Türk. entomol. derg., 2023, 47 (2): 133-147
DOI: http://dx.doi.org/10.16970/entoted.1174064

ISSN 1010-6960
E-ISSN 2536-491X

Original article (Orijinal araştırma)

The effects of different Charleston pepper cultivars on the demographic parameters and the antioxidant levels of *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae)[1]

Farklı Charleston biber çeşitlerinin *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae)'nin demografik parametreleri ve antioksidan seviyeleri üzerine etkileri

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Abstract

Host plant diversity causes differences in the biology and adaptation of insects. In this study, variations in some biological properties and adaptive antioxidative response of *Myzus persicae* (Sulzer,1776) (Hemiptera: Aphididae) on five Charleston pepper, *Capsicum annuum* L. (Solanaceae) cultivars were investigated under laboratory conditions (25±1°C, 60±5% RH). The lowest intrinsic rate of increase (r = 0.193 d^{-1}) of *M. persicae* was estimated in the tested cohort fed with the Kanyon cultivar, while the highest intrinsic rate of increase (r = 0.248 d^{-1}) was found on the Tufan cultivar. The cohort fed with Safkan cultivar exhibited the highest levels of GST-CDNB and EST-PNPA at 562.80 and 207.64 nmol/mg protein, respectively, whereas the cohort fed with Kanyon cultivar showed the lowest levels at 317.04 and 132.14 nmol/mg protein, respectively. Analysis of life table parameters and enzymatic/non-enzymatic antioxidant levels of *M. persicae* showed that among the cultivars we tested, the Tufan cultivar was the most preferred host by *M. persicae,* while Kanyon cultivar was a less suitable host.

Keywords: Age-stage two-sex life table, *Capsicum annuum*, enzymatic antioxidant, *Myzus persicae*

Öz

Konukçu bitki çeşitliliği, böceklerin biyolojisinde ve adaptasyonunda farklılıklara neden olur. Bu çalışmada, laboratuvar koşullarında (25±1°C, %60±5 orantılı nem) *Myzus persicae* (Sulzer,1776) (Hemiptera: Aphididae)'nin beş Çarliston biber, *Capsicum annuum* L. (Solanaceae) çeşidi üzerindeki bazı biyolojik özellikleri ve adaptif antioksidan tepkilerindeki değişimler incelenmiştir. *Myzus persicae*'nin en yüksek kalıtsal üreme oranı (r = 0.248 g^{-1}) Tufan çeşidi üzerinde, en düşük ise (r = 0.193 g^{-1}) Kanyon çeşidi üstünde beslenen test edilen grupta kaydedilmiştir. Safkan çeşidi üstünde beslenen grup, sırasıyla 562.80 ve 207.64 nmol/mg protein ile en yüksek GST-CDNB ve EST-PNPA seviyelerini sergilerken, Kanyon çeşidi üstünde beslenen grup sırasıyla 317.04 ve 132.14 nmol/mg protein düzeyleri ile en düşük seviyeleri göstermiştir. *Myzus persicae*'nin yaşam çizelgesi parametreleri ve enzimatik/enzimatik olmayan antioksidan düzeylerinin analizleri, test ettiğimiz çeşitler arasında *M. persicae* tarafından en çok tercih edilen konukçunun Tufan çeşidi olduğunu, Kanyon çeşidinin ise daha az uygun konukçu olduğunu göstermiştir.

Anahtar sözcükler: Yaş ve döneme özgü iki eşeyli yaşam çizelgesi, *Capsicum annuum*, enzimatik antioksidan, *Myzus persicae*

[1] Data in this article was derived from second author's Master thesis in Van Yüzüncü Yıl University, Institute of Science, Department of Plant Protection.

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Received (Alınış): 12.09.2022 Accepted (Kabul ediliş): 04.06.2023 Published Online (Çevrimiçi Yayın Tarihi): 11.06.2023

Introduction

One of the most critical factors that determine the level of damage caused by herbivorous insects is the quality and suitability of the host plant (Hong et al., 2019). Depending on the physical differences and biochemical compounds of the host plants, the biology of the insect feeding on it is also affected in different ways. Even different cultivars of the same host plant species can have varying effects on the development, reproduction, and survival rates of the insect (La Rossa et al., 2013; Razazzian et al., 2015; Özgökçe et al., 2018).

Insects produce enzymatic antioxidants, which are proteins that help protect cells from oxidative stress by neutralizing harmful free radicals as a defense mechanism against their damaging effects. They include catalase (CAT), glutathione (GSH), superoxide dismutase (SOD), ascorbate peroxidase (APX) and guaiacol peroxidase (GPX) (Ologundudu, 2021). Non-enzymatic antioxidants work by interrupting free radical chain reactions. They include ascorbate, carotenoids, flavonoids, and other phenolics (Ologundudu, 2021). Lukasik et al. (2011) reported that changing the host plant affected the levels of enzymatic and non-enzymatic antioxidants in *Acyrthosiphon pisum* (Harris, 1776) (Hemiptera: Aphididae). This suggests that oxidative stress may play a significant role in the interactions between herbivorous insects and their host plants, as noted by Lukasik & Goławska (2013). Superoxide anion, hydroxyl radical, and hydrogen peroxide are typical reactive oxygen species (ROS), generally produced by oxidative metabolism in herbivorous insect cells (Lukasik & Golawska, 2013). Additionally, they are exposed to exogenous ROS, which is created by the defense mechanism of plants (Orozco-Cardenas & Ryan, 1999). Furthermore, the saliva and damage caused by aphids have been claimed to induce ROS production in the host plant cells, particularly in phloem cells (Lukasik & Golawska, 2013). ROS are crucial for the defense of host plant against insects that feed on plants.

Insects have detoxifying enzyme systems that include esterases (EST) and glutathione S-transferases (GST). These enzymes take a role in the metabolism of xenobiotic substances that could cause cellular and tissue damage, derived from oxidative stress (Konuş, 2014). Furthermore, insect cells have non-enzymatic ROS scavenger compounds such as ascorbate and glutathione (Kazek et al., 2020). Lastly, the total thiol content of insect cells depletes due to the enhanced metabolism of xenobiotics (Vontas et al., 2001).

