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The impact of host plant on biological parameters of *Diuraphis noxia*

Hamideh Tabasian [1], Shila Goldasteh [1], Gholamhossein Moravvej✉[2], Elham Sanatgar[1], Mohammad Ghadamyari [3]

[1]*Department of Entomology, Faculty of Agriculture, Islamic Azad University, Arak Branch, Markazi, Arak, Iran.*[2]*Department of Plant Protection, Faculty of Agriculture, Ferdowsi University of Mashhad, Khorasan Razavi, Mashhad, Iran.*[3]*Department of Plant Protection, Faculty of Agriculture, University of Guilan, Guilan, Rasht, Iran.*
✉moravej@um.ac.ir

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Abstract

Russian wheat aphid, *Diuraphis noxia*, is one of the economic pests of small grain cereals with worldwide distribution. In current research, susceptibility of *D. noxia* to a number of host plants including two cultivars of wheat (cv. Shiroodi and Gascogne) and triticale (cv. Sanabad and Juanillo 92) were evaluated under greenhouse conditions (23 ± 5°C, 60 ± 10% RH and the photoperiod cycle of 16L:8D). The parameters of fertility life table were determined using age-stage two-sex life table theory. The highest developmental time belonged to cv. Sanabad population with a mean value of 11.6 ± 0.21 days and the lowest to cv. Shiroodi population with a mean value of 7.29 ± 0.19 days. The aphids reared on Shiroodi and Juanillo 92 cultivars with mean values of 47.45 ± 2.86 and 12.85 ± 3.13 represented the highest and lowest numbers of offspring, respectively. The intrinsic rate of increase varied from 0.25 female/female/day in aphids reared on cv. Shiroodi to 0.11 ± 0.01 female/female/day in those reared on cv. Juanillo 92. Mean generation time for aphids ranged from 14.2 ± 0.07 days on cv. Shiroodi to 19.99 ± 0.07 days on cv. Juanillo 92. According to the results, Shiroodi and Juanillo 92 cultivars exerted the lowest and highest antibiosis effects on *D. noxia* population, respectively.

Key words: Russian wheat aphid, Wheat, Triticale, Fertility, Age-stage two-sex life table

تاثیر گیاه میزبان بر پارامترهای زیستی *Diuraphis noxia*

حمیده طبسیان[۱]، شیلا گلدسته[۱]، غلامحسین مروج✉[۲]، الهام صنعتگر[۱]، محمد قدمیاری[۳]

[۱]*گروه حشره‌شناسی، دانشکده کشاورزی، دانشگاه آزاد اسلامی، واحد اراک، ایران.* [۲]*گروه گیاهپزشکی، دانشکده کشاورزی، دانشگاه فردوسی مشهد، خراسان رضوی، مشهد، ایران.*[۳]*گروه گیاهپزشکی، دانشکده کشاورزی، دانشگاه گیلان، گیلان، رشت، ایران.* ✉moravej@um.ac.ir

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چکیده

شته روسی گندم، *Diuraphis noxia*، یکی از آفات دارای اهمیت اقتصادی غلات دانه‌ریز با پراکنش جهانی است. در تحقیق حاضر، حساسیت *D. noxia* به تعدادی از گیاهان میزبان شامل دو رقم گندم (شیرودی و گاسکوژن) و تریتیکاله (سناباد و جوانیلو۹۲) تحت شرایط گلخانه‌ای (دمای ۵ ± ۲۳ درجه سلسیوس، رطوبت نسبی ۱۰ ± ۶۰ درصد و دوره نوری ۱۶ ساعت روشنایی/ ۸ ساعت تاریکی) ارزیابی شد. پارامترهای جدول زندگی باروری با استفاده از تئوری جدول زندگی دوجنسی سن-مرحله رشدی تعیین شد. بیشترین زمان رشد به جمعیت روی سناباد با میانگین ۰/۲۱± ۱۱/۶ روز و کمترین ترین زمان به جمعیت شیرودی با میانگین ۰/۱۹± ۷/۲۹ روز تعلق داشت. شته‌های پرورش‌یافته روی رقم‌های شیرودی و جوانیلو۹۲ با میانگین۲/۸۶± ۴۷/۴۵ و ۳/۱۳ ± ۱۲/۸۵، به ترتیب بیشترین و کمترین تعداد نتاج را تولید کردند. نرخ ذاتی افزایش جمعیت از ۰/۲۵ ماده/ماده/روز در شته های پرورش یافته روی شیرودی تا ۰/۰۱ ± ۰/۱۱ ماده/ماده/روز برای شته‌های پرورش‌یافته روی جوانیلو۹۲ متغیر بود. متوسط زمان یک نسل شته‌ها از ۰/۰۷ ± ۱۴/۲ روز روی شیرودی تا ۰/۰۷ ± ۱۹/۹۹ روز روی جوانیلو۹۲ متغیر بود. با توجه به نتایج، رقم‌های شیرودی و جوانیلو۹۲، به ترتیب کمترین و بیشترین اثرات آنتی‌بیوزی را بر جمعیت *D. noxia* اعمال کردند.

