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Original article (Orijinal araştırma)

Biological parameters and population development of *Tetranychus urticae* Koch, 1836 (Acari: Tetranychidae) on different pepper cultivars[1]

Tetranychus urticae (Koch) (Acari: Tetranychidae)'nin farklı biber çeşitlerinde biyolojik parametreleri ve popülasyon gelişimi

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Summary

Pepper cultivar preferences of *Tetranychus urticae* Koch, 1836 (Acari: Tetranychidae) were determined by comparing its development, survival, oviposition, life table parameters and population development under controlled laboratory conditions with a 16L:8D photoperiod at 27±1ºC and 65±5% RH in Bursa (Turkey) during 2015-2016. Based on assays performed on leaf discs of six pepper cvs BT-Ince Sivri, BT-Burdem, BT-Burkalem, AHCRI-Çarliston, AHCRI-Yağlık and AHCRI-Kandil Dolma, there were significant differences in egg hatch, juvenile development duration, intrinsic rate of natural increase (r_m), net reproductive rate (R_o) and mean generation time (T) of the mite. The study showed that the life table parameters, r_m (0.16-0.24), R_o (10.99-35.19) and T (14.22-16.39) for *T. urticae* were different when it was fed on different pepper cultivars. Significantly lower life table parameter values (r_m, R_o and T) for *T. urticae* were observed on cv. BT-Ince Sivri, followed by cvs BT-Burdem and BT-Burkalem. Additionally, the mite densities on pepper seedlings of these three cultivars were significantly lower compared with those on seedlings of cvs AHCRI-Çarliston, AHCRI-Yağlık and AHCRI-Kandil Dolma. Furthermore, a lower survival rate was observed during juvenile development on cv. BT-Ince Sivri. Among the pepper cultivars, cv. BT-Ince Sivri had the lowest life table parameter values. Thus, the findings suggest that cvs AHCRI-Çarliston, AHCRI-Yağlık and AHCRI-Kandil Dolma are more susceptible to *T. urticae* than cvs Bursa BT-Ince Sivri, BT-Burdem and BT-Burkalem.

Keywords: Pepper, cultivar, demographic parameters, two-spotted spider mite, population development

Özet

Bu çalışmada *Tetranychus urtic*ae Koch, 1836 (Acari: Tetranychidae)'nin farklı biber çeşitleri arasındaki konukçu tercihi Bursa (Türkiye)'da 2015-2016 yılları arasında kontrollü laboratuvar koşullarında (16:8 aydınlık: karanlık, 27±1ºC sıcaklık, %65±5 orantılı nem) elde edilen zararlının gelişim, canlılık, ovipozisyon, hayat tablosu parametreleri ve popülasyon gelişim verileri karşılaştırılarak belirlenmiştir. Altı farklı biber çeşidi (BT-Ince Sivri, BT-Burdem, BT-Burkalem, AHCRI-Çarliston, AHCRI-Yağlık ve AHCRI-Kandil Dolma) yapraklarıyla yapılan testler sonucunda akarın yumurta açılımı, ergin öncesi dönemlerinin gelişme süresi, kalıtsal üreme yeteneği (r_m), net üreme gücü (R_o) ve toplam üreme oranı (GRR) açısından istatistikî anlamda önemli farklılıklar bulunmuştur. Bu çalışmada, *T. urticae* farklı biber çeşitleri üzerinde beslendiği zaman hayat tablosu parametre değerlerinin r_m (0.16-0.24), R_o (10.99-35.19) ve T (14.22-16.39) değişiklik gösterdiği belirlenmiştir. *Tetranychus urticae*'de önemli düzeyde daha düşük biyodemografik parametre değerleri (r_m, R_o ve T) sırasıyla BT-Ince Sivri, BT-Burdem ve BT-Burkalem çeşitlerinde saptanmıştır. Buna ek olarak, bu üç çeşidin biber fideleri üzerindeki popülasyon yoğunluğu da diğer üç çeşide (AHCRI-Çarliston, AHCRI-Yağlık ve AHCRI-Kandil Dolma) göre önemli düzeyde daha düşük bulunmuştur. Ayrıca, gelişme döneminde en düşük akar canlılığı BT-Ince Sivri çeşidinde gözlemlenmiştir. Sivri biber çeşitleri arasında ise istatistiki anlamda en düşük hayat tablosu parametreleri BT-Ince Sivri çeşidinde belirlenmiştir. Sonuçta, bulgular AHCRI-Çarliston, AHCRI-Yağlık ve AHCRI-Kandil Dolma çeşitlerinin diğer üç çeşide kıyasla *T. urticae*'ye daha hassas olduğunu ortaya koymuştur.

