied with immature stages of *E. frosti*. After 24 h, *T. bagdasarjani* females and all stages of the prey were removed, leaving only the newly laid *T. bagdasarjani* eggs, kept at  $27\pm 1^\circ\text{C}$ ,  $60\pm 10\%$  RH and 16:8 (L: D)h and monitored at daily intervals. Subsequently, the emerging predator larvae were reared on immature stages of *E. frosti* to adulthood. A cohort of mated females (four days old) was used in the functional response experiments. According to results of our preliminary test (Unpublished data) and those reported by Bazgir *et al.* (2020 b), *T. bagdasarjani* females preferred the protonymphal stage of *E. frosti* for feeding. To determine the functional response of the predator on the prey, a 24-h starved female was exposed to seven densities (2, 4, 8, 16, 32, 64 and 128) of newly emerged protonymphs of *E. frosti*. To obtain protonymph prey, approximately 50 adult female *E. frosti* were transferred from the stock colony to each leaf disc and allowed to oviposit for 24 h, following which the females

were removed. The hatched eggs were monitored under a stereomicroscope until reaching the protonymph stage and subsequently provisioned with a fine paintbrush (number 0000) to the respective arenas to reach the designated prey density, along with the starved female predator. After 24 h, the predators were removed and the number of prey eaten was recorded. Ten replicates were prepared for each prey density. All experiments were conducted at a constant temperature of  $27 \pm 1^\circ\text{C}$ ,  $60 \pm 10\%$  RH and 16:8 h L: D photoperiod in two incubators (Jal Tajhiz Company, Iran), which were able to control the RH, temperature and photoperiod.

## Data analysis

The data of functional response were analyzed in two steps (Juliano, 2001). First, to determine the type of functional response, the positive or negative sign of the linear coefficient was determined by logistic regression of the proportion of prey consumed ( $N_a/N_t$ ) as a function of prey density ( $N_t$ ):

$$\frac{N_a}{N_t} = \frac{\exp(P_0 + P_1N_t + P_2N_t^2 + P_3N_t^3)}{1 + \exp(P_0 + P_1N_t + P_2N_t^2 + P_3N_t^3)}$$

where  $N_a$  is the number of prey consumed,  $N_t$  is the initial prey density, ( $N_a/N_t$ ) is the probability of being eaten and  $P_0, P_1, P_2$  and  $P_3$  are the intercept, linear, quadratic and cubic coefficients, respectively, estimated using the maximum likelihood method. The type of functional response was determined by the signs of  $P_1$  and  $P_2$ . If the linear coefficient is negative ( $P_1 < 0$ ), it describes a type II functional response because the proportion of prey consumed declines gradually with increasing the initial prey density (Juliano, 2001). If  $P_1 > 0$  and  $P_2 < 0$ , the proportion of prey consumed is positively density dependent describing a type III functional response (Juliano, 2001). In the next step, the handling time ( $T_h$ ) and the attack rate ( $\alpha$ ) coefficients of a type II response were estimated using the Rogers' random predator equation (Royama, 1971; Rogers, 1972):

$$N_a = N_t \{1 - \exp[-\alpha T P_t / (1 + \alpha T_h N_t)]\}$$

where  $N_a$  is the number of prey consumed,  $N_t$  is the initial prey density,  $T$  is the total time available for predators during the experiment (in this study 24 hours),  $\alpha$  is the attack rate (searching efficiency), and  $T_h$  is the amount of time that a predator handles each prey individual (handling time) and  $P_t$  is the number of predators (Rogers, 1972). Nonlinear regression was used to estimate the attack rate and the handling time parameters (Proc NLIN, SAS Institute, 2003). The differences between numbers of prey consumed per day by each female of *T. bagdasarjani* on different densities of *E. frosti* on four apple cultivars and also the number and length of trichomes on each apple cultivars were analyzed using one way analysis of variance (ANOVA). When a significant difference was detected, the means were compared using Tukey's multiple range test ( $P < 0.05$ ). The ANOVA and mean comparison were carried out using the Minitab Version 18 (Minitab, 2017). The curves of the observed number and proportion of prey eaten by *T. bagdasarjani* females to the protonymphal stages of *E. frosti* at different densities on four apple cultivars were depicted by Excel software.

## Results

### Apple leaf characters

A significant difference was observed among the number of trichomes on  $1 \text{ cm}^2$  of lower surface of four apple cultivars. The highest and lowest number of trichomes were observed in Granny Smith and Kohanz Golab, respectively. Furthermore, the shortest trichomes was observed in Kohanz Golab (Table 1).