The green peach aphid, *Myzus persicae* Sulzer, 1776 (Hemiptera: Aphididae) is a polyphagous pest that can infest over 400 host plant species from more than 40 families, including pepper, and can also transmit more than 100 plant viruses (Bass et al., 2014; van Emden & Harrington, 2017). Under favorable environmental conditions, aphids can quickly produce a large population, significantly damaging plant growth and development by feeding on the phloem sap, which contains important photosynthesis products. Aphids also cause indirect damage by secreting sooty mold during feeding, which reduces the photosynthetic capacity of the plant (Naranjo & Legg, 2010; Cameron et al., 2013). Additionally, direct damage from aphids can include dehydration, loss of flower buds, weakness, and an overall decrease in vegetative growth (La Rossa et al., 2013).

Türkiye is the world's third-largest producer of peppers after China and Mexico, with a production of 2.6 million tons (FAO, 2020). In 2021, the country's pepper production increased to 3 million tons (TUIK, 2022). Charleston peppers are an essential agricultural commodity due to their economic value and nutritional and medicinal benefits (Emmanuel-Ikpeme, 2014). *Capsicum* cultivars are known to contain substantial amounts of vitamins B, C, E, and provitamin A (carotene) (Bozokalfa & Eşiyok, 2010). Peppers are composed of various compounds, including oil, colors, resin, protein, cellulose, pentosa, and minerals. Peppers are high in vitamin C, with some cultivars containing up to 340 mg/100 g (Eşiyok, 2006).

The green peach aphid, *M. persicae*, is a significant threat to pepper crops in Türkiye, and conventional pest control methods rely heavily on the use of pesticides, both within the country and worldwide (Bass et

al., 2014; Özgökçe et al., 2018). However, the extensive use of pesticides over the years has resulted in widespread and varied forms of resistance developing (Bass et al., 2014). Hence, there has been a growing emphasis on alternative methods to chemicals, specifically on the use of resistant varieties in recent years (Silva et al., 2012).

The use of resistant varieties or unsuitable host plants in agricultural production offers significant advantages such as compatibility with other control techniques like biological pesticides or biological agents, environmental friendliness, affordability, and reduction of harmful pest populations (Stansly & Natwick, 2009; Vieira et al., 2011; Silva et al., 2012). This approach can be particularly effective in integrated pest management (IPM) strategies, where multiple methods are used in combination to control pests while minimizing their impact on the environment and human health. By incorporating resistant varieties or unsuitable host plants into IPM, producers can reduce their reliance on traditional chemical pesticides, which can be expensive and have negative environmental consequences. These methods can help to slow the development of resistance in pest populations, making them a valuable long-term solution for sustainable agriculture. In addition, the genetic diversity offered by resistant varieties and unsuitable host plants provides a valuable resource for modern genetic research (Panda & Khush, 1995; Stout, 2007; Smith & Clement, 2012).

Life tables are an effective tool to comprehend how host plants influence the biology of insects. Using a life table is the most effective way to describe the development, stage differentiation, survival, reproduction, and population growth of a species (Yang & Chi, 2006; Huang & Chi, 2013; Yin et al., 2013; Özgökçe et al., 2018; Chi et al., 2020). Utilized the age-stage two-sex life table to determine the population parameters of *M. persicae* on various Charleston pepper cultivars in this study. To further substantiate the life table parameters, the impact of enzymatic/non-enzymatic antioxidant levels of *M. persicae* on diverse pepper cultivars was also assessed. The data acquired from this study will furnish significant fundamental insights for both Charleston pepper production programs and genetic studies.

Materials and Methods

Plant materials

Five Charleston pepper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan) were used in this study. Seedlings were obtained from commercial suppliers such as Rijk Zwaan (Bellisa), Yüksel Tohum (Cümbüş), Antema Tarım (Diyar), AG Tohum (Paşa), Nunhems Tohum (Sarp) and Mars Tohum (Serenat) in Antalya and Mersin, Türkiye. The cultivars were planted in 4-litter pots, and all the plants were kept in climatic rooms set to 25±1°C, 60±5%RH, and 16:8 (L:D) h periods.

Insects

Myzus persicae colonies were acquired from the Van Yüzüncü Yıl University Plant Protection Department's stock culture in 2019, and all studies were completed at Van Yüzüncü Yıl University, Faculty of Agriculture, Plant Protection Department laboratories in 2020. Aphids were reared on each cultivar plant for at least 3-4 generations to enable their adaptation to their new hosts in a climatic room set at the experimental conditions mentioned above.

Construction life table and analysis

To conduct the experiment, a single wingless adult green peach aphid was placed on the undersides of medium-sized leaves of each cultivar for each treatment. After 12 hours, only one of the newborn nymphs was kept in cylindrical Plexiglas cages with a height of 2 cm, a diameter of 2 cm and covered with cheesecloth for 24 hours. With daily observations, development and nymphal mortality data were recorded. Following the adult emergence, all adults' fecundity and survival rates were observed daily until their death. The study was conducted using 36-49 replicates for each cultivar.

The TWOSEX-MSChart (Chi, 2022a) computer software based on the concept of age-stage, two-sex table life was used to analyze the raw data which was obtained from development time, survival and fecundity of green peach aphid (Chi, 1988; Chi & Liu, 1985). The most important life table parameters [the intrinsic rate of increase (r), the finite rate of increase (λ), net reproductive rate (R_0), and mean generation time (T)], and some crucial population parameters [age specific survival rate (l_x), fecundity (m_x), age-stage-specific survival rate (s_{xj}; where x = age and j = stage), life expectancy (e_{xj}), and reproductive value (v_{xj})] were calculated (Goodman, 1982; Chi & Su, 2006; Huang & Chi, 2011; Tuan et al., 2014). By employing a paired bootstrap test with 100,000 resamples to get reliable estimates, it was possible to compare the life table and population characteristics of the green peach aphid that fed with different cultivars (Efron & Tibshirani, 1994; Özgökçe et al., 2018; Wei at al., 2020).