Anahtar sözcükler: Biber, çeşit, demografik veriler, ikinoktalı kırmızıörümcek, popülasyon gelişimi

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Introduction

Tetranychus urticae Koch, 1836 (Acari: Tetranychidae) is a polyphagous plant parasitic mite that can fed on more than 1100 plant species in 140 plant families (Osborne et al., 1999; Migeon & Dorkeld, 2016). In addition, the mite is one of the most important pest species in annually cultivated plants grown in greenhouse, including pepper (Yoldaş et al., 1990; Öncüer et al., 1992; Yaşarakıncı & Hıncal, 1997; Erdoğan, 2006; Can & Çobanoğlu, 2010; Çobanoğlu & Kumral, 2016). The species is also the main pest species feeding on different pepper cultivars grown in open fields (Çobanoğlu & Kumral, 2016). As a result of the feeding of *T. urticae* on pepper, chlorophyll and pigments are broken down. These plants, which experience reduced assimilation and photosynthesis, are subject to drying and high product losses due to high water loss (Tomczyk & Kropczynska, 1985; Herrmann et al., 2012). Although biological control agents are being used around the world as well as in Turkey, synthetic acaricides or insecticide/acaricides are still commonly used (Kılınçer et al., 2010). Such chemical-based control programs can lead to pesticide resistance over a short time. In particular, this pest can quickly gain resistant to many different mechanisms of action, and pesticide residue problems could be arisen in products because of the use of high doses (van Leeuwen et al., 2010; Whalon et al., 2016). In a commercial sense, a large majority of the peppers grown in the province of Bursa are exported to foreign countries. The population of the pests reached peak populations above the economic loss threshold when the harvest began in the middle of August. Growers avoid chemicals due to residual risks in the products (Çobanoğlu & Kumral, 2016). For all these reasons, the preference for pest-resistant pepper cultivars as an alternative and/or to support chemical control may help keep the damage below the economic injury level. In addition, determining more susceptible cultivars to *T. urticae* will help producers to take precautions against this pest while growing these cultivars.

Despite the extensive list of hosts, some plant species are less preferred by the mite (Kasap, 2002). For example, sweet pepper was poorly accepted by *T. urticae* compared to soybean, red pepper and eggplant (van den Boom et al., 2003, 2004). Additionally, the preferences, development and reproduction of the mite differ not only among plant species but also on different cultivars of the same plant species (Dehghan et al., 2009; Hoy, 2011; Atalay & Kumral, 2013; Najafabadi et al., 2014; Keskin & Kumral, 2015). The most important factors that affect host acceptability and fecundity of *T. urticae* are the presence of nutrients and alkaloid contents, and physical and chemical repellents (volatile compounds, and glandular and/or non-glandular trichomes) (van den Boom et al., 2003; Erdoğan et al., 2010; Hoy, 2011). Previous studies on pepper cultivars showed that the cultivar resistance to some mite species, such as *Polyphagotarsonemus latus* (Bank, 1904) (Acari: Tarsonemidae) correlated with the contents of chlorophyll, soluble sugar, free serine, polyphenol and tannin as well as the density of pubescence on leaves (Li et al., 2011, 2015). Similarly, the white fly resistance in pepper cultivars was strongly related to protective enzyme activity and secondary metabolites, especially total phenolic content (Kong et al., 2014). However, there has been no study focusing on the mechanism of *T. urticae* resistance in different pepper cultivars.

In fact, the biology of *T. urticae* on the pepper plants has been rarely investigated, and life table parameters associated with different pepper cultivars have not been determined (Zatyko & Martinovich, 1986; van den Boom et al., 2003; Gallardo et al., 2005). The developmental duration and survival of immatures, and longevity and oviposition of adults are the most critical features in the acceptance of a host plant or cultivars (Sedaratian et al., 2011). Additionally, intrinsic rate of natural increase is the other important biological characteristic parameter in population growth of species on host plants (Birch, 1948). Given that individual tests on mites are usually carried out using leaf discs in Petri dishes, semi-field test under controlled conditions must be conducted to confirm these results (Gutierrez & Helle, 1985). For this purpose, the development, survival, oviposition and life table parameters of *T. urticae* on leaf discs in Petri dishes and its population development on potted pepper plants were determined under controlled conditions using six pepper cultivars intensively grown by producers.

