

## Demographic Parameters of *Lipaphis erysimi* on Canola Cultivars under Different Nitrogen Fertilization Regimes

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### ABSTRACT

Increased nitrogen applications to crops influence plant-herbivore interactions and potentially increase herbivore population growth. In this research, the impact of nitrogen fertilizations on nutritional quality of three canola (*Brassica napus* L.) cultivars (Zarfam, Okapi and Modena), and, consequently, the performance of mustard aphids, *Lipaphis erysimi* Kalt., on them were investigated under green house conditions. Nitrogen fertilization treatments were 0, 75, 150, and 225 kg N. ha<sup>-1</sup>. The results showed that increased nitrogen fertilization resulted in enhancing plant nitrogen content and decreasing of C/N ratio of leaves. Based on N-content and C/N ratio, Zarfam had the highest nutritional quality for herbivore among the tested canola cultivars. Fertilization generally increased the susceptibility of plants to mustard aphid. Therefore, aphids feeding on plants receiving higher nitrogen levels had shorter nymphal developmental time, longer adult longevity as well as greater fecundity. The highest and the lowest values of aphids' intrinsic rate of increase ( $r_m$ ) were calculated on Zarfam and Modena cultivars, respectively. Moreover, nitrogen fertilization positively affected  $r_m$  of aphids on all canola cultivars. According to our results, management of nitrogen fertilization and cultivation of resistant cultivar could be suitable eco-friendly strategies to manage mustard aphid population.

**Keywords:** Life table parameters, Nitrogen fertilizer, Plant resistance.

### INTRODUCTION

Canola (*Brassica napus* L.) is one of the most important sources of edible oils in the world with about 62 million tons production in 2011 (FAO, 2013). New canola cultivars contain less than 2% erucic acid in the oil and are recognized as high quality and healthy edible oil (Gunasekera *et al.*, 2006). Canola is grown on a wide range of soil types. Consequently, growers have experienced a variety of nutritional problems with the crop (Öztürk, 2010). Compared to most other industrial crops, canola has a high demand for nutrient inputs, specially nitrogen (Barłog and Grzebisz, 2004). Many

studies have shown that both growth and yield of canola are significantly enhanced by high rates of applied nitrogen (Kumar *et al.*, 2001; Majnoun Hosseini *et al.*, 2009). However, some other researches indicated that the content of oil per unit seed weight decreased at high levels of N application (Barłog and Grzebisz, 2004). Accordingly, canola with high N was more sensitive to herbivore insects' infestation through increasing their overall population growth (Sarfrac *et al.*, 2009). For instance, the positive effect of nitrogen fertilization of canola (cv. RGS003) on the performance of *Brevicoryne brassicae* L. was documented by Zarghami *et al.* (2010).

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Different canola cultivars which have the same nutrient requirements are planted in Iran (Mostafavi Rad *et al.*, 2011), but they have different susceptibility to pests (Fathi *et al.*, 2010; Fathi *et al.*, 2011a, b). Host plant resistance is an effective strategy of integrated pest management programs in *Brassica* species production that can reduce initial infestations of pests and, therefore, minimize the usage of insecticides (Trdan *et al.*, 2005; Žnidarčič *et al.*, 2008; Ahuja *et al.*, 2010).

One of the important pests of canola is mustard aphid, *Lipaphis erysimi* (Hem., Aphididae) which has a worldwide distribution (Blackman and Eastop, 1984). This aphid causes damage to canola plants at vegetative, flowering, and pod formation stages (Goggin, 2007). In addition, the mustard aphid is a vector of about 10 plant viruses that cause greater yield losses (Blackman and Eastop, 1984).

Performance of mustard aphid on some Iranian canola cultivars have been evaluated in previous studies (Roudposhti *et al.*, 2012; Khajezade *et al.*, 2010). Nevertheless, the impacts of varying nitrogen nutrition of canola cultivars on the performance of this aphid have not been studied well. Thus, this research aimed to assess the effects of the selected Iranian canola cultivars under different nitrogen fertilization regimes on the life table parameters of mustard aphid.

## MATERIALS AND METHODS

### Plant, Fertilizer, and Insect

The seeds of three most-planted winter cultivars of canola in Iran, namely, 'Zarfam', 'Okapi' and 'Modena' were obtained from Agricultural and Natural Resources Research Center of Khorasan Razavi province, Iran. The seeds were planted in 4 liters capacity pots (20 cm diameter and 20 cm height), containing 4 kg soil, leaf compost, and sand (1:1:1), on April 20<sup>th</sup>, 2012. The cultivated pots were maintained in the greenhouse at 25±4°C,

70±10% RH, and a photoperiod of 16:8 (L:D) h. Two seedlings (5 cm in height) were kept in each pot after thinning and watered when needed. The first application of fertilizer was at four-leaf seedling stage, and the second fertilization was carried out 10 days later. Based on nitrogen fertilizer (ammonium nitrate as source of nitrogen), four different fertilization treatment including 0 (0), 75 (0.055), 150 (0.11), and 225 (0.165) kg N. ha<sup>-1</sup> (g N kg<sup>-1</sup> soil), respectively, equal to 0, 50, 100, and 150% of recommended nitrogen doses were applied (Kamkar *et al.*, 2011).

Aphids used in the experiment were collected from a *Lipaphis erysimi* colony established on *Brassica oleracea* L. plants in the research greenhouse of the College of Agriculture, Ferdowsi University of Mashhad, Iran.