Population projection

The population development of *M. persicae* was simulated using the computer software TIMING-MSChart (Chi, 2022b), which is based on the concepts of Chi & Liu (1985) and Chi (1990), using life table data collected from the experiments. The population size that *M. persicae* could reach at day 60 was simulated based on the initial population of 10 nymphs.

Preparation of insect homogenates and protein determination

Insect samples were homogenized with a homogenizer on ice in 0.75 ml of 100 mM potassium phosphate buffer (pH 7.2), containing 1 mM dithiothreitol (DTT) and 1 mM ethylenediaminetetraacetic acid (EDTA). In the homogenization process, the samples were observed homogeneously for 20 seconds and kept on ice for 20 seconds. This process was repeated five times. After homogenization, the samples were centrifuged at +4ºC and 10,000 x g for 30 minutes. As the final step, non-specific esterase, glutathione S-transferase, and total thiol group determination tests were performed using supernatant as enzyme source. Bradford assay was used to measure protein quantities (Bradford, 1976).

Determination of total thiol groups

To determine the total thiol groups of insect homogenates, a modified version of Sedlak and Lindsay method was used (Sedlak & Lindsay, 1968). This method depends on reducing DTNB (5,5'-dithiobis-(2-nitrobenzoic acid) by the thiol groups present in the tested samples. In this assay, the reaction mixture contained 20 mM EDTA, 2 mM DTNB, methanol, 10µL homogenate and 200 mM Tris buffer (pH: 8.2) with a final volume of 200 µL. After the addition of the thiol group containing homogenates to each well, the plates were incubated at 25ºC for 30 minutes. Finally, the absorbance value of each well was measured at a wavelength of 405 nm. Utilizing reduced glutathione standard curves, the total amount of thiol groups was determined. The amount of total thiol groups was given as nmol/mg protein.

Analysis of the activity of the GST enzyme against 1-chloro-2,4-dinitrobenzene (CDNB)

Using the substrate 1-chloro-2,4-dinitrobenzene (CDNB), the modified Habig et al. (1974) technique was used to evaluate the glutathione S-transferase activity. There were 100 mM potassium phosphate buffer (pH 7.4), 1 mM GSH, and 1 mM CDNB in each reaction mixture. GST-CDNB activity measurements were performed at 37ºC for 10 minutes at 340 nm. The activities of GST-CDNB were measured as described by Konus et al. (2014). The expression for GST-CDNB activities was nmol/min/mg protein.

Activity of non-specific esterase (EST-PNPA) determination

Using p-nitrophenyl acetate, the non-specific esterase enzyme activities of the insect samples were assessed using the van Asperen technique (PNPA) (van Asperen, 1962). 200 L of the reaction mixture including 100 mM potassium phosphate buffer, pH 7.0, 0.05% Triton X-100, and 3.8 mM PNPA was used as the final volume. EST-PNPA activity was calculated as described by Konus et al. (2014). The expression for EST-PNPA activity was nmol/min/mg protein.

Statistics for thiol and enzyme assays

All measurements were conducted between 3-to 7 times, and for the comparison purposes, 100,000 bootstrap simulations were executed using the Twosex MSCHART (Chi, 2022a) software. The paired test was employed to estimate the difference between the means.

Results

Development survival and reproduction

All the nymphs that were tested on different Charleston pepper cultivars have become adult by completing their developmental periods, and then adults gave birth. No any individuals died during their development periods, so survival rates were 100% in all cohorts. The data on each nymphal stage and total preadult durations of *M. persicae* on five different Charleston pepper cultivars were presented in Table 1. The durations of developmental stages of *M. persicae* were found to be significantly affected by feeding on different host plants. It had the longest total preadult development time when fed with Kanyon cultivar (10.95 days), while the shortest development time was observed in the cohort fed with the Tufan cultivar (8.21 days) ($p < 0.05$).

Table 1. The development times, longevity, fecundity and oviposition of *Myzus persicae* on different Charleston pepper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan) (mean±SE)

Parameters	n	A.3055	n	Kanyon	n	Maraton	n	Safkan	n	Tufan
Nymph1	36	1.47±0.109c*	41	2.27±0.16a	49	2.06±0.138a	40	1.5±0.08c	48	1.75±0.076b
Nymph2	36	2.89±0.186a	41	2.34±0.183a	49	2.59±0.167a	40	3.08±0.194a	48	2.5±0.133a
Nymph3	36	2.33±0.154a	41	2.8±0.216a	49	2.53±0.173a	40	2.33±0.173a	48	2.19±0.142a
Nymph4	36	2.58±0.230b	41	3.54±0.288a	49	2.21±0.179b	40	2.23±0.184b	48	1.77±0.124c
Preadult time	36	9.28±0.315b	41	10.95±0.413a	49	9.42±0.323b	40	9.12±0.218b	48	8.21±0.181c
Adult longevity	36	29.56±1.066a	41	25.32±0.926bc	49	23.96±0.83c	40	27.75±0.928ab	48	25.96±0.639bc
Total longevity	36	38.83±1.047a	41	36.27±0.974ab	49	32.84±1.029c	40	36.88±0.899a	48	34.17±0.653bc
Fecundity	36	67.92±5.01a	41	31.10±2.42c	49	49.62±3.01b	40	59.95±2.07a	48	62.21±2.71a
TPRP	36	9.28±0.32b	41	10.95±0.41a	49	9.5±0.32b	40	9.12±0.22b	48	8.21±0.18c
Oviposition	36	25.67±1.04a	41	17.93±0.96b	49	20.19±0.87b	40	24.88±0.77a	48	23.42±0.61a

* Differences between means signed in the same line with the same letters are not significantly important ($p > 0.05$).