Material and Methods

Pepper cultivars and growth

Six cultivated pepper cultivars (*Capsicum annuum* L.) [Bursa Tohum (BT)-Ince Sivri, BT-Burdem, BT-Burkalem, Atatürk Horticultural Central Research Institute (AHCRI)-Çarliston, AHCRI-Yağlık and AHCRI-Kandil Dolma] which are the most preferred for open field production were used. Based on Bozokalfa (2009) and Keleş (2009), the leaf and fruit features of the pepper cultivars are provided in Table 1. Pepper seeds were sown in a peat medium (Klasmann TS 1-Deilmann, Geeste, Germany) in Bursa (Turkey) during 2015-2016. Twenty to 25 d after sowing, the pepper seedlings were transplanted into 1.5-L pots (40 x 130 cm) filled with the peat and placed in a growth room with a 16L:8D photoperiod at 27±1ºC and 65±5% RH. Seedlings were irrigated every 2 d with tap water and fertilized weekly with 100 mL a water-soluble fertilizer containing 3% total nitrogen (N), 7% phosphorus (P_2O_5), 4.5% potassium (K_2O), 0.1% sulfur (SO_4-S), 0.25% iron (Fe), 0.01% copper (Cu), 0.1% zinc (Zn), 0.1% manganese (Mn), 0.01% boron (B) and 0.001% molybdenum (Mo) prepared by Uludag University, Department of Soil Science and Plant Nutrition (Bursa, Turkey). Three weeks after transplant, nine uniforms, full blooming plants with five fully developed leaves were selected for the experiments.

Table 1. The leaf and fruit features of different pepper cultivars (Keleş, 2007; Bozokalfa, 2009)

Cultivar	Leaf color	Leaf shape	Trichome density on leaf	Trichome density on stem	Leaf index (leaf length/leaf weight)	Fruit shape	Fruit bitterness
BT-Ince Sivri	DK	O	S	D	W	Tn, L	H
BT-Burdem	DK	O	S	D	W	Tn, L	H
BT-Burkalem	DK	O	S	D	W	Tn, L	Sw
AHCRI-Çarliston	DK	O	S	D	N	Tc, L	Sw
AHCRI-Kandil Dolma	G	O	S	D	N	O, Sh	Sw
AHCRI-Yağlık	G	O	S	D	W	F, L	Sw

D: dense; DK: dark green; F: Flattened; G: green; H: hot; L: long; N: narrow; O: oval; S: sparse; Sh: short; Sw: sweet; Tc: thick; Tn: thin; W: wider.

Mass rearing of *Tetranychus urticae* colony

A colony of *T. urticae*, collected from a greenhouse located Yalova city, Turkey (40.62311º N; 29.31373º E; 54 m) was reared for 8 years on potted plants, was used. The colony was reared in a growth room with a 16L:8D photoperiod at 27±1ºC and 65±5% RH. A synchronous *T. urticae* colony was provided by rearing at least two generations on each experimental pepper cultivar.

Development and survival of immature stages

The method using a leaf disc in Petri dish followed Keskin & Kumral (2015). Briefly, each leaf disc (120 mm diameter) was placed with its lower surface facing up in a Petri dish in 2% agar. The ventilation of Petri dish was ensured by holes pierced with a steel needle. For mating, one newly emerged female and two males were transferred onto each leaf disc in an insectarium (Nüve, Ankara, Turkey) with a 16L:8D photoperiod at 27±1ºC and 65±5% RH. Oviposition was monitored for 6 h, and females that had oviposited and males were removed from each Petri dish. Egg hatch and immature development were checked twice per day. The leaf discs were changed every week, and individuals were transferred to fresh leaves. Unhatched eggs and dead immatures were recorded to calculate survival rates.

Oviposition and life table parameters

When an individual was a deutonymph chrysalid female, two adult males were added onto her leaf disc for mating. After females emerged, pre-oviposition, oviposition, post oviposition periods, the daily number of eggs laid and the female longevity were recorded daily during the life of each female. For each pepper cultivar, daily age-specific survival (lx) and fecundity (mx) rates were calculated using the method described by Birch (1948), Howe (1953) and Watson (1964) using RmStat-3 software (Özgökçe & Karaca, 2010). The intrinsic rate of natural increase (r_m) was estimated based on the following equation:

$$\Sigma\ lxm\ xe^{-rmx} = 1$$

where x is female age in days, lx is the age-specific survival rate and mx is the expected number of daughters produced per female alive at age x. The net reproductive rate is given by $R_0 = \Sigma lxmx$, the mean generation time (T) in days is given by $T = lnR_0/rm$, the finite rate of increase (λ) is given by $\lambda = erm$ and the doubling time (DT) in days is DT = ln 2/rm.

Population development on potted pepper plants

To detect the population development of the mite on potted pepper plants, full blooming plants were artificially infested with 25 deutonymph chrysalid females at a density of 5 mites/leaf. Each pepper cultivar included three replicates (with three plants). The plants were grown in a growth room with a 16L:8D photoperiod at 27±1ºC and 65±5% RH. Fourteen d after infestation, mobile and immobile (egg) stages of the mite on all surfaces of the plant leaves were counted using a template (5 cm^2) stereomicroscope (Leica, Wetzlar, Germany). For each leaf, a total area of 50 cm^2 was inspected on same locations of leaves.