### Effect of Nitrogen Levels on Plant Nutritional Quality

When plants attained the eight- to ten-leaf stage (approximately 4 weeks old), the effect of different levels of N fertilization on leaf quality of canola cultivars were determined by measuring N and C content (% dry mass), and C/N ratio of 30 fully expanded uppermost leaves, chosen randomly from 10 plants within each treatment combination. Fresh leaves were subsequently washed in tap water, rinsed three times in deionized water, and oven-dried for 48 h at 60°C. Then, dried leaves were mechanically ground into powder and packed inside paper packs (each sample contained 1–3 mg dry matter). The samples were analyzed for total N and C using Kjeldahl digestion method (Rund, 1984) and simple acidimetric titration (Richards, 1954), respectively. The total amount of C and N and their ratio (C/N) were subjected to two-way ANOVA to evaluate the interaction effect of N levels by canola cultivars. Means were separated by least significant difference (LSD) test when a significant F-value was obtained.

Prior to ANOVA, data were assessed for normality and homogeneity of variance.

### Effects of N Levels and Canola Cultivars on *L. erysimi*

To determine the performance of *L. erysimi* on various canola cultivars fertilized with different N-levels, life table parameters of aphids were assessed. Forty pots were assigned to each canola cultivar with different N fertilization levels (ten pots per N level). In each treatment, at least 35 same-age alate aphids were placed individually on the surface of fully expanded uppermost canola leaves (approximately 4 weeks old). A ventilated clip cage held in position by an aluminum hair clip encaged each individual aphid. After 24 hours, adults and all young, except one first instar nymph, were removed. The remaining nymph was allowed to develop to adulthood. All aphids were examined daily for the onset of reproduction. The newborn nymphs produced by each aphid (age-specific fecundity) were recorded for the remainder of its life and then removed from the leaf to prevent intra-specific interactions. Counting and observation were continued until the death of all aphids.

The performance of the aphids was assessed by measuring nymphal developmental period (the number of days between birth and adult emergence), adult longevity (from adult emergence to death), fecundity (number of offspring per aphid), and estimating the intrinsic rate of natural increase ( $r_m$ ). The intrinsic rate of natural increase ( $r_m$ ) was calculated by iteratively solving the following equation (Birch, 1948):

$$\sum L_x m_x e^{-r_m x^*} = 1$$

Where,  $r_m$  is the per capita instantaneous rate of population growth (number per day),

$$L_x = \frac{l_x + l_{x+1}}{2}, \quad \text{and}$$

$$x^* = \text{pivotal } x = \frac{x_N + x_{N+1}}{2}, \quad l_x \text{ is the}$$

probability of surviving to age  $x$ , and  $m_x$  the mean fecundity at age  $x$ .

Other parameters of fertility life table including net reproduction rate ( $R_0 = \sum L_x m_x$ ), generation time ( $T = \frac{\ln R_0}{r_m}$ ), population doubling time ( $DT = \frac{\ln 2}{r_m}$ ) as well as finite rate of increase ( $\lambda = e^{r_m}$ ) were likewise computed.

Jackknife method was used for producing pseudo values (Meyer *et al.*, 1986; Maia *et al.*, 2000) to find differences in  $R_0$ ,  $T$ ,  $DT$ ,  $\lambda$ , and  $r_m$  values. To assess N fertilization and cultivar effects, aphid performance parameter values, except aphid nymphal survivorship that was analyzed with non-parametric Kruskal–Wallis test, were subjected to one-way ANOVA (SAS, 2004) for each treatment. If significant differences were detected, LSD test was used. Linear regression was also applied to determine the relationship between N-fertility levels and performance parameter values. Correlations between variables were examined using Pearson correlation coefficients.

## RESULTS

### Effects of N-levels on Nutritional Quality of Canola Cultivars

Air-dried soil samples were analyzed for physical and chemical properties. Some characteristics of the experimental soil are presented in Table 1.

The difference among total percentage of leaf carbon content was significant in both groups of treatments (cultivar treatment:  $F_{2, 48} = 41.6$ ,  $P < 0.01$ ; N-fertilization levels:  $F_{3, 48} = 21.5$ ,  $P < 0.01$ ) but interactive effect of treatments was not significant ( $F_{6, 48} = 1.72$ ,  $P = 0.138$ ). Leaf-C content had a decreasing trend with increasing N level and the lowest C-leaf rate was measured at the maximum N-fertilization treatments in Zarfam cultivar (Table 2). Total leaf nitrogen content was significantly affected by N fertilization

**Table 1.** Physical and chemical properties of experimental soil.

Particle size distribution (%)			Texture grade	OC <sup>a</sup> (%)	pH	EC <sup>b</sup>	%SP <sup>c</sup>	%TNV <sup>d</sup>	%N	P (mg kg <sup>-1</sup> )	K (mg kg <sup>-1</sup> )	%S
Sand	Silt	Clay										
65.5	28.5	6	Sandy loam	0.56	7.34	0.63	25.72	11.34	0.04	36.9	367.5	0.08

<sup>a</sup> Organic Carbon; <sup>b</sup> Soil Electrical Conductivity (dS m<sup>-1</sup>); <sup>c</sup> Saturation Percentage, <sup>d</sup> Total Neutralizing Value.

levels ( $F_{3, 48} = 35.72$ ,  $P < 0.01$ ). The maximum amounts of N-leaf were detected in plants fertilized with 225 kg N ha<sup>-1</sup>. The effect of canola cultivars on N-leaf content ( $F_{2, 48} = 24.37$ ,  $P < 0.01$ ) and the interaction effect were significant ( $F_{6, 48} = 2.64$ ,  $P < 0.05$ ). Zarfam and Okapi cultivars fertilized with either 150 or 225 kg N ha<sup>-1</sup> had the highest N-leaf content in comparison with the other fertilized plants (Table 2).