کلمات کلیدی: شته روسی گندم، گندم، تریتیکاله، باروری، جدول زندگی دوجنسی سن-مرحله رشدی

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Introduction

The Russian wheat aphid, *Diuraphis noxia* (Kurdjumov, 1913) (Hemiptera: Aphididae), is an invasive pest of small grains in the world with extensive distribution. Among host plants of *D. noxia*, barley, wheat and triticale have more susceptibility to aphid attack than oat and rye (Melaku *et al.* 1993; Webster *et al.* 1993). The aphid-infested leaves show chlorosis, streaking and rolling which are usually covered by honeydew leading to reduced photosynthesis and stem resources (Damsteegt *et al.* 1992; Chander *et al.* 2006; Saheed *et al.* 2010). Belay & Araya (2015) reported the losses in range of 67 to 68% in wheat grain yield, 44 to 55% in biomass and 20% in the 1000-seed weight. The Russian wheat aphid is also able to transfer the pathogenic viruses such as *Barley yellow dwarf virus* (BYDV), (Damsteegt *et al.* 1992).

Various tactics such as chemical, cultural and biological control have been proposed for population management of *D. noxia* (Bayoun *et al.* 1995; Hopper *et al.* 1995). Selection and breeding of resistant cultivars to *D. noxia* is considered as one of the most economical and ecological strategies which has attracted the attention of many researchers (Turanli *et al.* 2012; Sinha *et al.* 2016).

Resistant plant cultivars to insect pest reduce the number of insects or compensate for the plant damage and is conveyed by three main mechanisms including antixenosis, antibiosis and tolerance.

In addition, plant resistance to insects contributes to the more effective performance of natural and biological control agents, cultural management tactics and insecticides application (Teetes 1994). In antibiosis studies, various measures such as developmental time, survival rate, total fecundity, reproductive rate, reproductive periods, longevity and the intrinsic rate of increase (*r*), have been used to introduce cereal resistance to Russian wheat aphid (Behle & Michels Jr 1990; Kazemi 2010; Kazemi *et al.* 2010; Veisi *et al.* 2012; Ngenya *et al.* 2013).

The present study aimed to evaluate the effects of a number of cultivars of triticale and wheat on growth, reproductive and survival characteristics of *D. noxia* in greenhouse conditions. This information can enable growers to choose suitable cereal crop for cultivation in the regions, depending on the purpose of planting and invasion rate of *D. noxia*. Moreover, it is expected that the findings should be effective in planning the most appropriate strategies towards integrated pest management (IPM) of a particular cereal crop. Knowing the demographic parameters of *D. noxia* will be a basis for cereal breeding studies.

Materials and Methods

Host plants

The seeds of wheat cultivars including Shiroodi and Gascogne and triticale including Sanabad and Junanillo 92 were obtained from Agricultural and Natural Resources Research Center of Khorasan Razavi, Mashhad, Iran and Seed and Plant Certification Research Institute, Karaj.

Insect and plant cultures

Seeds were cultivated in plastic pots (18 cm height × 20 cm diameter) at 23 ± 5°C, 60 ± 10% RH and the 16L: 8D photoperiod cycle in a greenhouse. A mixture of 2:1:1 of field soil, sand and manure were used as cultivation substrate (Veisi *et al.* 2012). After germination, the pots were transferred onto wooden cages (50 × 50 × 50 cm), covered with transparent nylon sheets equipped with fine cloth mesh for ventilation.

Russian wheat aphid collected from a barely field from Torbat-e Jam, Razavi Khorasan Province, Iran (64°96´16.54" N, 35°12´16.468" W, H 928.5 m). The aphid species were identified using morphological characteristics according to available identification keys (Blackman & Eastop 2000). The individual aphids from an aphid colony were transferred on a two-week old seedling of each cultivar in wooden cages (50 × 50 × 50 cm) covered with fine cloth mesh, allowed to reproduce and create related colonies.

Antibiosis experiments

Experiments were carried out in the greenhouse, under the same conditions of plant rearing. Fertility life table parameters were measured according to Webster *et al.* (1993) with few modifications.

Forty apterous one-day-old adults from one-month-old colonies were transferred individually on one-week old seedlings which were confined with transparent plastic cage (25 cm height × 15 cm diameter) and covered with fine cloth mesh. By inspection of seedlings, the adult and all offspring except one new-born were removed. Newborn aphids (born within 0-4 h, being classified as 0-day old nymphs) were reared separately on the respective cultivar seedlings until death. One nymph per seedling was regarded as a replicate. Initially, there were 40 replicates per cultivar. Nevertheless, during the experimental period, replicates where aphids were lost or died before the onset of reproduction, were discarded and excluded from analyses of all performance measures, but included in the analysis of the measure of developmental time (i.e. time from birth to maturity or adult stage) if adult molt was reached before loss. The experimental seedlings were examined daily and the biological parameters including mortality, developmental time, fecundity and adult longevity were recorded. During the experiments, the seedlings were renewed once a week.

Estimation and analyses of biological parameters

The estimation of biological parameters were performed based on the theory of age-stage, two sex life table theories (Chi & Liu 1985; Chi 1988) using TWOSEX-MSChart software (Chi 2016). Estimation of mean and standard error of life table indices was determined using bootstrap method (Huang & Chi 2013). The software uses the following equations for estimating age-specific survival rate (l_x), age-specific fecundity (m_x) and the net reproductive rate (R_0) in which the parameter S_{xj} indicates the probability that a newborn individual will survive to age *x* and stage *j*. Age-stage specific fecundity (f_{xj}) is defined as daily number of offspring produced by each female of age *x*.