All the tested individuals began reproducing the day they reached adulthood. Therefore, it was determined that the durations for total preadult time and TPRP (total pre-reproductive period, which is defined as the average duration from birth to the first reproduction) were the same. Significantly longest adult longevities were observed in the A.3055 (29.56 days) and Safkan (27.75 days) cultivars, while the shortest longevity was observed in the Maraton cultivar (23.96 days) ($p < 0.05$). The cohort of the Maraton cultivar displayed the shortest total longevity (32.84 days), while the longest total longevity was observed in the A.3055, Safkan, and Kanyon cultivars (38.83, 36.88, and 36.27 days, respectively) ($p < 0.05$). The fecundity of *M. persicae* was affected by the pepper cultivars fed with. Among the tested pepper cultivars, the A.3055, Tufan, and Safkan cultivars resulted in the highest fecundity of *M. persicae* with 67.92, 62.21, and 59.95 offspring, respectively, while the Kanyon cultivar had the lowest fecundity with 31.10 offspring ($p < 0.05$). Compared to the Maraton (20.19 days) and Kanyon (17.93 days) cultivars, the oviposition time of the *M. persicae* was significantly longer on the A.3055, Safkan, and Tufan cultivars (25.67, 24.88, and 23.42 days, respectively) (Table 1) ($p < 0.05$).

The detailed age-stage survival rates (s_{xj}) (it reflects the probability that a newborn survives to age x and j stage) of the five cohorts of *M. persicae* fed with different cultivars are demonstrated in Figure 1. In this study, the probability that the newly born nymph of the pest to reach the adult stage was 1.00 (100%) on all cultivars because of no death during the preadult duration. The survival curves displayed stage overlapping, owing to the different developmental periods of individuals across all cultivars. It was observed that the first adults emerged in 4-7 days in all cultivars.

The age-specific survival rate (l_x), illustrated in Figure 2 for the green peach aphid on different cultivars, represents the probability that a newborn individual will live to age x. In all cultivars, the green peach aphid seems to have a fairly high survival rate up to the conclusion of the adult stage. At the end of its lifetime, survival rates of *M. persicae* on the Tufan, and Safkan cultivars dramatically decreased with a sharper trend than other cultivars.

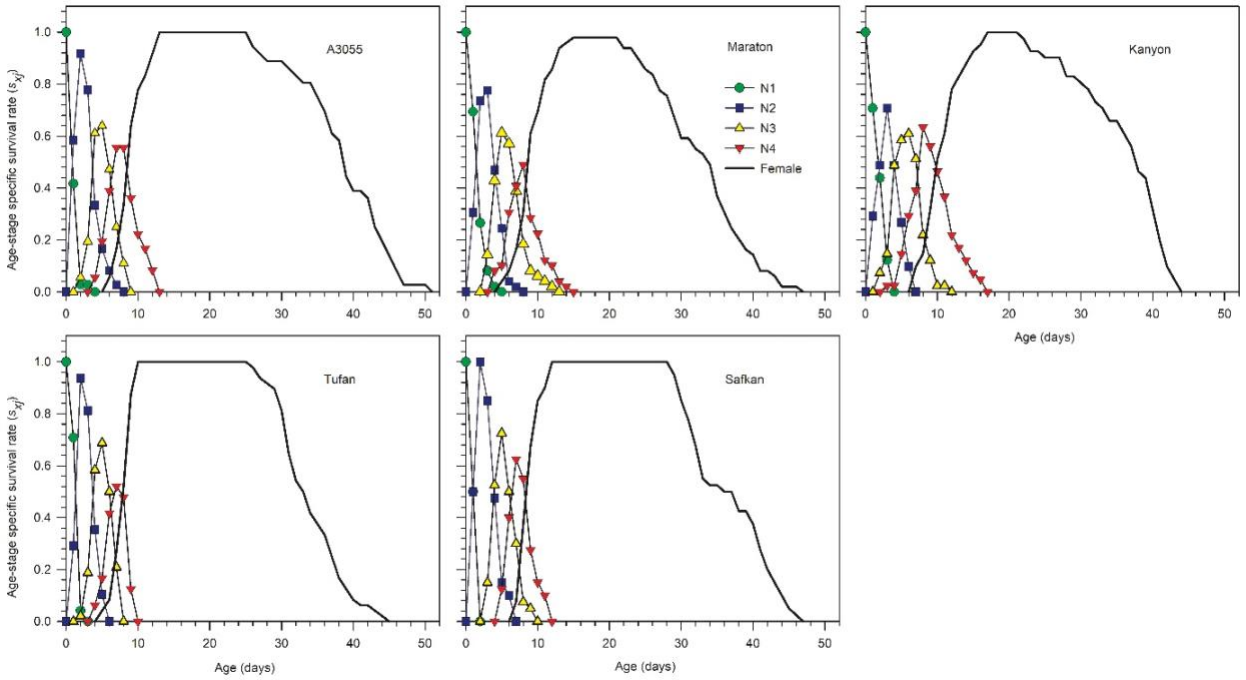

Figure 1. Age-stage specific survival rate (s_{xj}) of *Myzus persicae* reared on Charleston pepper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan).

Based on the information provided, Figure 2 shows the age-specific rates of fecundity (m_x) and maternity ($l_x m_x$) of *M. persicae* on different cultivars. The curves indicate that the pest starts reproducing within 4-7 days of its lifetime on all the cultivars tested. The curves also show that the age-specific fecundity (m_x) and age-specific maternity ($l_x m_x$) peaks of *M. persicae* on the Kanyon cultivar were notably lower than those observed on the other cultivars. This suggests that the Kanyon cultivar may not be as suitable for the pest's reproduction as the other cultivars. Furthermore, the maternity curves were found to be very close and parallel to the fecundity curves on all cultivars tested until the end of the adult lifespan. This indicates that the percentage of adult females reproducing at each age was relatively constant, and that the reproductive output of the pest was primarily influenced by its age-specific fecundity.