Regression analysis demonstrated a significant positive relationship ( $P < 0.01$ ) between N-leaf content and N-fertilization levels (g N kg<sup>-1</sup> soil) and a significant negative relationship ( $P < 0.01$ ) between leaf C content and N-fertilization levels. Three different lines were fitted for Modena ( $Y = 1.49 + 2.94X$ ,  $R^2_{adj} = 0.67$ ,  $P < 0.01$ ), Okapi ( $Y = 1.82 + 3.65X$ ,  $R^2_{adj} = 0.66$ ,  $P < 0.01$ ) and Zarfam ( $Y = 1.61 + 4.99X$ ,  $R^2_{adj} = 0.67$ ,  $P <$

0.01) for N-leaf content. Leaf N content showed 30.92, 43.03 and 36.05% increase in Modena, Okapi and Zarfam, respectively (Figure 1-A).

The regression lines for leaf C content were also fitted for Modena ( $Y = 52.30 - 21.88X$ ,  $R^2_{adj} = 0.71$ ,  $P < 0.01$ ), Okapi ( $Y = 51.89 - 24.33X$ ,  $R^2_{adj} = 0.38$ ,  $P < 0.01$ ) and Zarfam ( $Y = 49.03 - 38.14X$ ,  $R^2_{adj} = 0.51$ ,  $P < 0.01$ ) (Figure 1-B).

The differences of C/N ratio among cultivars ( $F_{2, 48} = 19.14$ ,  $P < 0.01$ ) and for N-treatment ( $F_{3, 48} = 27.02$ ,  $P < 0.01$ ) were statistically significant. However, their interaction ( $F_{6, 48} = 0.85$ ,  $P = 0.54$ ) was not significant. The lowest C/N ratio was observed in Zarfam fertilized with the highest nitrogen level (Table 2).

Regression analysis revealed a significant negative relationship ( $P < 0.01$ ) between C/N

**Table 2.** Total nitrogen and carbon contents, and carbon/nitrogen (C/N) ratio of sampled canola leaves (Mean±SEM) in response to different nitrogen fertilization levels (kg ha<sup>-1</sup>) (n= 15).

Cultivar	Nitrogen treatment <sup>a</sup>	C-content (%)	N-content (%)	C/N ratio
Modena	0	52.19± 0.80 a*	1.52± 0.12 de	34.63± 2.61 a
	75	51.39± 0.62 a	1.61± 0.04 d	32.18± 1.05 ab
	150	49.61± 0.79 b	1.83± 0.07 c	28.04± 0.95 bc
	225	48.77± 1.32 bc	1.99± 0.05 bc	24.70± 0.95 c
Zarfam	0	48.44± 0.29 bc	1.65± 0.07 d	30.15± 1.8 b
	75	46.88± 0.30 c	1.73± 0.07 cd	27.13± 1.65 bc
	150	46.69± 0.45 c	2.35± 0.13 a	19.99± 2.74 d
	225	41.51± 0.49 d	2.36± 0.07 a	17.69± 1.18 de
Okapi	0	51.35± 1.11 a	1.72± 0.07 cd	30.11± 1.82 b
	75	51.04± 0.96 a	2.15± 0.05 b	23.87± 0.94 c
	150	49.24± 0.91 b	2.29± 0.07 a	21.67± 1.04 cd
	225	47.49± 0.29 bc	2.34± 0.04 a	20.30± 0.51 d

<sup>a</sup> kg N ha<sup>-1</sup>; \* Means within a column followed by different letters indicate that they were significantly different (factorial ANOVA followed by fisher exact LSD test,  $P < 0.05$ )

ratio of leaf and N levels (g N kg<sup>-1</sup> soil) and different lines were fitted for Modena (Y= 34.98-61.7X, R<sup>2</sup>adj= 0.46, P< 0.01), Okapi (Y= 28.73-57.51X, R<sup>2</sup>adj= 0.61, P< 0.01)

and Zarfam (Y= 30.42-80.98X, R<sup>2</sup>adj= 0.68, P< 0.01) (Figure 1-C).