[1] $$l_x = \sum_{j=1}^{m} S_{xj}$$

[2] $$m_x = \frac{\sum_{j=1}^{m} S_{xj} f_{xj}}{\sum_{j=1}^{m} S_{xj}}$$

[3] $$R_0 = \sum_{x=0}^{\infty} \sum_{j=1}^{m} S_{xj} f_{xj}$$

The intrinsic rate of increase (*r*) is estimated using the iterative bisection method from the Euler–Lotka formula.(Goodman 1982):

[4] $$\sum_{x=0}^{\infty} e^{-r(x+1)} lxmx = 1$$

The mean generation time (*T*) is considered as the average time between two consecutive generations for increase of population to size of R_0-fold and reaching to stable age-stage distribution and was calculated as:

[5] $$T = \frac{lnR_0}{r}$$

The equation for calculation of doubling time (*DT*) is:

[6] $$DT = \frac{ln2}{r}$$

According to Birch (1948), the finite rate of increase (λ) represents the multiplication of population per unit time and calculated as and the gross reproductive rate (*GRR*) was calculated as:

[7] $$\lambda = e^{rm}$$

[8] $$GRR = \sum m_x$$

Life expectancy (e_x) is defined as the period after which an individual at age *x* is expected to be alive at experimental conditions (i.e. on host cultivars). It was calculated by:

[9] $$e_x = \frac{T_x}{l_x}$$

Where T_x is the total units when average individuals are alive within a cohort from age *x* (in days) to death.

The differences between the obtained statistical results were analyzed by paired bootstrap tests (Smucker *et al*. 2007) at 95% confidence interval. The dendrogram of cereal cultivars was constructed using cluster analysis on developmental and reproductive parameters of *D. noxia* on host cultivars by Ward's method, using computer program of SPSS V. 16.0 (SPSS 2007).

The intrinsic rate of increase (*r*) was also estimated by Wyatt & White (1977) equation as:

[10] $$r = 0.74 \frac{l_n M_d}{d}$$

Where d is total pre-reproductive period (sum of the nymphal duration and adult pre-reproductive period) and M_d is the effective fecundity (as the numbers of offspring deposited early in reproductive period over a period of time equal to that of d). The estimates of r values calculated by two methods were compared using unpaired Student's t-test.

Results

Developmental time and reproductive parameters

The results indicated that the performance of the Russian wheat aphid was influenced by host plant species and cultivars (Table 1). The longest and shortest time for each instar belonged to aphids reared on Sanabad and Shiroodi cultivars, respectively.

The nymphal periods on triticale species lasted averagely 1.59 times longer than the counterpart periods on wheat species. The pre-reproductive periods on triticale cultivars were in average 2.05 times as those recoded on wheat cultivars. The average of reproductive periods of *D. noxia* on wheat cultivars was 1.24 times compared to those observed on triticale cultivars. The adult aphids lived significantly longer on cv. Gascogne compared to those on cultivar Juanillo 92. The adult longevity on other cultivars was intermediate. The highest total longevity of *D. noxia* was attained by aphids reared on cv. Shiroodi and the lowest longevity by those reared on cv. Sanabad. The highest number of offspring was produced on cv. Shiroodi (47.45 per aphid) whereas the lowest was on cv. Juanillo 92 (12.85 per aphid), although no significant difference was detected in terms of total fecundity between triticale cultivars. The reproductive rate of aphids reared on wheat cultivars was 1.73 times compared to those on triticale cultivars.

The survival rates at nymphal stage were 67.5, 75, 62.5 and 65% on Gascogne, Shiroodi, Sanabad and Juanillo 92 cultivars, respectively. According to results, the survival rate of adults varied from 26.3 to 39.3% on different host plants. Additionally, the mean lifespan of aphids on wheat and triticale cultivars were recorded at 23.74 and 20.84 days, respectively.

Table 1. Biological statistics (Mean ± SE) of *Diuraphis noxia* on different host plants in greenhouse conditions.

Statistics	**Host plant (Species/Cultivar)**			
	Triticum aestivum		*X Triticosecale Wittmack*	
	Shiroodi	Gascogne	Sanabad	Juanillo 92
Nymphal stage				
1^{st} instar (days)	2.28 ± 0.09^{b}	$2.43. \pm 0.08^{b}$	3.5 ± 0.07^{a}	3.45 ± 0.09^{a}
2^{nd} instar (days)	1.33 ± 0.08^{b}	1.54 ± 0.07^{b}	2.11 ± 0.05^{a}	2.08 ± 0.05^{a}
3^{nd} instar (days)	1.32 ± 0.07^{b}	1.44 ± 0.08^{b}	2.0 ± 0.08^{a}	1.91 ± 0.07^{a}
4^{th} instar (days)	2.08 ± 0.11^{b}	2.17 ± 0.12^{b}	3.55 ± 0.12^{a}	3.40 ± 0.12^{a}
Developmental time (day)	7.29 ± 0.19^{b}	7.85 ± 0.19^{b}	11.6 ± 0.21^{a}	11.22 ± 0.19^{a}
Nymphal survival rate (%)	75.0 ± 0.01^{a}	67.50 ± 0.01^{b}	62.50 ± 0.01^{bc}	65.0 ± 0.01^{c}
Adult stage				
Pre-reproductive period (days)	1.06 ± 0.11^{c}	2.29 ± 0.12^{b}	3.32 ± 0.12^{a}	3.57 ± 0.15^{a}
Reproductive period (days)	17.97 ± 1.17^{a}	17.03 ± 1.26^{ab}	12.72 ± 0.31^{bc}	8.96 ± 1.28^{c}
Post-reproductive period (days)	4.71 ± 0.22^{b}	5.85 ± 0.24^{a}	2.2 ± 0.25^{c}	2.0 ± 0.24^{c}
Adult longevity (days)	22.81 ± 1.29^{ab}	24.52 ± 1.38^{a}	17.76 ± 1.44^{bc}	16.93 ± 1.38^{c}
Total longevity (days)	24.28 ± 1.94^{a}	$23.20 \pm 1.\ 8^{a}$	20.68 ± 1.7^{a}	21.03 ± 1.8^{a}
Adult survival rate (%)	39.28 ± 0.4^{a}	36.43 ± 0.3^{a}	27.75 ± 0.4^{a}	26.28 ± 0.4^{a}
Reproduction				
Total fecundity (female/female/generation)	47.45 ± 2.86^{a}	38.41 ± 3.07^{a}	18.64 ± 3.19^{b}	12.85 ± 3.13^{b}
Reproductive rate (female/female/day)	2.73 ± 0.07^{a}	2.35 ± 0.07^{b}	1.5 ± 0.07^{c}	1.43 ± 0.07^{c}
Effective fecundity (female/female/day)	28.65 ± 1.85^{ab}	24.63 ± 1.98^{a}	32.16 ± 2.06^{a}	25.58 ± 2.02^{ab}