### Functional response experiments

The logistic regression analysis of consumed prey by *T. bagdasarjani* at different densities of prey showed that  $P_1 < 0$  for all cultivars (Table 2), indicating the percentage of prey consumed on each cultivar gradually declined as prey density increased. Therefore *T. bagdasarjani* showed a type II functional response on protonymphal stages of the *E. frosti* on all tested cultivars. Analysis of variance of the data obtained from the functional reaction test showed that at different prey densities there was a significant difference between the numbers of prey consumed by the predator in different cultivars (Table 3). As shown, with increasing the number of prey in all tested cultivars, the number of prey eaten increased, but on the contrary the ratio of prey eaten decreased. Only in Granny Smith the percentage of prey eaten firstly slightly increased, then similar to other cultivars decreased (Figures 1 and 2).

Rogers’s type II model showed a good fit with the data obtained on the four tested cultivars. The highest and lowest values of attack rate were  $0.0747 h^{-1}$  and  $0.0334 h^{-1}$ , respectively, which were observed in Kohanz Golab and Granny Smith, respectively (Table 4). The handling time ( $T_h$ ) of *T. bagdasarjani* was also affected by apple cultivars. The longest and shortest handling time were 1.1189 h on Granny Smith and 0.7005 h on Kohanz Golab, respectively. The theoretical maximum predation rate ( $1/T_h$ ) is the upper asymptote of the functional response curve and represents the high potential of a predator to eat its prey during a period of 24 h (Cave and Gaylor, 1987; Jafari *et al.*, 2012). Theoretical maximum predation rate ( $1/T_h$ ) of the predatory mite was the highest and lowest on the Kohanz Golab (34.26 prey/day) and Granny Smith (21.45 prey/day) cultivars, respectively (Table 4).

### Discussion

This is the first study that assessed host plant effects, using four apple cultivars, on the functional response of the predatory mite *T. bagdasarjani* to varying densities of *E. frosti*. In this study, the functional response of *T. bagdasarjani* females to different densities of *E. frosti* protonymphs in four apple cultivars was type II. The type II functional response has been reported for other phytoseiid mite species (Zhang *et al.*, 1999; Skirvin and Felon, 2003; Badii *et al.*, 2004; Gotoh *et al.*, 2004; Shirdel *et al.*, 2004; Sepulveda and Carrillo, 2008; Marafel *et al.*, 2011; Ferla *et al.*, 2011; Jafari *et al.*, 2012; Bazgir *et al.* 2020a; Fu *et al.*, 2021).

The surface properties of host plant including trichome density and shape may affect the functional response of predators by changing search efficiency or by affecting their prey (Price *et al.*, 1980; Coll *et al.*, 1997; Scott Brown *et al.*, 1999; Madadi *et al.*, 2009). It is expected that the host plant properties will affect the type of functional response and/or change in value of the functional response parameters. The results of the current study show that the physical traits of the plant surface can affect functional response parameters and predation rate of *T. bagdasarjani* feeding on *E. frost* protonymphs but not on the type of functional response. These findings are consistent with those of Rezaie *et al.*, (2017) who found a type II functional response for *N. californicus* females on *Frankliniella occidentalis* (Pergande) larvae on different strawberry cultivars. Also, the functional response type of *N. californicus* to *T. urticae* on different strawberry cultivars was type II (Ahn *et al.*, 2010). Unlike, *Podisus nigrispinus* (Dallas) (Het.: Pentatomidae) exhibited a type II functional response to beet armyworms on sweet pepper and cucumber and a type III on tomato (De Clercq *et al.*, 2000).

**Table 1** Mean ( $\pm$ SE) number and length of trichomes on lower surface of four apple cultivars.

Parameters	Imperial Gala	Kohanz Golab	Granny Smith	Lebanon Red
Number of trichomes in 1 cm <sup>2</sup>	196.9 $\pm$ 3.14b	165.2 $\pm$ 4.01c	221.4 $\pm$ 1.74a	206.1 $\pm$ 2.62b
Length of trichomes (mm)	1.4 $\pm$ 0.02a	1.2 $\pm$ 0.03b	1.5 $\pm$ 0.03a	1.4 $\pm$ 0.02a