Statistical analyses

The distributions of all biological data were tested by Shapiro-Wilk method (SPSS, 2015). Non-normally distributed data were log_{10} transformed, before being used in one-way analysis of variance. In addition, Levene's test for homogeneity of variance was performed. Post hoc testing ($P < 0.05$) of the multiple comparisons was performed using either the Games-Howell or Tukey test, respectively, depending on whether Levene's test was significant or not (SPSS, 2015). Hatch and survival rates were compared with the chi-square test. The bootstrap technique was used to estimate the means, variances and standard errors of the population parameters (rm, R_0 and T). To generate viable results, 10,000 replicates were used (Efron & Tibshirani, 1993).

Results

Development and survival

The total developmental time of *T. urticae* were varied from 8.15 to 11.73 d for females and 7.45 to 10.61 d for males on different pepper cultivars at long daylight, 27±1ºC and 65±5% RH (female $F_{5,204} = 50.3$, $P < 0.01$; and male $F_{5,1394} = 35.9$, $P < 0.01$; Table 2). The development times were significantly longer on cv. AHCRI-Yağlık (11.73 for females and 10.61 for males) and shorter on cv. AHCRI-Çarliston (8.15 for females and 7.45 for males). Also, there were significant variations in the development times for other stages (egg $F_{5,472} = 11.0$, $P < 0.01$; larva $F_{5,410} = 12.2$, $P < 0.01$; protonymph $F_{5,390} = 11.6$, $P < 0.01$; and deutonymph $F_{5,360} = 28.6$, $P < 0.01$).

Survival of *T. urticae* showed that the mite successfully developed on all pepper cultivars, but there were no differences between the cultivars (Table 3). The highest survival rate was found on cv. BT-Burdem (81.58%). Survival rates on cvs BT-Ince Sivri and BT-Burkalem were lowest with 53.26 and 62.50%, respectively. The most death was recorded in the larval stage on cv. BT-Ince Sivri. Similar to mite development time, the survival rates on cv. AHCRI-Çarliston were higher than those on cvs BT-Burkalem and BT-Ince Sivri.

Table 2. Developmental time (d, mean±SE) of *Tetranychus urticae* stages on different pepper cultivars

Cultivar	Egg	Larva	Protonymph	Deutonymph	Total development ♀	Total development ♂
BT-Ince Sivri	3.62±0.07ab*	1.67±0.08d	1.89±0.08a	1.59±0.10cd	8.81±0.23c	8.39±0.19c
BT-Burdem	3.25±0.05d	1.95±0.06bc	1.68±0.06ab	1.84±0.09bc	10.00±0.22b	9.14±0.08b
BT-Burkalem	3.35±0.06cd	1.98±0.06bc	1.91±0.05a	1.80±0.08bcd	9.98±0.19b	9.07±0.18bc
AHCRI-Çarliston	3.52±0.07bc	1.70±0.07d	1.31±0.06c	1.50±0.08d	8.15±0.15c	7.45±0.19d
AHCRI-Kandil Dolma	3.67±0.06ab	2.04±0.07ab	1.46±0.06bc	2.04±0.08b	10.54±0.15b	9.87±0.16a
AHCRI -Yağlık	3.90±0.09a	2.31±0.06a	1.67±0.07ab	2.70±0.07a	11.73±0.15a	10.61±0.25a

* Means followed by the same letter in a column are not significantly different (Tukey, $P < 0.05$).

Table 3. Hatch and survival rates of immature stages of *Tetranychus urticae* on different pepper cultivars

Cultivar	n	Hatch (%)	Survival of larvae (%)	Survival of protonymph (%)	Survival of deutonymph (%)	Overall survival (egg to adult) (%)
BT-Ince Sivri	93	92.47	66.28	92.98	92.45	53.26
BT-Burdem	75	98.68	95.83	95.65	86.89	81.58
BT-Burkalem	96	92.71	88.76	96.20	88.16	62.50
AHCRI-Çarliston	74	91.89	83.82	94.73	98.15	71.62
AHCRI-Kandil Dolma	93	84.95	92.41	97.26	97.18	74.19
AHCRI -Yağlık	98	82.65	95.06	92.21	91.55	66.33
X^2 (df = 5)		1.88	7.46	0.198	1.135	7.232
P		0.865	0.189	0.999	0.951	0.204

Oviposition and adult longevity

Unlike the post-oviposition period, the pre-oviposition ($F_{5,81} = 16.1$, $P < 0.01$) and oviposition ($F_{5,81} = 3.65$, $P < 0.01$) durations of *T. urticae* differed significantly among the six pepper cultivars (Table 4). The mite showed a significantly longer oviposition period of 12.60 d on cvs AHCRI-Çarliston and AHCRI-Yağlık with 11.85 d. The oviposition periods on cvs BT-Ince Sivri, BT-Burdem and BT-Burkalem were significantly lower than that on cvs AHCRI-Çarliston and AHCRI-Yağlık. There was lower fecundity on cv. BT-Ince Sivri (18.92 eggs/female) followed by cv. BT-Burdem (21.72 eggs/female) ($F_{5,81} = 7.28$, $P < 0.01$). AHCRI-Yağlık, AHCRI-Çarliston and AHCRI-Kandil Dolma showed the highest fecundities of 55.77, 52.13 and 51.33 eggs/female, respectively. Significantly differences in adult longevities on different pepper cultivars were found ($F_{5,81} = 2.53$, $P = 0.04$). The highest longevity was recorded on cv. AHCRI-Çarliston (16.33 d) and shortest female longevity was observed on cv. BT-Burkalem (10.47 d) followed by cvs BT-Burdem and BT-Ince Sivri.