### Effects of N Levels and Canola Cultivars on Aphid Performance

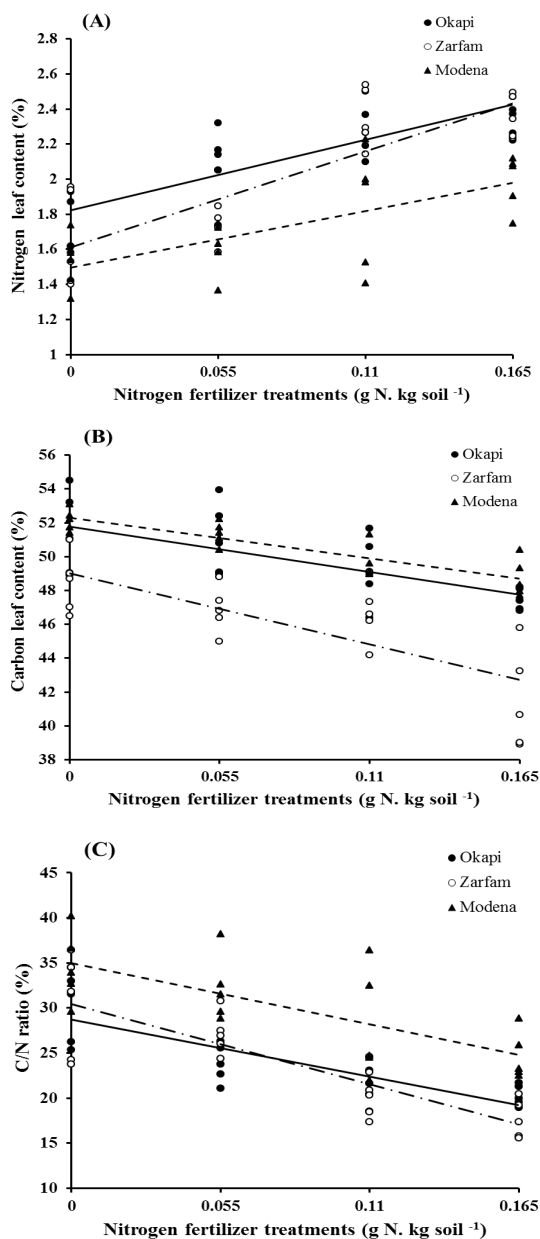
#### Developmental Time and Survivorship

Juvenile developmental time of *L. erysimi* was significantly affected by the level of nitrogen (F<sub>3, 289</sub>= 5.17, P< 0.01) and cultivar (F<sub>2, 289</sub>= 12.84, P< 0.01). The interaction between N-level and cultivar also had significant effect on developmental time (F<sub>6, 289</sub> = 2.08, P = 0.05). Aphids fed on plants fertilized with 150 and 225 kg N ha<sup>-1</sup> in Zarfam had the shortest nymphal period (Table 3). The effect of treatments on nymph survivorship (*I<sub>x</sub>*) was significant (Friedman ANOVA,  $\chi^2$ = 19.69, P= 0.04) (Hosseini *et al.*, 2010) and the highest nymph survivorship was obtained on Zarfam fertilized with 150 and 225 kg N ha<sup>-1</sup> (100 and 96%, respectively), whereas it was the lowest on non-fertilized plants (69, 74, and 76%, respectively, for Modena, Zarfam, and Okapi) [Figure 2, (A, B and C)].

#### Adult Longevity and Reproduction

In adult longevity, not only the main effect of treatments (F<sub>2, 285</sub>= 14.57, P< 0.01 and F<sub>3, 285</sub>= 3.98, P< 0.01 for cultivar and N-treatment, respectively) but also the interaction effect was significant (F<sub>6, 285</sub>= 4.30, P< 0.01). The longest adult longevity was observed in aphids reared on Zarfam fertilized with the highest nitrogen fertilization (225 kg N ha<sup>-1</sup>). Nevertheless, adult longevity of aphids grown on Modena fertilized with 0, 75, and 150 kg N ha<sup>-1</sup> was significantly shorter than the other treatment combinations (Table 3).

Effect of either nitrogen fertilization or canola cultivars was significant in mustard aphid fecundity. The maximum number of