Within a row, means followed by the same letters are not significantly different (P > 0.05).

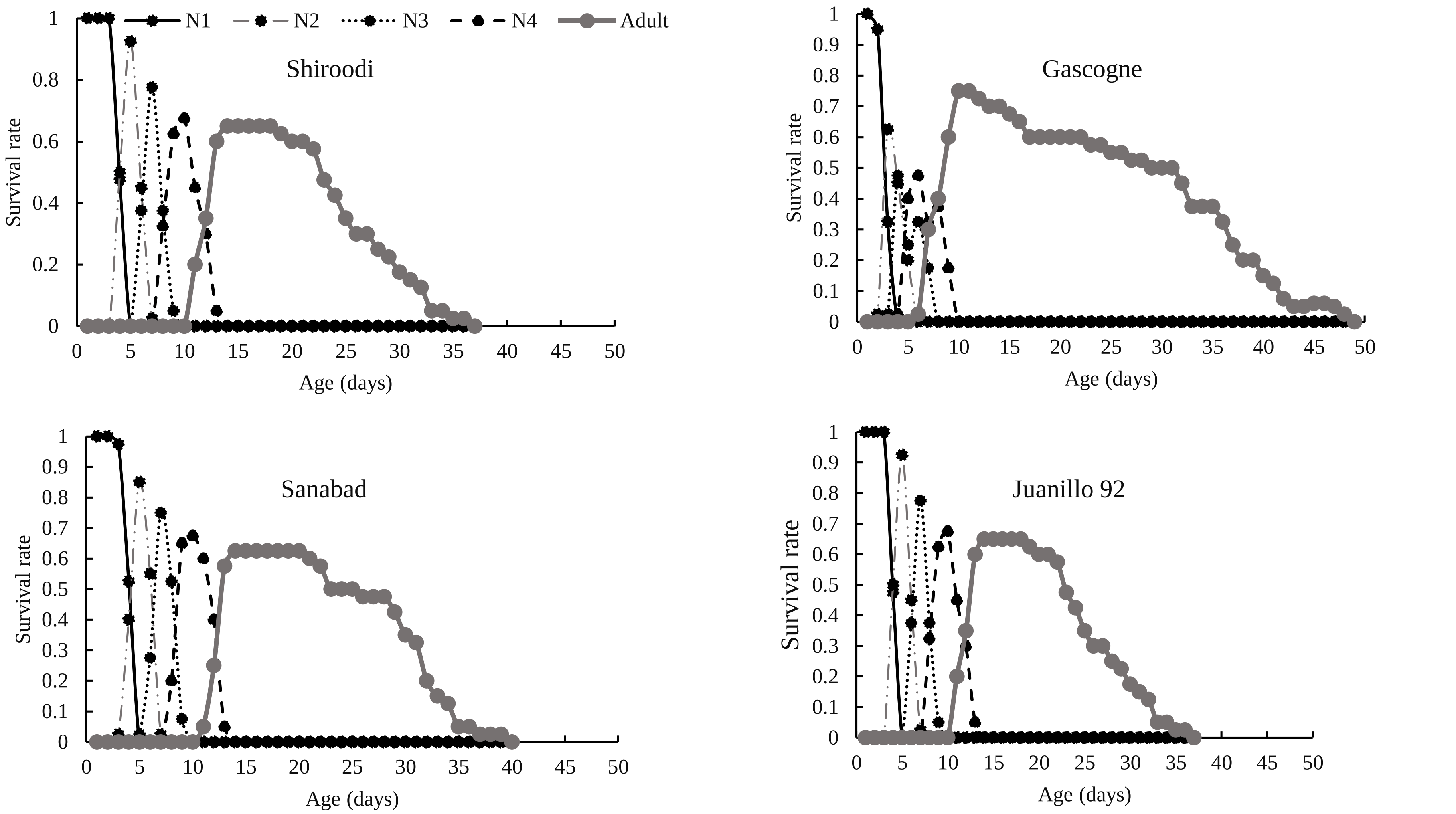

Figure 1. Age-stage specific survival rate (S_{xj}) of *Diuraphis noxia* on wheat and triticale cultivars in greenhouse conditions.