Table 4. Daily egg production (mean±SE), oviposition duration and adult female longevity (mean±SE) of *Tetranychus urticae* on different pepper cultivars

Cultivar	Adult female longevity (d)	Pre-oviposition (d)	Oviposition (d)	Post-oviposition (d)	Total number of eggs/female
BT-Ince sivri	11.86±0.88b*	2.50±0.14a	7.57±0.93b	1.71±0.49a	18.92±3.16c
BT-Burdem	11.69±0.99b	1.31±0.13cd	8.39±1.17b	2.00±0.48a	21.72±6.30c
BT-Burkalem	10.47±0.64b	1.73±0.18bc	6.93±0.70b	1.80±0.47a	29.73±6.45bc
AHCRI-Çarliston	16.33±2.05a	2.00±0.19ab	12.60±1.70a	1.80±0.45a	52.13±7.65a
AHCRI-Kandil Dolma	12.50±1.49ab	1.08±0.08d	9.25±1.12ab	2.00±0.56a	51.33±7.22ab
AHCRI-Yağlık	14.54±1.35ab	1.08±0.08d	11.85±1.21a	1.69±0.26a	55.77±6.49a

* Means followed by the same letter in a column are not significantly different (Tukey, $P < 0.05$).

Life table parameters

The intrinsic rates of natural increase (r_m) of the spider mite were the lowest on cv. BT-Ince Sivri (0.1635) followed by cvs BT-Burdem (0.1688) and BT-Burkalem (0.2021) ($F_{5,53} = 962$, $P < 0.01$) (Table 5). The highest r_m value was found on cv. AHCRI-Çarliston (0.2384) followed by cvs AHCRI-Kandil Dolma (0.2325) and AHCRI–Yağlık (0.2239). Significant differences in the net reproductive rate (R_0) among different pepper cultivars were found ($F_{5,53} = 885$, $P < 0.01$). The R_0 value was significantly lowest on cv. BT-Ince Sivri (10.987) followed by cvs BT-Burdem (15.922) and BT-Burkalem (22.629) ($F_{5,53} = 885$, $P < 0.01$). The mean generation time (T) of the mite varied significantly among the pepper cultivars ($F_{5,53} = 1090$, $P < 0.01$). The T value of *T. urticae* was the lowest on cv. AHCRI-Kandil Dolma (14.220) followed by cvs AHCRI-Çarliston (14.597) and BT-Ince Sivri (14.658) ($F_{5,53} = 1090$, $P < 0.01$). The gross reproduction rate (GRR) of *T. urticae* exhibited results that were similar to those of its R_0. Similarly, the doubling time (DT) was the longest on cv. BT-Ince Sivri (3.952) following by cvs BT-Burdem (3.824) and BT-Burkalem (3.191). The other life table parameter, the finite rate of increase (λ) of the mite, was similar to T value for all cultivars.

Table 5. Life table parameters of population growth in *Tetranychus urticae* on different pepper cultivars

Cultivar	Intrinsic rate of natural increase, rm (female/female/d)	Net reproductive rate, R_0 (female/female/ generation)	Mean generation time, T (d)	Gross reproduction rate, GRR (female egg/ female/generation)	Doubling time, DT (d)	Finite rate of increase, λ (individual/ female/d)
BT-Ince Sivri	0.1635±0.001e*	10.987±0.17f	14.658±0.017d	15.022	3.952	1.192
BT-Burdem	0.1688±0.002e	15.922±0.38e	16.385±0.028a	22.058	3.824	1.199
BT-Burkalem	0.2021±0.001d	22.629±0.45d	15.424±0.021c	28.632	3.191	1.243
AHCRI-Çarliston	0.2384±0.001a	32.507±0.31b	14.597±0.025d	46.625	2.683	1.295
AHCRI-Kandil Dolma	0.2325±0.001b	27.285±0.26c	14.220±0.027e	35.643	2.749	1.287
AHCRI-Yağlık	0.2239±0.001c	35.189±0.26a	15.905±0.032b	46.104	2.886	1.271

*Means followed by the same letter in a column are not significantly different (Tukey, $P < 0.05$).