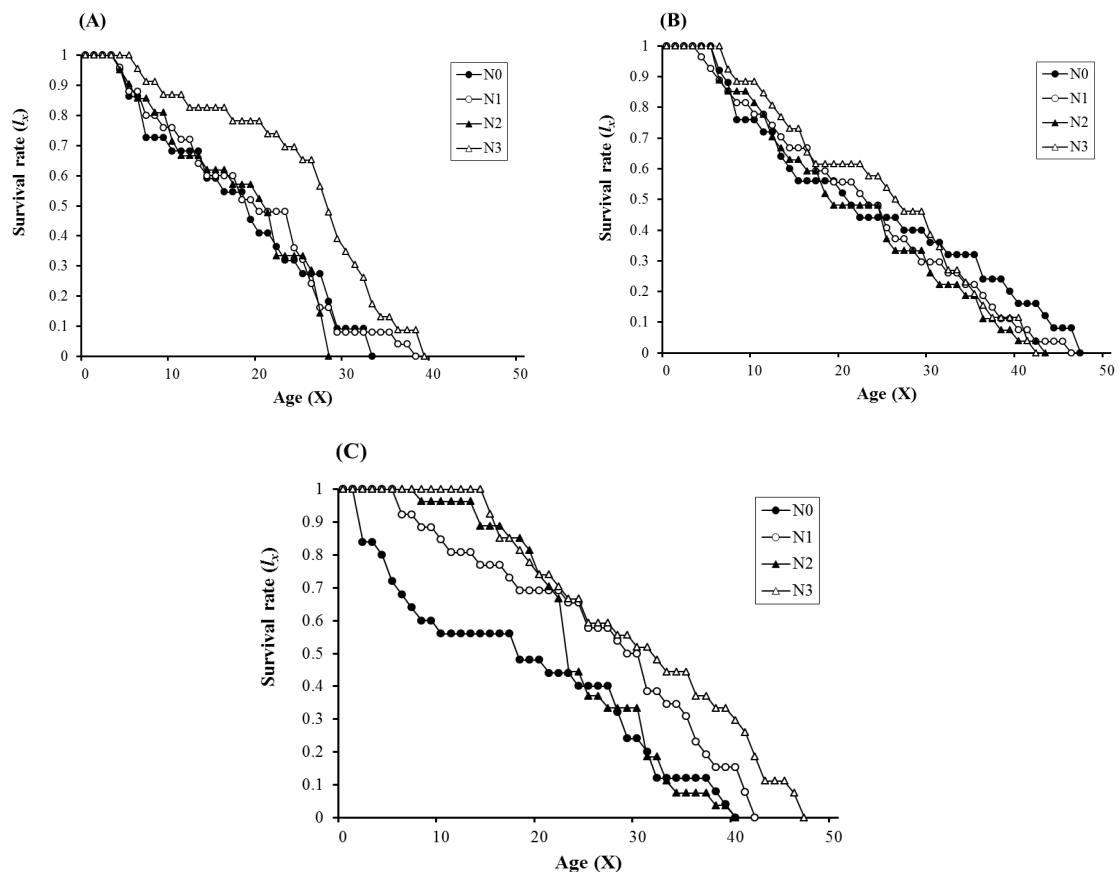


**Figure 1.** Relationship between leaf N content (A), leaf C content (B) and C/N ratio (C) of canola cultivars (—: Okapi; ---: Zarfam, - - -: Modena) and nitrogen fertilization levels. N treatments were 0 (0), 0.055 (75), 0.11 (150) and 0.165 (225) g N kg<sup>-1</sup> soil (kg N ha<sup>-1</sup>). Each point represents one replicate. All fitted lines were significant (P< 0.01).

**Table 3.** Biological parameters of *Lipaphis erysimi* on three studied cultivars at different nitrogen fertilization levels.

Cultivar	Nitrogen treatment <sup>a</sup>	Biological parameter		
		Nymphal developmental time (d)	Adult longevity (d)	Fecundity
Modena	0	8.68±0.28 a*	9.36± 1.79 d	6.10±1.99 d
	75	8.40±0.30 ab	10.14± 2.00 d	8.45 ±2.28 d
	150	7.98±0.34 bc	8.38± 1.62 d	9.05±2.16 d
	225	7.97±0.21 bc	19.91± 1.15 b	16.56±2.63 c
Zrafam	0	7.44±0.28 bc	15.20± 2.22 c	23.16±4.14 b
	75	7.00±0.21 c	17.44±1.51b	27.33±3.05 b
	150	6.96±0.20 cd	19.73± 2.26 b	33.35±4.17 ab
	225	6.82±0.26 d	23.22± 2.07 a	37.15±3.95 a
Okapi	0	8.64±0.34 a	15.45± 2.95 c	21.20±4.91bc
	75	7.93±0.32 bc	15.19± 2.34 c	19.52±4.02 bc
	150	7.62±0.20 bc	21.59± 2.20 ab	21.59±3.30 bc
	225	7.25±0.31 cd	17.15± 2.34 bc	30.23±4.38 ab

<sup>a</sup> kg N ha<sup>-1</sup>; \* Means within a column followed by different letters indicate that they were significantly different (factorial ANOVA followed by fisher exact LSD test, P< 0.05).

**Figure 2.** Survival curves for *Lipaphis erysimi* reared on the tested canola cultivars, fertilized with different nitrogen levels. [—●, N<sub>0</sub>: 0 kg N ha<sup>-1</sup>; —○, N<sub>1</sub>: 75 kg N ha<sup>-1</sup>; —▲, N<sub>2</sub>: 150 kg N ha<sup>-1</sup>; —△, N<sub>3</sub>: 225 kg N ha<sup>-1</sup>; (A) Modena; (B) Okapi, and (C) Zarfam].

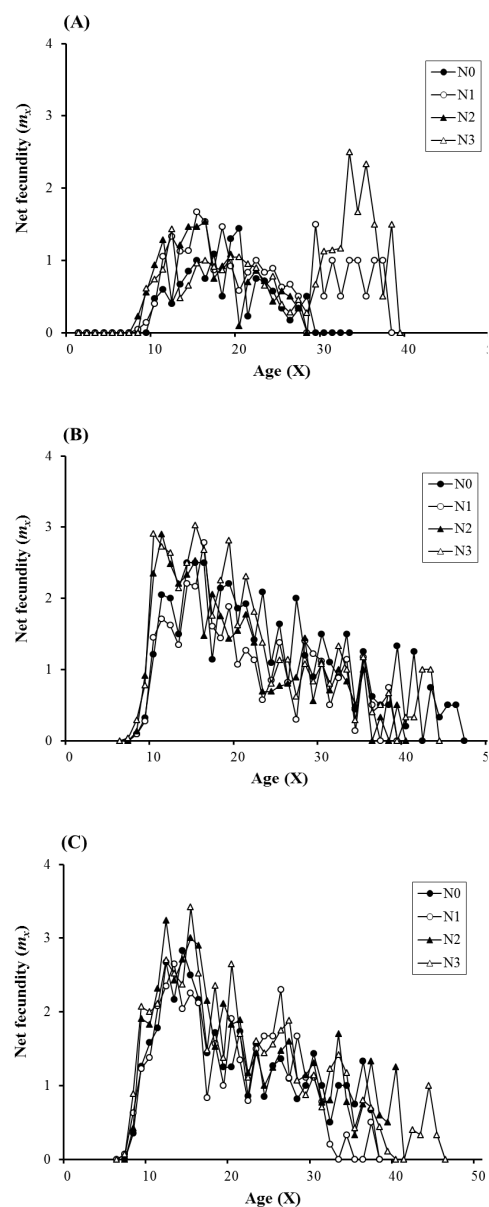
nymphs per adult was recorded in Zarfam cultivar ( $F_{2, 285} = 30.49$ ,  $P < 0.01$ , Table 3) and in plants treated with the highest amount of nitrogen fertilization ( $225 \text{ kg N ha}^{-1}$ ) ( $F_{3, 285} = 5.00$ ,  $P < 0.01$ , Table 3). However, the interaction between N-treatment and canola cultivars was not significant on fecundity ( $F_{6, 285} = 0.57$ ,  $P = 0.75$ ) (Table 3). Increasing N application enhanced the production of nymphs per aphid on the tested canola cultivars. In addition, when aphids were reared on Modena (Figure 3-A),  $m_x$  was lower than that of aphids grown on Okapi (Figure 3-B) or Zarfam (Figure 3-C) in the same N treatments.