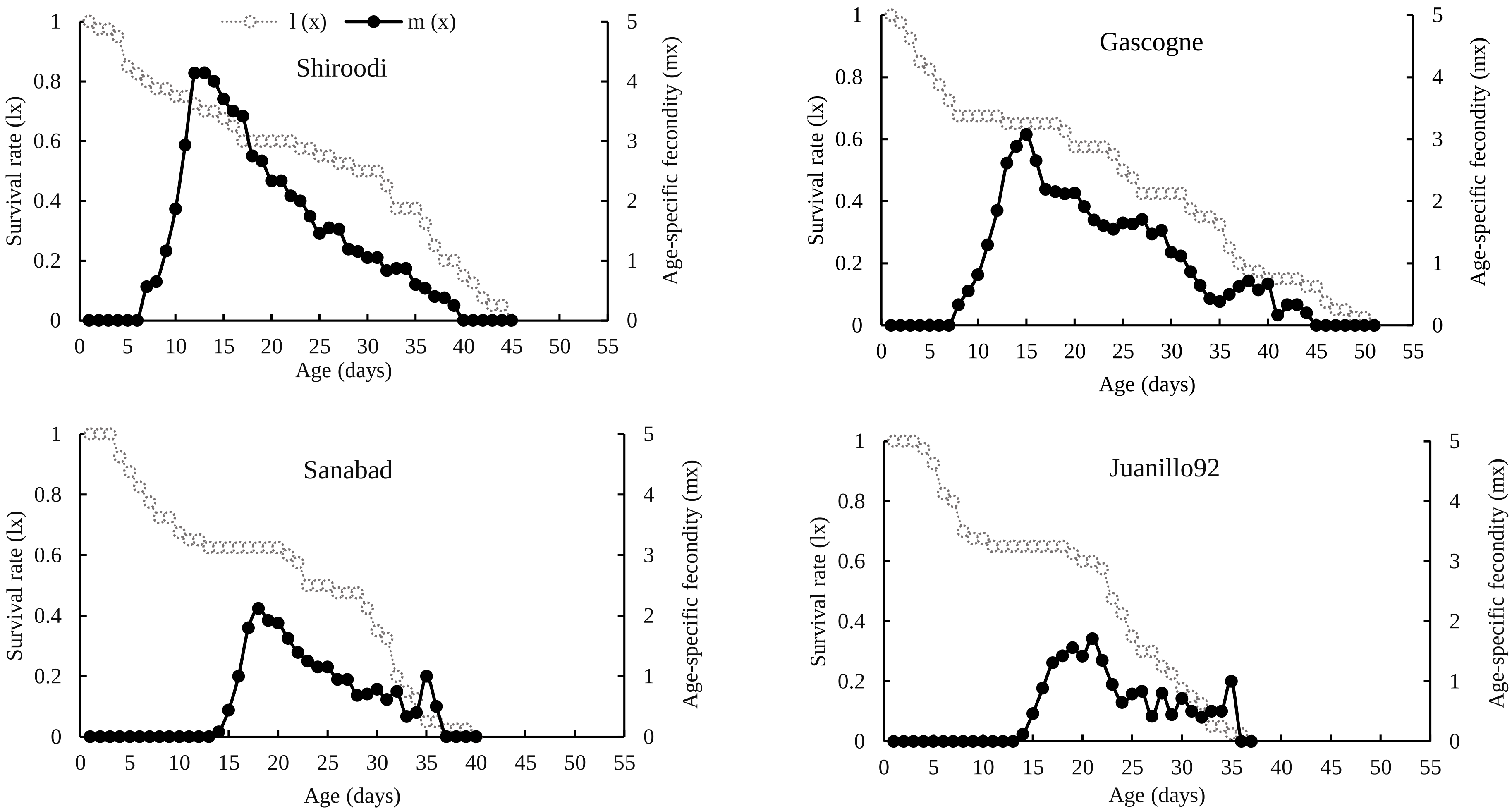

Figure 2. Age-specific survival rate (l_x) and age-specific fecundity (m_x) of *Diuraphis noxia* on wheat and triticale cultivars in greenhouse conditions.

The curves of age-stage specific survival rates (S_{xj}) of *D. noxia* showed details of differences in terms of survival rate among various stages of aphids reared on experimental cultivars (Figure 1). The results indicated that host cultivar had no significant effect on survival rate of aphids when compared within each instar. Additionally, considering nymphal stages as a whole single parameter (pre-adult stage), there was no significant differences in survival rates of aphids among host cultivars.

The simple presentation of aphid survivorship, i.e. the age-specific survival rate (l_x) along with age-specific fecundity rate is illustrated in Figure 2. There was no significant difference between survival rate of aphids reared on different cultivars.