The life tables of the different pepper cultivars prepared with data obtained from emergence until death of *T. urticae* are given in Figure 1. *Tetranychus urticae* females produced the maximum number of females at 13-14 d after emergence in all cultivars. The females began to oviposit 8-10 d after emergence and terminated oviposition 27 d after emergence except on cvs AHCRI-Yağlık and AHCRI-Çarliston (31-35 d after emergence). Relatively fewer females were produced on cvs BT-Ince Sivri and BT-Burdem. The longevity of *T. urticae* was shortened depending on the pepper cultivar. For example, female longevity on cvs BT-Ince Sivri, BT-Burdem and BT-Burkalem was much lower than that on the other cultivars. The longest female longevity was found on cvs AHCRI-Yağlık and AHCRI-Çarliston.

Population development

Significant differences were found in the mean numbers of all mobile and immobile stages of the spider mite among pepper cultivars (Table 5). Similar to life table parameters, the highest number of eggs were found on cvs AHCRI-Kandil Dolma, AHCRI-Çarliston and AHCRI-Yağlık ($F_{5,53}$ = 27.8, P < 0.01). The numbers of mobile stages were the highest on cv. AHCRI-Çarliston followed by cvs AHCRI-Kandil Dolma and AHCRI-Yağlık (larva $F_{5,53}$ = 6.93, P < 0.01; nymphs $F_{5,53}$ = 45.2, P < 0.01; males $F_{5,53}$ = 6.14, P < 0.01; females $F_{5,53}$ = 76.8, P < 0.01; and all mobile stages $F_{5,53}$ = 40.4, P < 0.01). Additionally, the lowest number of eggs and mobile stages was observed on cv. BT-Burdem, followed by cvs BT-Burkalem and BT-Ince Sivri (Table 6).

Significant differences were found in the mean numbers of all mobile and immobile stages of the spider mite among the pepper cultivars (Table 5). Similar to life table parameters, the highest number of eggs were found on cvs AHCRI-Kandil Dolma, AHCRI-Çarliston and AHCRI-Yağlık ($F_{5,53}$ = 27.8, P < 0.01). The number of mobile stages was the highest on cv. AHCRI-Çarliston, followed by cvs AHCRI-Kandil Dolma and AHCRI-Yağlık (larva $F_{5,53}$ = 6.93, P < 0.01; nymphs $F_{5,53}$ = 45.2, P < 0.01; males $F_{5,53}$ = 6.14, P < 0.01; females $F_{5,53}$ = 76.8, P < 0.01; and all mobile stages $F_{5,53}$ = 40.4, P < 0.01). Additionally, the lowest number of egg and mobile stages were observed on cv. BT-Burdem followed by cvs BT-Burkalem and BT-Ince Sivri (Table 6).

Table 6. Number of mites and eggs (mean±SE) of *Tetranychus urticae* per 1 cm^2 leaf area of different pepper cultivars

Cultivar	egg	larva	nymph	male	female	all mobile stages
BT-Ince Sivri	0.44±0.17c	0.06±0.02b	0.59±0.05bc	0.20±0.02b	0.23±0.02bc	1.09±0.09cd
BT-Burdem	0.26±0.04c	0.18±0.02ab	0.25±0.02cd	0.32±0.02ab	0.02±0.01c	0.76±0.05d
BT-Burkalem	0.31±0.07c	0.17±0.03ab	0.18±0.04d	0.39±0.07ab	0.02±0.01c	0.75±0.14d
AHCRI-Çarliston	2.06±0.24b	0.32±0.07a	1.44±0.09a	0.18±0.03b	1.06±0.08a	3.00±0.22a
AHCRI-Kandil Dolma	3.53±0.45a	0.12±0.02b	0.94±0.07b	0.45±0.06a	0.39±0.04b	1.89±0.07b
AHCRI-Yağlık	1.51±0.33bc	0.08±0.02b	0.78±0.56b	0.33±0.03ab	0.31±0.06b	1.50±0.16bc

* Means followed by the same letter in a column are not significantly different (Tukey, P < 0.05).