### Life Table Parameters

Age specific life table parameters of mustard aphid on the tested canola cultivars in different N-treatments are presented in Table 4. The interaction effect of nitrogen fertilization and canola cultivars on  $R_0$ ,  $T$ ,  $\lambda$ ,  $DT$  were not significant ( $R_0$ :  $F_{6, 285} = 0.42$ ,  $P = 0.88$ ;  $T$ :  $F_{6, 285} = 1.51$ ,  $P = 0.17$ ;  $\lambda$ :  $F_{6, 285} = 0.21$ ,  $P = 0.97$ ;  $d_t$ :  $F_{6, 285} = 0.52$ ,  $P = 0.79$ ). However, the mentioned parameters were significantly influenced by different amount of N fertilization ( $R_0$ :  $F_{3, 285} = 5.58$ ,  $P < 0.01$ ;  $\lambda$ :  $F_{3, 285} = 9.36$ ,  $P < 0.01$ ;  $DT$ :  $F_{3, 285} = 5.00$ ,  $P < 0.01$ ) except aphids' mean generation time ( $F_{3, 285} = 1.46$ ,  $P = 0.23$ ). Moreover, life table parameters of *L. erysimi* were significantly affected by canola cultivars ( $R_0$ :  $F_{2, 285} = 29.39$ ,  $P < 0.01$ ;  $T$ :  $F_{2, 285} = 5.44$ ,  $P < 0.01$ ;  $\lambda$ :  $F_{2, 285} = 56.37$ ,  $P < 0.01$ ;  $DT$ :  $F_{2, 285} = 33.46$ ,  $P < 0.01$ ).

Cultivar and N-level interaction was not significant for aphids'  $r_m$  ( $F_{6, 285} = 0.23$ ,  $P = 0.96$ ). Nevertheless, there was a significant effect of cultivars ( $F_{2, 285} = 57.9$ ,  $P < 0.01$ ) and nitrogen levels ( $F_{3, 285} = 9.49$ ,  $P < 0.01$ ) on aphids'  $r_m$ . The highest and the lowest  $r_m$  ( $0.250$  and  $0.120 \text{ day}^{-1}$ ) were achieved for aphids reared on Zarfam and Modena, respectively. In addition, a significant positive relationship ( $P < 0.01$ ) between  $r_m$  and N-fertilization levels ( $\text{g N kg soil}^{-1}$ ) was found. Three different linear regression lines

were fitted for Modena ( $Y = 0.123 + 0.291X$ ,  $R^2_{\text{adj}} = 0.32$ ,  $P < 0.01$ ), Okapi ( $Y = 0.177 + 0.308X$ ,  $R^2_{\text{adj}} = 0.27$ ,  $P < 0.01$ ), and Zarfam ( $Y = 0.211 + 0.231X$ ,  $R^2_{\text{adj}} = 0.25$ ,  $P <$



**Figure 3.** Age-specific net fecundity rates of *Lipaphis erysimi* reared on tested canola cultivars, fertilized with different nitrogen levels. [—●,  $N_0$ :  $0 \text{ kg N ha}^{-1}$ ; —○,  $N_1$ :  $75 \text{ kg N ha}^{-1}$ ; —▲,  $N_2$ :  $150 \text{ kg N ha}^{-1}$ ; —△,  $N_3$ :  $225 \text{ kg N ha}^{-1}$ ; (A) Modena; (B) Okapi, and (C) Zarfam].

**Table 4.** Life-table parameters mean ( $\pm$ SEM) for *Lipaphis erysimi*, on different canola cultivars in response to nitrogen fertilization levels ( $\text{kg ha}^{-1}$ ).