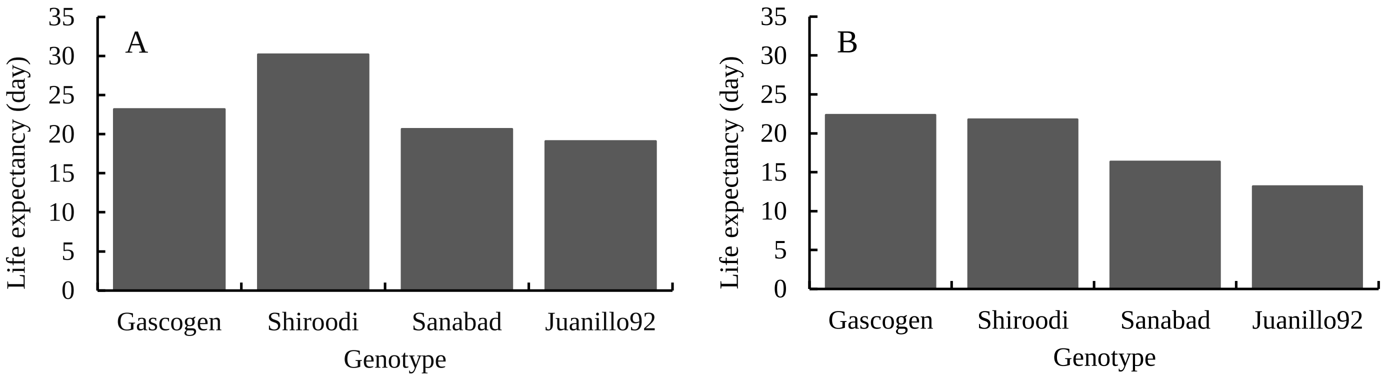

Figure 3. Life expectancy (e_x) of newborns (A) and one-day-old adults (B) of *Diuraphis noxia* on wheat and triticale cultivars in greenhouse conditions.

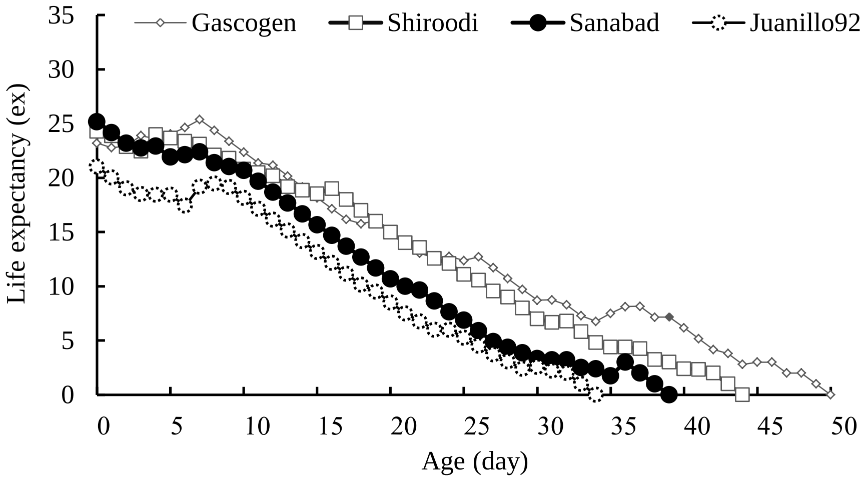

Figure 4. Age -specific life expectancy (e_x) of *Diuraphis noxia* on wheat and triticale cultivars in greenhouse conditions.

The age-specific fecundity rate (m_x) was significantly affected by host plant cultivar. The nymphiposition was started immediately after adult emergence to five days later, lasting 1 to 32 days on different cultivars. The maximum age-specific fecundity rates were attained by aphids reared on Gascogne, Shiroodi, Sanabad and Juanillo 92 cultivars at the age of 14, 11, 19 and 20 days from birth, being 2.97, 3.42, 2.1 and 2.12 female/female/day, respectively. As females aged, nymphiposition declined gradually on all experimental cultivars. The aphids started nymphiposition and reached a maximum rate of fecundity on the Shiroodi cultivar sooner than those reared on other cultivars. The last oviposition day had no significant difference between aphids reared on four cultivars. After reproducing their final nymph, the aphids were alive between 1-4 days on triticale cultivars and 2-12 days on the wheat cultivars.

The result indicated that the life expectancy of newborn aphids was not significantly different among various host cultivars (Figure 3-A). A similar result was obtained on the life expectancy of one-day-old adults (Figure 3-B). The life expectancies of aphids were illustrated at different ages during their lifespan (Figure 4).

Life table parameters

The life table parameters of *D. noxia* were affected by host cultivar (Table 2). The gross reproductive rate (*GRR*) of *D. noxia* varied from 18.30 on cv. Juanillo 92 to 59.74 offspring on cv. Shiroodi. The maximum net reproductive rate, R_0, (36.86 female/female/generation) was obtained by the aphids reared on Shiroodi and the minimum (8.41 female/female/generation) by those reared on Juanillo 92. The intrinsic rate of increase (*r*) and finite rate of increase (λ) ranged respectively from 0.11 to 0.25 and 1.11 to 1.28 female/female/day on experimental cultivars, which represented for both parameters the highest values on Shiroodi and least values on Juanillo 92.

The highest (20.53 days) and lowest (14.20 days) mean generation time (*T*) of *D. noxia* occurred on Sanabad and Shiroodi cultivars, respectively. In addition, the highest doubling time (*DT*) of this aphid by 6.57 days and the lowest by 2.73 days occurred on Juanillo 92 and Shiroodi cultivars, respectively.

The Wyatt & White (1977) formula gives a good estimate of population growth rates in aphids (Dixon 1987, 1998). According to Table 1, the effective fecundity of *D. noxia* were significantly altered by rearing on experimental host cultivars. The same result was repeated for the recently estimated *r*. The estimated *r* values by Wyatt & White (1977) were significantly higher than those by Euler-Lotka method (Table 2).

Table 2. The life table estimates (Mean ± SE) of *Diuraphis noxia* by bootstrap test on wheat and triticale cultivars in greenhouse conditions.