Attack rate ( $a$ ) and handling time ( $T_h$ ) are two key parameters in evaluating the effectiveness of natural enemies that were estimated in functional response studies (Juliano, 2001) and determine the magnitude of the functional response (Pervez and Omkar, 2005). The predator shows the highest attack rate and the shortest handling time on Kohanz Golab in comparison to others. It is possible that the high rate of feeding on Kohanz Golab is related to the lower density and shortest length of trichome on the lower side leaves of this cultivar (table 1), facilitating access to prey. Similarly, Madadi *et al.* (2007) showed that the physical properties of host plants, especially difference in trichome density between the three plants including sweet pepper, eggplant and cucumber significantly affected the functional response parameters of the *Neoseiulus cucumeris* (Oudemans) to *Thrips tabaci* Lindeman. According to Krips *et al.* (1999) the attack rate of *Phytoseiulus persimilis* Athias-Henriot was lowest on gerbera cultivars that had higher trichome density. Koveos and Broufas (2000) reported that the searching efficiency of *Euseius finlandicus* (Oudemans) was lower on apple leaves in comparisons to peach, possibly due to the presence of trichomes on both surfaces of the apple leaf. A similar

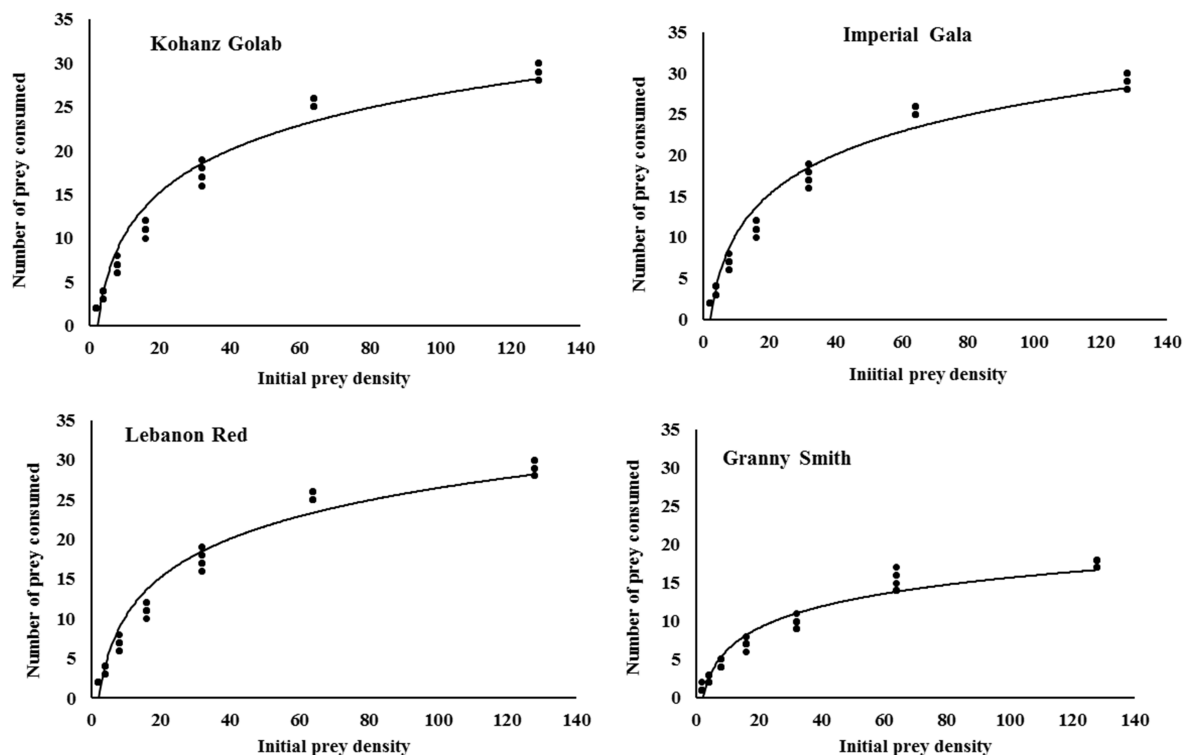
**Table 2** Maximum likelihood estimates from logistic regression of the proportion of *Eotetranychus frosti* protonymphs eaten by *Typhlodromus bagdasarjani* adult females as a function of initial prey density on four apple cultivars.