The age-stage life expectancy (e_{xj}) curves of *M. persicae* were presented in Figure 3. The overall lifespan, which was previously described, is also the life expectancy of a newborn individual (e_{01}) (Table 1).

According to Yang & Chi (2006), life expectancy is an estimate of how long an individual would live under specific circumstances. For example, the expected life time of a newborn individual on the A.3055 cultivar will be 37.45 days, while on the Maraton cultivar it will be only 32.84 days.

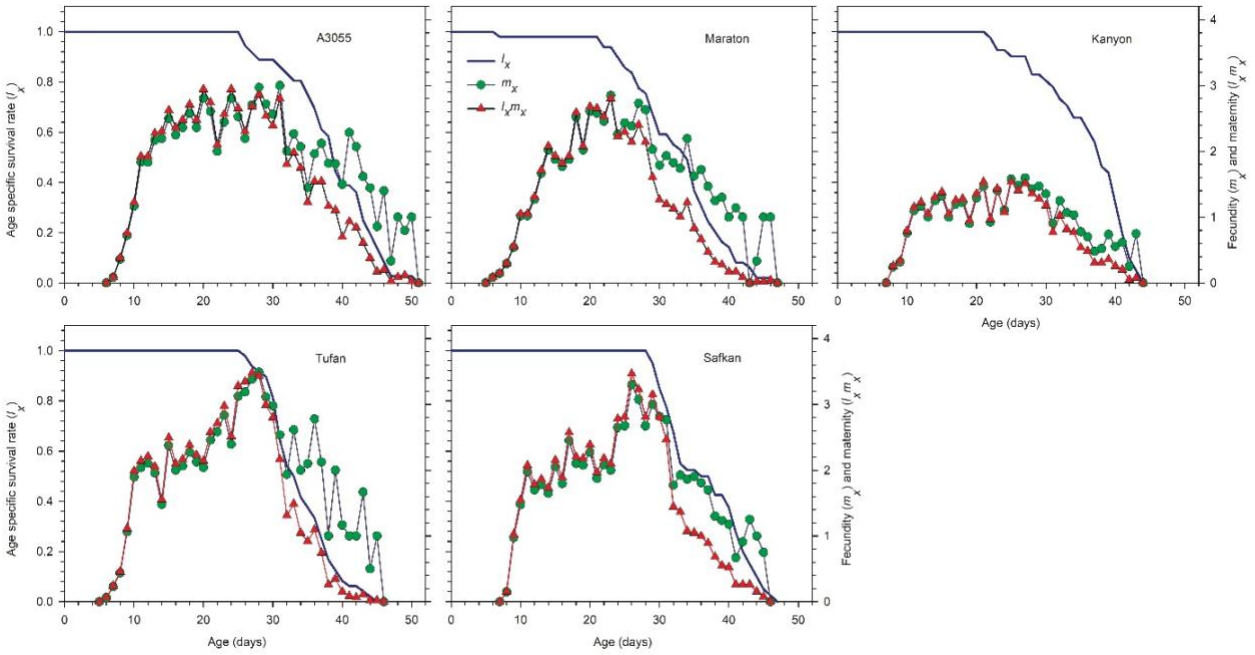

Figure 2. Age-specific survival rate (l_x), fecundity (m_x) and maternity ($l_x m_x$) of *Myzus persicae* reared on Charleston pepper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan).

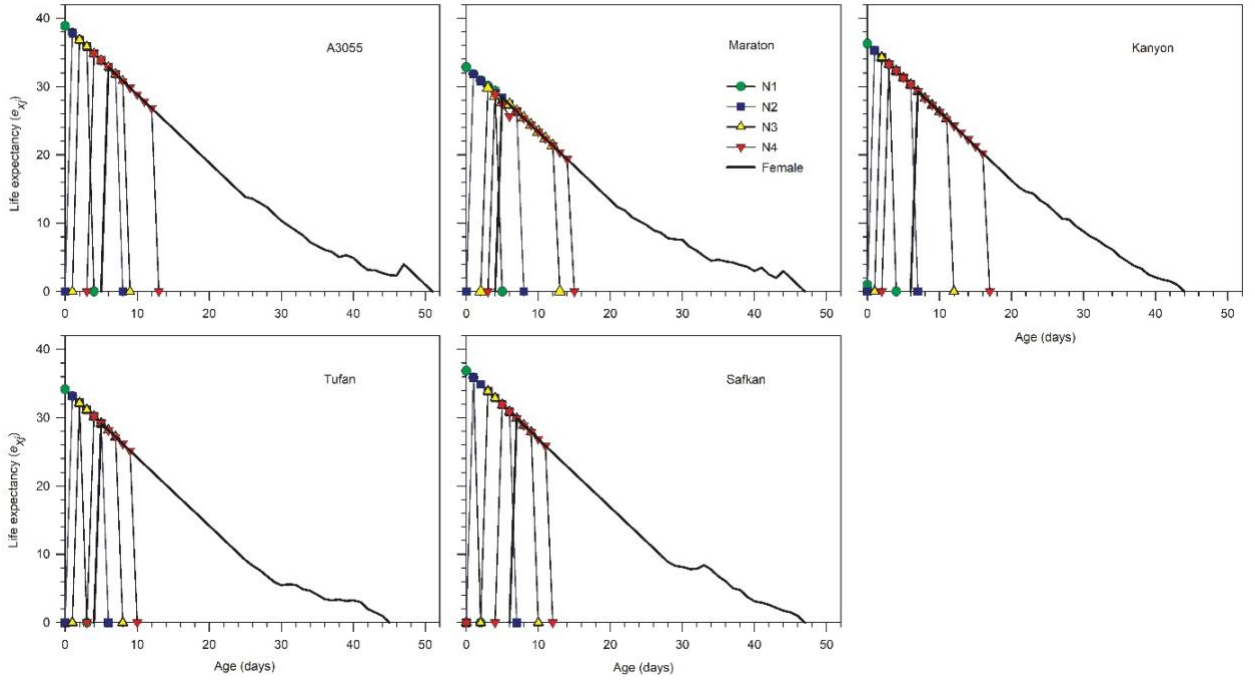

Figure 3. Age-stage-specific life expectancy (e_{xj}) of *Myzus persicae* reared on Charleston pepper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan).