Parameter	Host plant (Species/Cultivar)			
	Triticum aestivum		*X Triticosecale witmack*	
	Shiroodi	Gascogne	Sanabad	Juanillo 92
GRR (offspring)	59.74 ± 0.35 [a]	48.30 ± 0.4 [b]	23.15 ± 0.34 [c]	18.30 ± 0.34 [d]
R_0 (female/female/generation)	36.86 ± 0.45 [a]	26.02 ± 0.47 [b]	11.57 ± 0.4 [c]	8.41 ± 0.42 [d]
r (female/female/day)	0.25 ± 0.00 [a] (0.28 ± 0.01 [a])*	0.20 ± 0.01 [b] (0.24 ± 0.01 [b])*	0.12 ± 0.01 [c] (0.17 ± 0.01 [c])*	0.11 ± 0.01 [d] (0.16 ± 0.01 [c])*
λ (female/female/day)	1.30 ± 0.00 [a]	1.22 ± 0.01 [b]	1.13 ± 0.01 [c]	1.11 ± 0.01 [d]
T (days)	14.2 ± 0.07 [d]	16.17 ± 0.07 [c]	20.53 ± 0.06 [b]	19.99 ± 0.07 [a]
DT (days)	2.73 ± 0.04 [d]	3.45 ± 0.03 [c]	5.85 ± 0.03 [b]	6.57 ± 0.04 [a]

The means followed by the same superscript letters in each row are not significantly different (P > 0.05) by using paired bootstrap test. Wyatt and White Equation were used for estimation of *r* values in parenthesis. The asterisk * indicates a significant difference between two methods of *r* estimation using unpaired t-test.

Cluster analysis

The dendrogram of cereal cultivars based on the demographic parameters of *D. noxia* revealed two noticeable clusters (Figure 5). The upper cluster A consisted of the wheat cultivars and the down cluster B, consisted of triticale. The A and B groups were considered as “susceptible” and “partially resistant” groups, respectively.

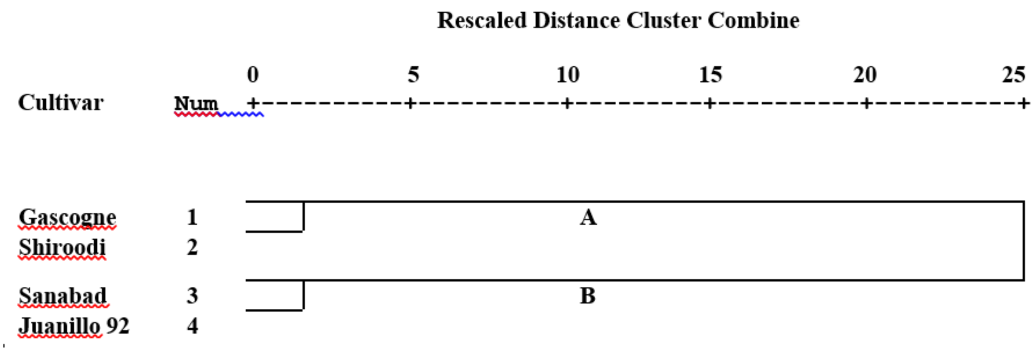

Figure 5. The dendrogram of resistance of wheat and triticale cultivars against *Diuraphis noxia*.

Discussion

The life table parameters of insect pests are considered not only as the effective means for host plant resistance comparisons, but also as important components of forecasting population growth in control management programs of invasive pests (Kavousi *et al.* 2009; Hou & Weng 2010; Hou *et al.* 2014).This is the first study in Iran on the evaluation of susceptibility of some cultivars of wheat and triticale to *D. noxia*. The results indicated that development, survivorship and fecundity of the aphid varied significantly among different cultivars although the establishment of *D. noxia* was fairly supported on all cereal cultivars. The findings are in line with previous results suggesting the impact of host plant variability on growth and reproduction parameters of *D. noxia* (Gianoli & Niemeyer 1998; Kazemi 2010; Veisi *et al.* 2012; Zanganeh *et al.* 2015).

The nymphal period of *D. noxia* took averagely 7.45 days on wheat cultivars, which was shorter than those on triticale cultivars (Table 1). The nymphal periods of aphids on wheat cultivars were close to those reported by Veisi *et al*. (2012) while they differed from those reported by Kazemi *et al.* (2010) and Ngenya *et al.* (2013). The variation in developmental time of a specific pest might be due to feeding of parent insects on different host plants before the onset of reproduction (Mahmoudi *et al.* 2015). The information on developmental periods helps to determine host plant susceptibility to insects (Ngenya *et al.* 2013) and exposure time of various instars to their natural enemies (Tanga *et al.* 2013). In this study, all instars developed significantly longer on triticale cultivars in comparison to those on other cultivars. Ngenya *et al.* (2013) reported such a variability in developmental time of the first and second instars of *D. noxia* when rearing on various wheat cultivars.

The longest pre-reproductive period of *D. noxia* (3.57 days) belonged to aphids reared on cv. Juanillo 92 and the shortest period (1.06 days) belonged to cv. Shiroodi. The reproductive period of *D. noxia* lasted 17.97 days on Shiroodi cultivar; whereas averagely, it lasted 8.96 days on cv. Juanillo 92. The later was close to the reproductive period of 8.8 days reported by Ngenya *et al.* (2013) for Eldoret population on the wheat cultivar Kwale. Adult aphid longevity varied from 16.93 days on cv. Juanillo 92 to 24.52 days on cv. Gascogne. The mean adult longevity on wheat cultivars (23.7 days) in the present study was close to that recorded by Veisi *et al.* (2012) on wheat cultivar Darab 2.