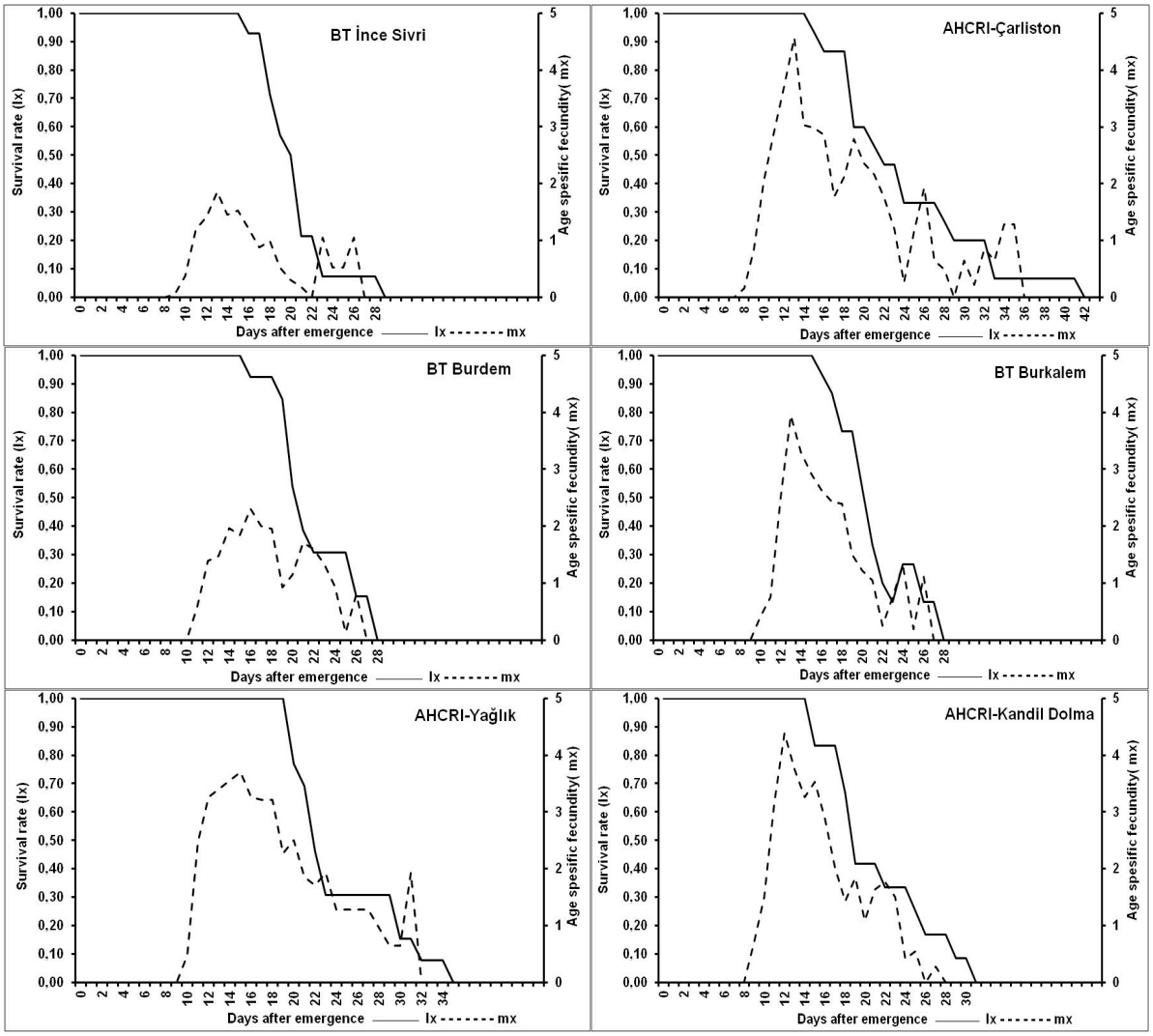

Figure 1. Age-specific survival rate (lx), age-specific fecundity rate (mx) and lxmx curves in *Tetranychus urticae* on different pepper cultivars; lx = (egg hatch) (proportion of females alive at age x), mx = (proportion of females) (age-specific oviposition).

Discussion

This study showed that the life cycle of *T. urticae* can be successfully completed on the pepper cultivars tested. However, cultivar differences significantly affected development of *T. urticae*. The total development duration of *T. urticae* was 7.5-10.6 d for males and 8.2-11.7 d for females under long day lighting, 27±1ºC and 65±5% RH. This period was very similar to those found in previous studies performed under similar conditions: sweet peppers (8.2 d), cucumber (10.4 d), beans (10.9 d) and tomato (11.4-11.6 d) (Kasap, 2002; Gallardo et al., 2005; Atalay & Kumral, 2013). The most remarkable result is the values of some pepper cultivars in current study are very similar to those for bean and sweet pepper, which are favorable hosts for *T. urticae.* As reported by Gallardo et al. (2005), the rapid development of mite on pepper cultivars was confirmed.

The other factor affecting the development of the spider mite is survival rates. Low survivability was observed some pepper cultivars in this study. These results indicate that cvs BT-Burkalem and BT-Ince Sivri are less suitable hosts because the high mortality was observed in egg and larval stages. While low survival rates were found on cvs BT-Ince Sivri and BT-Burkalem, the survival rates were quite high on cvs AHCRI-Kandil Dolma and AHCRI-Çarliston. This result is consistent with van den Boom et al. (2004), who suggested that some defensive compounds (i.e., capsaicin and dihydrocapsaicin) in pepper plants can cause mortality in some immature stages of *T. urticae* and these may be found in the tested cultivars.

Similarly, Erdogan et al. (2010) showed that the leaf extracts (12%) of hot cultivars caused high mortality in larval, nymph and adult stages of *T. urticae* and significantly reduced the reproductive capacity of females. However, further studies are needed to confirm this hypothesis.