Fisher (1930) defined the term "reproductive value" as the value an individual has in terms of contributing to the future population. The Twosex life table theory, proposed by Chi in 1988, defines the age-specific and stage-specific reproductive value (v_{xj}) as an individual's contribution to the future population at a particular age x and stage j. It is equivalent to the finite rate of increase (λ) for a newborn individual (v_{01}). Age-stage reproductive value (v_{xj}) reached its highest level in the female stage in all cohorts,

with the following estimates: 11.2 at age 16 for A.3055, 12.19 at age 23 for Safkan, 10.76 at age 7 for Kanyon, 11.44 at age 17 for Maraton, and 12.2 at age 24 for Tufan (as shown in Figure 4).

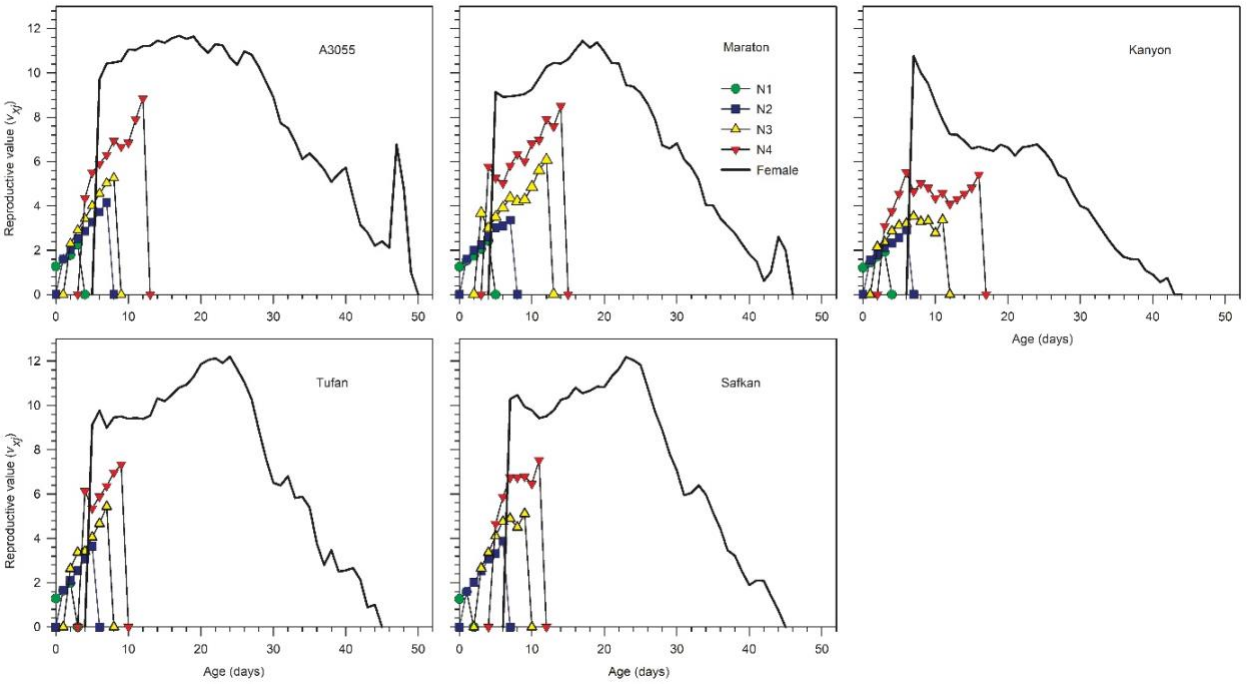

Figure 4. Age-stage-specific reproductive value (v_{xj}) of *Myzus persicae* reared on Charleston pepper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan).

The life table parameters

The life table parameters of the green peach aphid, which include intrinsic rate of increase (r), net reproduction rate (R_0), mean generation time (T), and finite rate of increase (λ), were estimated on various Charleston pepper cultivars and are displayed in Table 2. The cohort of green peach aphid fed with the Kanyon cultivar exhibited significantly lower values of r, λ and R_0 (0.193 d^{-1}, 1.213 d^{-1}, and 31.09 offspring, respectively) compared to other cohorts ($p < 0.05$). Conversely, the Tufan cultivar had the highest values of r and λ (0.248 d^{-1}, 1.282 d^{-1}, respectively) among all the cultivars. No significant differences were observed in the mean generation time of *M. persicae* on different pepper cultivars, which ranged from 16.64 days to 17.84 days.

Table 2. The life table parameters of *Myzus persicae* on different Charleston peper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan) (mean±SE)

Life table parameters	A3055	Kanyon	Maraton	Safkan	Tufan
The intrinsic rate of increase, r (d^{-1})	0.238±0.009ab	0.193±0.009c	0.222±0.007b	0.233±0.005b	0.248±0.006a
The finite rate of increase, λ (d^{-1})	1.269±0.012ab	1.213±0.011c	1.248±0.008b	1.263±0.006b	1.282±0.007a
Net reproductive rate, R_0 (offspring)	67.92±4.92a	31.09±2.38c	48.61±3.09b	59.95±2.04a	62.21±2.68a
Mean generation time, T (day)	17.72±0.61a	17.84±0.61a	17.51±0.44a	17.55±0.34a	16.64±0.38a

* Differences between means signed in the same line with the same letters are not significantly important ($p > 0.05$).