Cultivar	Nitrogen treatment <sup>a</sup>	$R_0^b$ (♀/♀/Generation)	$r_m^c$ (Day <sup>-1</sup> )	$\lambda$ (Day <sup>-1</sup> ) <sup>d</sup>	T (d) <sup>e</sup>	DT (d) <sup>f</sup>
Modena	0	6.56±1.16 d*	0.120±0.014d	1.127±0.0156 e	15.954±0.71 <sup>n.s.</sup>	5.520±0.98 a
	75	8.87±1.34 d	0.139±0.005 d	1.146±0.0059 de	16.134±0.47	5.063±0.17 ab
	150	10.57±1.27 d	0.152±0.009 cd	1.164±0.0109 d	15.750±0.63	4.521±0.31 b
	225	16.53±1.56 c	0.171±0.007 c	1.186±0.0083 cd	16.470±0.51	4.053±0.18 bc
Zraifam	0	22.76±4.10 bc	0.209±0.013 b	1.232±0.016 b	15.030±0.52	3.306±0.21 cd
	75	26.75±3.03 b	0.229±0.009 ab	1.257±0.0118 ab	14.381±0.53	3.025±0.13 d
	150	32.83±4.19 ab	0.234±0.011 ab	1.264±0.0132 ab	14.924±0.40	2.952±0.13 d
	225	36.61±3.96 a	0.250±0.013 a	1.283±0.0163 a	14.430±0.60	2.771±0.14 ed
Okapi	0	21.58±4.70 bc	0.182±0.013 bc	1.200±0.0152 c	16.971±0.75	3.787±0.25 c
	75	19.05±3.99 bc	0.187±0.014 bc	1.205±0.0163 c	15.877±0.71	3.689±0.28 c
	150	21.06±3.31 bc	0.212±0.013b	1.236±0.014 b	14.410±0.53	3.257±0.18 cd
	225	29.59±4.39 ab	0.230±0.011 ab	1.258±0.0129 ab	14.787±0.51	3.012±0.14 d

<sup>a</sup> kg Nha<sup>-1</sup>; <sup>b</sup> Intrinsic rate of increase; <sup>c</sup> Net reproductive rate; <sup>d</sup> Finite rate of increase; <sup>e</sup> Mean generation time (days); <sup>f</sup> Doubling Time (days).

\* Means within a column followed by different letters indicate that they were significantly different (P<0.05).



0.01), as presented in Figure 4.

A significant positive correlation was detected between aphids'  $r_m$  and the leaf nitrogen content of canola cultivars (Modena:  $r= 0.32$ ,  $P< 0.01$ ; Zarfam:  $r= 0.23$ ,  $P= 0.01$ ; and Okapi:  $r= 0.26$ ,  $P< 0.01$ ). However, the correlation between  $r_m$  of *L. erysimi* and the C/N ratio of plants were negative and Pearson correlation coefficients in Modena ( $r= -0.32$ ,  $P< 0.01$ ), Zarfam ( $r= -0.24$ ,  $P= 0.01$ ) and Okapi ( $r= -0.25$ ,  $P= 0.01$ ) were significant.

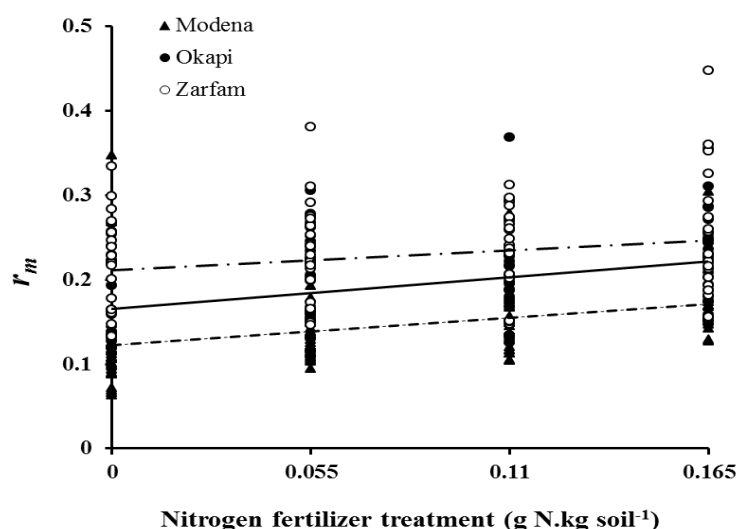
## DISCUSSION

Application of high levels of nitrogen clearly increased the N content of the leaf tissue in all canola cultivars. The results also showed that higher N fertilization levels decreased both the leaf carbon content and C/N of canola plants. Similarly, enhancement of plant nitrogen content and decreasing C/N following N fertilization have been reported in many other plant species (Davies and He, 2004; Svečnjak and Rengel, 2006; Hosseini *et al.*, 2010; Žanić *et al.*, 2013).

In the present study, canola cultivars had different responses to nitrogen application.

The possible reason for this finding could be due to difference of various cultivars in nutrient efficiency, which is an inherited characteristic (Svečnjak and Rengel, 2006; Zhang *et al.*, 2012).

Resource quality including nutritional value (e.g. nitrogen content), secondary metabolite compounds (Chen *et al.*, 2010) and genetic differences of host plants (Soufbağ *et al.*, 2012) can influence many aspects of behavior and physiology of plant herbivore insects (Žnidarčič *et al.*, 2011). These effects can, in turn, impact consumer survival, development rates, or fecundity (Golizadeh *et al.*, 2009; Daugherty, 2011). In the current research, life-history parameters of *L. erysimi* on tested canola cultivars were positively influenced by nitrogen fertilization rates. Utilization of nitrogen increased the susceptibility of canola cultivars to *L. erysimi*. Developmental time of aphids showed a decreasing trend with rising nitrogen levels and had a significant negative correlation with N-content of the host plants. Similar results have been reported by other researchers. For instance, Zarghami *et al.* (2010) demonstrated a reduction of pre-reproduction period of *Brevicoryne brassicae* L. with increasing nitrogen