Apple cultivars	Parameters	Estimate	SE	$\chi^2$	P- value
<b>Imperial Gala</b>	Intercept ( $P_0$ )	1.9273	0.2828	46.45	<0.0001
	Linear ( $P_1$ )	-0.1070	0.0209	26.26	<0.0001
	Quadratic ( $P_2$ )	0.0015	0.0004	15.38	<0.0001
	Cubic ( $P_3$ )	-6.97E-06	1.92E-06	13.23	0.0003
<b>Kohanz Golab</b>	Intercept ( $P_0$ )	2.3455	0.3152	55.37	<0.0001
	Linear ( $P_1$ )	-0.1068	0.0225	22.59	<0.0001
	Quadratic ( $P_2$ )	0.0014	0.0004	11.07	0.0009
	Cubic ( $P_3$ )	-5.93E-06	2.02E-06	8.65	0.0033
<b>Granny Smith</b>	Intercept ( $P_0$ )	0.7465	0.2421	9.51	0.0020
	Linear ( $P_1$ )	-0.0807	0.0195	17.20	<0.0001
	Quadratic ( $P_2$ )	0.0011	0.0004	8.39	0.0038
	Cubic ( $P_3$ )	-4.86E-06	1.89E-06	6.61	0.0101
<b>Lebanon Red</b>	Intercept ( $P_0$ )	2.0091	0.2826	50.54	<0.0001
	Linear ( $P_1$ )	-0.1269	0.0211	36.24	<0.0001
	Quadratic ( $P_2$ )	0.0018	0.0004	21.46	<0.0001
	Cubic ( $P_3$ )	-8.29E-06	1.95E-06	18.06	<0.0001

**Table 3** Mean ( $\pm$ SE) daily consumption of *Typhlodromus bagdasarjani* adult female at different densities of *Eotetranychus frosti* protonymphs on four apple cultivars.

Prey density	Imperial Gala	Kohanz Golab	Granny Smith	Lebanon Red
2	1.17 $\pm$ 0.15 bc	2.0 $\pm$ 0.00 a	1.1 $\pm$ 0.10c	1.5 $\pm$ 0.16 ab
4	3.3 $\pm$ 0.15a	3.6 $\pm$ 1.16a	2.5 $\pm$ 0.16b	3.2 $\pm$ 0.13a
8	6.4 $\pm$ 0.16a	6.8 $\pm$ 0.20a	4.4 $\pm$ 0.16b	6.2 $\pm$ 0.13a
16	9.4 $\pm$ 0.22b	11.2 $\pm$ 0.20a	7.1 $\pm$ 0.18c	8.7 $\pm$ 0.21b
32	15.3 $\pm$ 0.21b	17.4 $\pm$ 0.34a	9.7 $\pm$ 0.21d	13.2 $\pm$ 0.20c
64	24.6 $\pm$ 0.22a	25.5 $\pm$ 0.17a	14.8 $\pm$ 0.35c	20.1 $\pm$ 0.23b
128	27.2 $\pm$ 0.20a	29.1 $\pm$ 0.28b	17.6 $\pm$ 0.16d	22.4 $\pm$ 0.22c