The intrinsic rate of increase, a key tool for summarizing an organism's physiological characteristics in relation to its growth potential, is widely used to compare the fitness of organisms in various climatic and nutritional settings (Andrewartha & Birch, 1954; Tsai & Wang, 2001; Hong et al., 2019). This parameter often provides important information independently from other life table parameters (Petitt et al., 1994). The intrinsic rate of increase is a single parametric value derived from variables of development, survivorship, fecundity and reproductive age of an organism kept under certain conditions. To use this value in comparisons, their pseudo values are derived by using Jacknife method in the classical method. However,

because the number of pseudo values derived from the Jacknife method depends on the number of repetitions in the trial and often does not show normal distribution, reliability in the comparison tests decreases. As a matter of fact, the Jacknife technique has proven to be inadequate in life table analysis (Huang & Chi, 2012, 2013; Yu et al., 2013). In this study, the 100,000 resampling bootstrap technique was used to obtain a precise estimate of population parameters.

Population projection

Using an initial population of 10 newborn nymphs, the age-stage population sizes were calculated for each cohort under the same experimental conditions, as shown in Figure 5. At the end of 60th days, the population size of green peach aphid was estimated as follows 10 654 406, 5 142 569, 4 264 705, 2 182 228, and 420 470 individuals on the Tufan, A.3055, Safkan, Maraton, and Kanyon cultivars, respectively (Table 3). The green peach aphid was able to produce a considerably lower population density on the Kanyon cultivar than others.

Table 3. Population size of *Myzus persicae* with 10 nymphs initial population on Charleston pepper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan) after 60th days

Cultivars	N1	N2	N3	N4	Female	Total
A.3055	1 608 830	1 909 965	870 771	521 693	671 310	5 142 569
Kanyon	144 208	98 047	72 266	49 540	56 409	420 470
Maraton	775 706	613 216	322 507	175 410	295 389	2 182 228
Safkan	1 239 255	1 513 088	626 794	354 917	530 651	4 264 705
Tufan	3 694 497	3 151 651	1 562 075	788 511	1 457 672	10 654 406

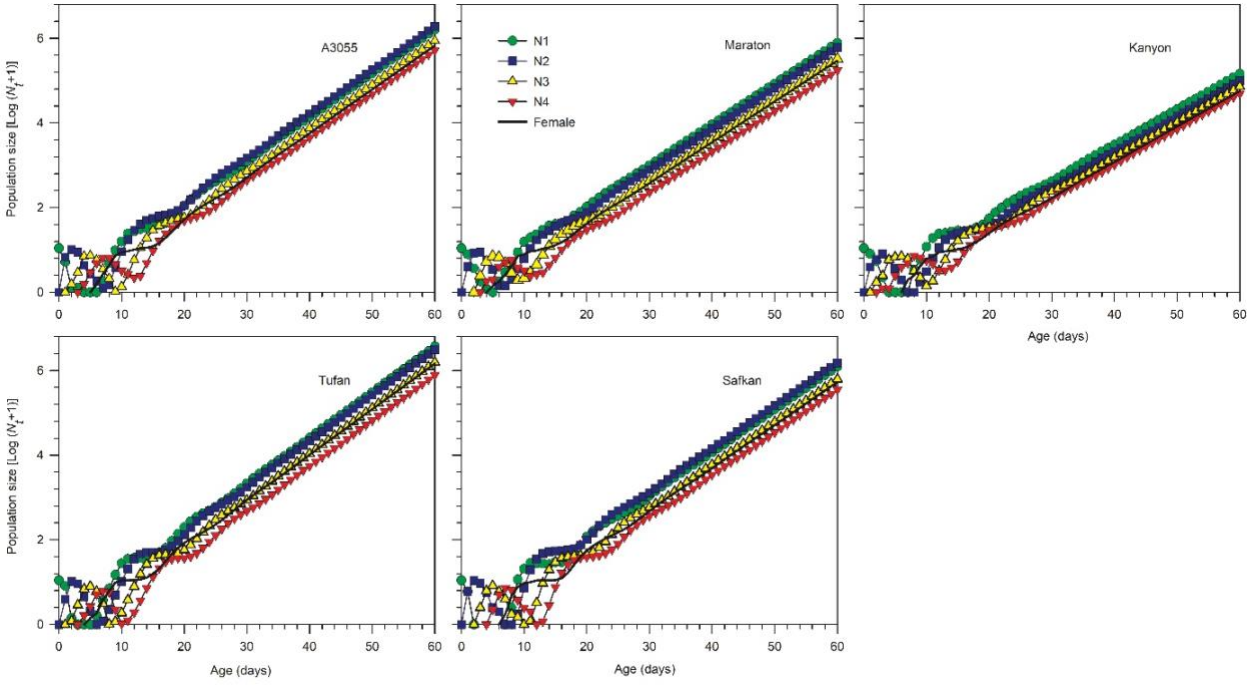

Figure 5. Population projection of *Myzus persicae* reared on Charleston pepper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan).

Determination of total thiol groups

The results indicated that the highest amount of total thiol groups (15.59 nmol/mg protein) was obtained in the *M. persicae* individuals reared on the Safkan cultivar, however, the lowest amount was in individuals reared on the Kanyon and the Tufan cultivars as follows, 3.26, 3.53 nmol/mg protein, respectively ($p < 0.05$) (Table 4).

Table 4. Summary of overall enzyme activities and total thiol content results of *Myzus persicae* on different Charleston peper cultivars (A.3055, Tufan, Kanyon, Maraton, and Safkan) (mean±SD)

ASSAY	A.3055	Kanyon	Maraton	Safkan	Tufan
Total Thiol Content (nmol/mg protein)	4.24±0.5c	3.26±0.18d	5.12±0.27b	15.59±0.42a	3.53±0.23d
GST-CDNB (nmol/min/mg protein)	497.38±26.21b	317.04±11.98d	547.68±28.1a	562.8±21.91a	419.9±26c
EST-PNPA (nmol/min/mg protein)	196.33±36.21a	132.14±22.53b	204.23±15.19a	207.64±27.46a	154.94±9.55b

* Differences between means signed in the same line with the same letters are significantly not important ($P > 0.05$).