In addition, there were significant differences in duration of oviposition, fecundity and egg production of *T. urticae.* In the current study, the oviposition period was 6.9-12.6 d and the number of eggs/female was 21.5-55.8. In some previous studies, these values were 10 d and 27.5 eggs on sweet pepper; 5-13 d and 85-276 eggs on tomato; 24 d and 231 eggs on bean and 19 d and 124 eggs on soybean and 21 d and 172 eggs on cucumber (Kasap, 2002; Dehghan et al., 2009, Atalay & Kumral, 2013). Compared with the most suitable host plants, i.e., bean and cucumber, the fecundity on all pepper cultivars of this study were lower. However, our results correspond with the findings of Gallardo et al. (2005), demonstrating that *T. urticae* feed on different sweet pepper cultivars. Thus, these results show that *T. urticae* can grow quickly on pepper cultivars, but fecundity is lower than more favorable host plants such as tomato, bean, soybean and cucumber. For example, the net reproductive rates on different pepper cultivars varied from 11.19-35.8 female/female/generation, and the intrinsic rate of natural increase was 0.18-0.26 female/female/day in this study. Similarly, these values were found to be consistent with the findings (11.5 and 0.29) from the different pepper cultivars used by Gallardo et al. (2005). In contrast, our results were low compared with the findings on some other host plants: tomato (56.9-131.2 and 0.26-0.29), beans (185.4 and 0.27), soybeans (65.7 and 0.26) and soybeans (110.7 and 0.25) (Kasap, 2002; Dehghan et al., 2009; Atalay & Kumral, 2013). Considering these results, pepper can be regarded as a less suitable host plant compared to the plants, in accordance with the findings of van den Boom et al. (2003, 2004). This research indicates that pepper has a strong direct defense mechanism against *T. urticae* and it is less preferred by the mite than tomato, eggplant and bean plants.

In this study, some cultivars were shown to be less suitable for *T. urticae* based on both the life table parameters in Petri dishes under controlled conditions and population development data on potted pepper plants under semi-field conditions. For example, the net reproductive rate and intrinsic rate of natural increase of *T. urticae* were found to be significantly lower in cvs BT-Ince Sivri, BT-Burdem and BT-Burkalem. Sabelis (1985) reported that the intrinsic rate of natural increase of *T. urticae* varies between 0.22 and 0.34 female/female/day under optimum climatic conditions depending on the condition of the host. In our study, these values were determined to be 0.163 and 0.169 female/female/day on cvs BT-Ince Sivri and BT-Burdem, respectively. Thus, these cultivars are less suitable for population development of *T. urticae*. These findings indicate that hot cultivars, cvs BT-Ince Sivri and BT-Burdem, are more resistant compared with other cultivars, probably because they have a higher capsaicin content (Table 1; Bozokalfa, 2009). In addition, the results of population development studies on potted plants at the flowering stage supported the findings obtained on leaf discs in Petri dishes. Similarly, both fewer eggs and living mites were found on cvs BT-Ince Sivri and BT-Burdem as well as cv. BT-Burkalem. In contrast, significantly more eggs and mites were found on cvs AHCRI-Çarliston, AHCRI-Kandil Dolma and AHCRI-Yağlık. Cultivars BT-Ince Sivri and BT-Burdem have strong plant habitus, dark green leaves and thin-hot fruits (Table 1). Cultivar BT-Burkalem has similar physical features but the fruits are sweet. Cultivars AHCRI-Çarliston, AHCRI-Yağlık and AHCRI-Kandil Dolma have light green leaves, thin skin and sweet fruit (Table 1). Although there are no differences among morphologically leaf features of these cultivars in terms of physical barriers such as trichome density, cvs AHCRI-Çarliston, AHCRI-Kandil Dolma and AHCRI-Yağlık are more susceptible for *T. urticae.* This difference among the cultivars is likely to be related to concentrations of phenolic compounds and alkaloids (i.e., capsaicin) in these cultivars (Keleş, 2007; Bozokalfa, 2009; Li et al., 2011, 2015) and/or possibly the lack of nutrients needed for fecundity of the mite (van den Boom et al., 2004; Antonious et al., 2006). Although the quantity of capsaicin in the hot cultivars (about 10-15 fold compared with sweet ones) is well known (Bozokalfa, 2009), the phenolic content of the pepper cultivars has not been tested.

In a conclusion, this study showed that some pepper cultivars are less suitable for population growth of *T. urticae*. Among the different pepper cultivars tested, the most suitable were cvs AHCRI-Çarliston, AHCRI-Kandil Dolma and AHCRI-Yağlık. Whereas, cvs BT-Ince Sivri, BT-Burdem and BT-Burkalem were less suitable. In the future, further pepper cultivars should be tested, and their physical and chemical properties related to population development of *T. urticae,* especially leaf phenolic content should be clarified.

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