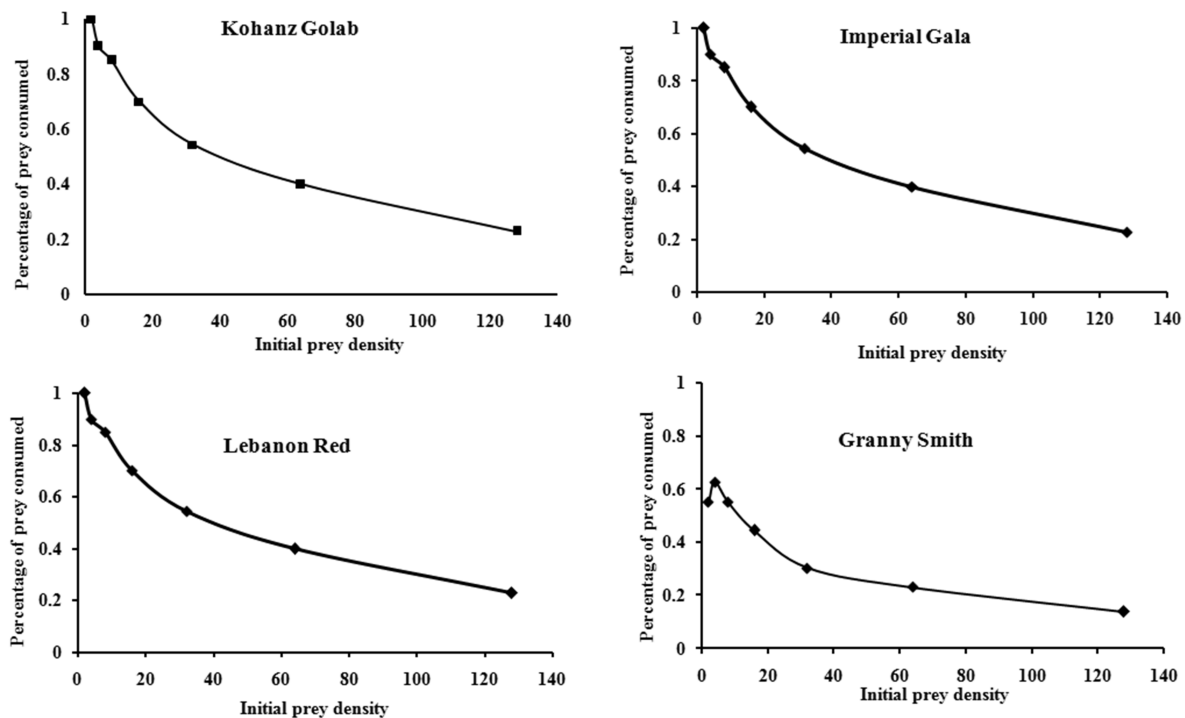


**Figure 1** The functional responses curves of adult females of *Typhlodromus bagdasarjani* to different densities of *Eotetranychus frosti* protonymphs on four apple cultivars.

effect was reported for the predatory mite *N. cucumeris* on the leaves of *Dombeya acutangula* Cav., where fewer *F. occidentalis* were eaten due to the presence of trichomes on both leaf surfaces (Scott Brown *et al.*, 1999). The presence of trichomes on leaf surfaces may physically disrupt the movement of either pest or predator physically by impeding or trapping them, or chemically by subjecting them to sticky, deterrent or toxic compounds in the exudates from glandular trichome (van Lenteren *et al.*, 1995).

**Table 4** Estimated (mean ±SE) attack rate (*a*) and handling time (*T<sub>h</sub>*) (days) for *T. bagdasarjani* adult females on *E. frosti* protonymphs on four apple cultivars.

Parameters	Imperial Gala	Kohanz Golab	Granny Smith	Lebanon Red
<i>a</i> ± SE (h <sup>-1</sup> )	0.0583±0.0081	0.0747± 0.0060	0.0334 ± 0.0034	0.0522 ± 0.0065
<i>T<sub>h</sub></i> ± SE (h)	0.7102 ±0.0434	0.7005± 0.0211	1.1189 ± 0.0548	0.8939 ± 0.0483
<i>a/T<sub>h</sub></i>	0.082	0.107	0.030	0.058
<i>T/T<sub>h</sub></i>	33.79	34.26	21.45	26.85
<i>R</i> <sup>2</sup>	0.993	0.994	0.991	0.989
<i>R</i> <sup>2</sup> <sub>adj</sub>	0.991	0.993	0.989	0.986
<i>P</i> value	<0001	<0001	<0001	<0001
<i>F</i>	7423.07	14353	5608.39	6934.15



**Figure 2** Proportion of protonymphal stages of *Eotetranychus frosti* consumed by *Typhlodromus bagdasarjani* female at different densities on four apple cultivars.

The handling time of a predator can be affected by time spent for pursuing and capturing, eating and digesting a prey (Hassell, 1978). The present study shows that the handling time of *T. bagdasarjani* to protonymphs of *E. frosti* on different apple cultivars was different. The shortest and longest handling times were obtained on Kohanz Golab and Granny Smith cultivars, respectively. These results show that on Granny Smith, the predator needed more time to manipulate and eat a prey, while on Kohanz Golab in a shorter time the predator can consume more prey. A possible reason for longer handling time of predators on Granny Smith leaves might be that Granny Smith leaf trichomes prevent the movement of predators, subsequently interfere with its searching efficiency or may provide shelter for prey and make them less vulnerable against their predators (Sabelis and van Rijn, 1997).

Also, the estimated  $a/T_h$  in the functional reaction experiment showed that *T. bagdasarjani* has an effective predatory potential for the control of *E. frosti* on Kohanz Golab. In our previous study, Kohanz Golab was the least suitable for development and reproduction of *E. frosti*, whereas Granny Smith was the most suitable cultivar (Jafarian *et al.*, 2020). Inadequacy of the host plant can affect the efficiency of its predator by affecting the size, weight and population growth of the prey. Also, according to estimate  $a/T_h$ , *T. bagdasarjani* has less efficiency for the control of *E. frosti* on Granny Smith. The decrease in predation efficiency of *T. bagdasarjani* on Granny Smith may also affect its fecundity, resulting in population decrease and hampering the efficacy of *T. bagdasarjani* to control of the *E. frosti*.

Although the functional response is a relatively important and rapid way to determine the effects of the host plant's defense on the effectiveness of the natural enemy, it alone does not indicate the success or failure of a natural enemy in pest control. Many factors influence the

efficiency of a predator that should be considered.

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