The survivorship of adult and nymphal stages of aphids varied depending on cereal host plant. The highest survival was achieved on cv. Shiroodi and the lowest was achieved on cv. Sanabad. According to Chi & Su (2006), the overlapping curves of age-stage specific survival rates on cereal cultivars might be due to variability among replicates in terms of developmental rate (Figur 1). The mortality rate of aphids had no significant difference between on four cultivar (Figur 2). The life expectancy of aphids in each age was estimated based on the age-specific survivorship, which attained the highest value on cv. Shiroodi and lowest value on cv. Juanillo 92 by both one-day-old nymphs and one-day-old adults (Figur 3). The life expectancy of aphids declined with aging aphids due to influence of age-dependent mortality factors (Murphy *et al.* 2003).

Reproductive performance of aphids was affected by cereal host cultivar. Number of offspring produced on cv. Shiroodi was 57% higher in comparison with those on cv. Juanillo 92 (Table 1). The cv. Shiroodi also supported the highest age-specific fecundity (m_x) with the shortest time from birth to the onset of reproduction (Figur 2). Rapid increase in m_x, particularly at the end of reproductive period, as seen by aphids reared on triticale cultivars (Figur 2) might be due to low survival rate at this time (Chi & Su 2006). The average reproductive rate of 2.5 female/female/day achieved by aphids on wheat cultivar were similar to those reported by the same aphid on the susceptible wheat cultivars; Shole (Moharramipour *et al.* 2002) and Yavarus (Veisi *et al.* 2012). The reproductive rate of aphids was adversely affected by triticale cultivars (Figur 2).

The intrinsic rate of increase (*r*) of *D. noxia* was significantly affected by host plant species which increased by 32% on wheat compared to the corresponding value on triticale species (Table 2). A similar variation could be detected between host plant cultivars within each species. This parameter is of value as a means of describing the growth potential of a population under given climatic and food conditions and is reflective of many biological traits of an insect pest such as development, reproduction and survival (Southwood & Henderson 2000). The highest value of fecundity and survival rate and the shortest nymphal duration of *D. noxia*, which occurred on cv. Shiroodi led to the highest *r* obtained by aphids reared on this cultivar. In contrast, the cv. Juanillo 92 supported the lowest *r*, which may refer to possible resistance factors to *D. noxia*. In a similar study, Veisi *et al.* (2012) recorded two distinct *r* values of 0.005 and 0.159 female/female/day associated with *D. noxia* on wheat cv. Omid and Sardari, respectively. The estimated *r* values of *D. noxia* on cv. Gascogne (0.20 female/female/day) in this research was similar to the value recorded by Zanganeh *et al.* (2015) on Sardari wheat cultivar. *R* variation was studied regarding the association of host plant and aphid biotypes in south Africa (Jankielsohn 2013) and host plant growth stage and aphid rearing temperature in the United States (Ma & Bechinski 2009). The value of *r* could be varied according to the method used for estimation. The values of *r* for *D. noxia* on all experimental cultivars were higher when estimated by Wyatt & White (1977) equation in comparison to Euler-Lotka equation. This finding has been demonstrated for *Acyrthosiphon pisum* (Harris) by Fattah-Hosseini & Allahyari (2009).

Similar comparisons among experimental treatments could be drawn in terms of other reproductive parameters including gross reproductive rate, net reproductive rate and finite rate of increase (Table 2). Mean generation time (*T*) of *D. noxia* varied from 15.19 days on wheat cultivars to 20.25 days on triticale cultivars. These findings were close to those reported on Sardari (as a susceptible host) and Omid (as a resistant host) wheat cultivars, respectively (Zanganeh *et al.* 2015).

Antibiosis resistance affects the biology of the insect and subsequent damage is decreased compared to that which would have occurred if the insect was on a susceptible crop cultivar (Teetes 1996). Antibiosis resistance often results in increased mortality or reduced longevity and reproduction of the insect. A number of biological parameter have been used for demonstration of antibiosis resistance to insects including developmental time, mean generation time, pre-adult survival rate, adult longevity, fecundity, gross reproductive rate, net reproductive rate, intrinsic rate of increase and finite rate of increase (Van Lenteren & Noldus 1990; Hu *et al.* 2010; Tanga 2012). In the present study for detection of resistance of cultivars to *D. noxia*, cluster analysis was performed based on all the above-mentioned parameters. The cluster analysis sequestrates cultivars into clusters which exhibit high homogeneity within a cluster and high heterogeneity between clusters (Jaynes *et al.* 2003). The results revealed that Shiroodi and Gascogne cultivars in cluster A, with the high values of *r* and the low values of *T* could be introduced as the sustainable hosts for *D. noxia*. In addition, Sanabad and Juanillo 92 cultivars in cluster B are the non-favorite hosts due to the longer developmental duration and mean generation time and lower fecundity and fertility of *D. noxia* on them.

According to results, *D. noxia* can complete its growth and development stages on experimental cultivars of wheat and triticale. The obtained information can help to choose the appropriate laboratory host for rearing of *D. noxia* in future research. Wheat cultivars could be regarded as favorite targets for mass rearing of aphid's parasitoids. However, triticale cultivars can be used in the wheat breeding program to develop germplasm resistant to *D. noxia*. These cultivars by preventing the increase of aphid's population and decrease of transferring cereal viruses, would result in reduction of pesticide application. These cultivars could be considered as the alternative cereals when high aphid population is a concern. Further research is recommended to detect plant resistance to aphid in field conditions.

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