**Figure 4.** Relationship between the intrinsic rate of increase ( $r_m$ ) of *Lipaphis erysimi* and nitrogen fertilization levels in different canola cultivars (—: Okapi; - - -: Zarfam, - · - ·: Modena). N levels are 0 (0), 0.055 (75), 0.11 (150) and 0.165 (225) g N kg<sup>-1</sup> soil (kg N ha<sup>-1</sup>).



application. According to the developmental time and fecundity, *cv* Zarfam was a more suitable host for *L. erysimi* which is in agreement with the results of *M. persicae* on *cv* Zarfam in comparison to five other cultivars (Fathi et al., 2010). The results also showed a rising trend of fecundity with increasing nitrogen levels in all cultivars. Similarly, increasing the fecundity of *Aphis gossypii* Glover on cucumber (Hosseini et al., 2010) and cotton (Nevo and Coll, 2001), as well as for *B. brassicae* on canola (Zarghami et al., 2010) in response to nitrogen application were reported by the other researchers.

Our finding indicated that the aphids achieved the highest  $r_m$  on *cv* Zarfam. Previous studies also reported that the  $r_m$  of other pests such as *M. persicae* (Fathi et al., 2010), *Plutella xylostella* L. (Fathi et al., 2011a) and *Thrips tabaci* Lind. (Fathi et al., 2011b) was the highest on this cultivar compared to other cultivars. In our study, a significant positive effect of nitrogen fertilization on the  $r_m$  of aphids was observed, which is in accordance with the findings of other researchers (Nevo and Coll, 2001; Aqueel and Leather, 2011). Effects of various conditions including temperature (Godoy and Cividanes, 2002), phenological stages of host plant (Agarwala and Datta, 1999) and genetic variation of canola cultivars (Kumar et al., 2011) on the  $r_m$  of *L. erysimi* have been reported in previous studies. However, to our knowledge, this is the first assessment of nitrogen fertilization effect on  $r_m$  of mustard aphid.

In this research, experimental conditions were the same for all treatments. Therefore, a possible mechanism that contributed to variation of *L. erysimi* performance is the inherited differences of cultivars in nitrogen efficiency, which made various qualities in cultivars (e.g. leaf N content and C/N). It is known that higher nitrogen fertilization contributes to an increase in the total amino acid concentration in plants (Aqueel and Leather, 2011) and decrease in carbon-based defensive chemicals (Muzika and Pregitzer,

1992), consequently, enhancing aphid performance (Bethke et al., 1998). Another possible reason for the variation in mustard aphids'  $r_m$  could be attributed to the concentration of secondary metabolites, glucosinolates (GS), in different canola cultivars (Embaby et al., 2010). In this regard, results of Cole (1997) showed a negative correlation between aphids'  $r_m$  (*M. persicae* and *B. brassicae*) and GS concentration in different *Brassica* species. GS concentration of the tested canola cultivars under different N regimes were not evaluated in the current study, thus, the possibility of this hypothesis needs more studies.

In summary, results obtained in this study revealed the obvious influence of canola cultivars and nitrogen fertilization on life history parameters of *L. erysimi*. Based on our experimental results, *cv* Modena could be used as a part of an IPM strategy for population management of mustard aphid in the field conditions. In addition, optimization of nitrogen application with respect to canola yield and aphid population could be effective in attaining environmentally friendly agriculture and decreasing canola production costs.

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## پارامترهای زیستی شته خردل در تغذیه از ارقام کلزا تحت تأثیر سطوح مختلف کوددهی نیتروژن

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### چکیده

افزایش مصرف کودهای نیتروژن در گیاهان زراعی، اثرات متقابل میان گیاه و حشرات گیاهخوار را تحت تأثیر قرار می‌دهد و می‌تواند باعث افزایش رشد جمعیت آفات گیاهخوار گردد. در این تحقیق اثر کوددهی نیتروژن بر کیفیت غذایی سه رقم کلزا (*Brassica napus* L) شامل ارقام زرفام، اوکاپی و مودنا و اثر آن بر توانایی زیستی شته خردل (*Lipaphis erysimi* Kalt.) تحت شرایط گلخانه‌ای مورد بررسی قرار گرفت. سطوح تیمار نیتروژن شامل صفر، ۷۵، ۱۵۰ و ۲۲۵ کیلوگرم نیتروژن در هکتار بود. نتایج نشان داد که افزایش کاربرد کود نیتروژن سبب بهبود محتوای نیتروژن گیاه و کاهش نسبت کربن به نیتروژن برگ شد. بر این اساس رقم زرفام، بهترین کیفیت غذایی را برای آفت گیاهخوار نسبت به سایر ارقام داشت. به‌طور کلی کوددهی حساسیت گیاهان را به شته خردل افزایش داد. بنابراین شته‌های تغذیه شده از گیاهانی که نیتروژن بیشتری دریافت کردند دارای دوره نمو پورگی کوتاه‌تر، دوره رشدی بالغ طولانی‌تر و باروری بیشتر بودند. کمترین و بیشترین نرخ ذاتی رشد شته ( $r_m$ ) به ترتیب در ارقام مودنا و زرفام محاسبه شد. به علاوه کوددهی نیتروژن در تمام ارقام اثر مثبتی بر نرخ ذاتی رشد داشت. با توجه به نتایج این تحقیق، مدیریت کوددهی نیتروژن و کاشت ارقام مقاوم می‌تواند روش‌های زیست محور مناسبی در جهت مدیریت جمعیت شته خردل باشند.