Analysis of the activity of the GST enzyme against 1-chloro-2,4-dinitrobenzene (CDNB)

Using CDNB substrate, the GST enzyme activity of insect samples was measured. GST enzyme activity of the pest reared on A.3055, Kanyon, Tufan, Maraton, and Safkan cultivars were given in Table 4. According to these findings, while the highest GST-CDNB activity (562.8±21.91 nmol/min/mg protein) was seen in the *M. persicae* individuals reared on the Safkan cultivar**,** and the lowest GST-CDNB activity (317.04±11.98 nmol/min/mg protein) was seen in the *M. persicae* individuals reared on the Kanyon cultivar ($p < 0.05$).

Activity of non-specific esterase (EST-PNPA) determination

The non-specific esterase enzyme activities of *M. persicae* samples were measured using the EST-PNPA test. The results showed that the samples of *M. persicae* reared on the Safkan, Maraton, and A.3055 cultivars had the highest EST-PNPA activity, whereas the individuals reared on the other two cultivars had the lowest EST-PNPA activity (Table 4).

Discussion

Plants have evolved diverse genetic variations over thousands of years, in response to both biotic and abiotic factors (Smith & Clement, 2012). Plant varieties exhibit varying pest-plant relationships, even within the same species, due to their wide range of genetic diversity. Plant growers have observed that certain varieties attract arthropods and cause substantial damage, while others are less preferred or even avoided. Early farmers engaged in agriculture thousands of years ago probably had knowledge of pest-resistant plants among those they grew (Smith & Clement, 2012). During the development of applied entomology in the eighteenth and nineteenth centuries, insect-resistant cultivars were frequently exploited (Smith & Clement, 2012).

Studies on the detection of insect-resistant varieties have become an area of interest, also in modern genetics, in recent years to discover resistant genes. In integrated pest management (IPM) programs, using resistant host plants is a crucial part of the control arthropod pests in modern agriculture. It provides primary data for genetic studies. Arthropod-resistant varieties provide economic benefits to producers by reducing or eliminating the need for pesticide applications (Smith, 2005; Smith & Clement, 2012). Arthropod-resistant genes used in global agriculture have an annual value of more than $ 2 billion (Smith, 2005; Smith & Clement, 2012).

The study findings indicated that the biology of the green peach aphid was affected by feeding on different Charleston pepper cultivars under laboratory conditions. Numerous studies have demonstrated that the biology of many aphid species can differ considerably based on the host plant, and even among different cultivars and varieties of the same host plant. These differences can be observed in terms of development time, survival rate, reproduction, and lifespan (Razmjou & Golizadeh, 2010; La Rossa et al., 2013; Özgökçe et al., 2018; Qayyum et al., 2018). Numerous studies have been carried out to demonstrate the significant impact of feeding on different pepper varieties on the population dynamics and biology of the green peach aphid. These studies include those conducted by Qing (2002), Luo et al. (2003), Nikolakakis et al. (2003), La Rossa et al. (2013), and Özgökçe et al. (2018). For example, Özgökçe et al. (2018) observed that the green peach aphid underwent development in 6.58-8.27 days and had an intrinsic rate of increase varying between 0.246-0.332 d^{-1} on different cultivars of *C. annuum* L. (Solanaceae), such as bell, sweet, or chili pepper, under similar laboratory conditions. These results closely resemble those of the present study.

Various factors can account for the differences in host preference among cultivars of the same plant species. Plant defense mechanisms against insect herbivores have been classified into three types: antixenosis (or non-preference), antibiosis, and tolerance (Painter, 1951; Kogan & Ortman, 1978). Antixenosis refers to the negative impact of the host plant on insect behavior, such as discouraging egg-laying, feeding, sheltering, and colonization processes (Kogan & Ortman, 1978; Cao et al., 2015; Sulistyo & Inayati, 2016; Stenberg & Muola, 2017). The non-preference behavior of an arthropod to a resistant plant is based on the host plant's morphological, biophysical, or allelochemical characteristics (Smith & Clement, 2012; Baldin et al., 2018). Antibiosis is the term used to describe how the biophysical or biochemical defense system of a resistant plant directly affects the physiology of harmful insects when they feed on the plant (Smith, 2005; Cruz & Baldin, 2017). The effects of insect antibiosis usually include a lengthening of immature stage duration, higher mortality rates, reduced fertility, and alterations to body size or weight (Panda & Khush, 1995; Smith, 2005). Tolerance, as defined by Smith (2005), is the capability of a plant to withstand or repair arthropod-induced damage while retaining its production capacity without altering the biology or behavior of the insect.

While host plants can produce ROS (especially in phloem cells) due to aphid injuries in host plants' cells, they may also cause the production of ROS in herbivorous insects by their allelochemicals (beta-carbonyl alkaloids, furanocoumarins, phenolic compounds, and thiophenes) (Lukasik & Golawska, 2013). These ROS may cause midgut cell breakdown and impair insect nutrition intake (Bi & Felton, 1995). Furthermore, ROS can interact with a wide range of intracellular biomolecules, including proteins, DNA, and lipids. Lipid peroxidation is harmful to herbivorous insects by changing the permeability of the cell membrane (Jamieson, 1989), decrease in the content of cuticle surface lipids, and juvenile hormone synthesis (Downer, 1985). Consequently, herbivorous insect performance on host plants directly affects the balance between the production and annihilation of ROS (Krishnan & Sehnal, 2006).

Levels of the GST-CDNB activities of *M. persicae* were ranked from highest to lowest as follows Safkan, Maraton, A3055, Tufan, and Kanyon, respectively. It has been proposed that increased GST activities might play an essential role in reducing oxidative stress (Konuş, 2014). Cells use modifying strategies such as glutathionylation of some important protein-based biomolecules to immediately cope with the oxidative stress that occurs during their natural metabolic activities (Musaoğulları et al., 2020). For example, caspase enzymes that might be essential in apoptosis are one of the protein groups that are inhibited due to the glutathionylation functions of GSTs (Huang et al., 2008; Singh & Reindl, 2021). According to these results, the increase in insect GST activity (1.8-fold) between Safkan and Kanyon cultivars shows the presence of oxidative stress and that it is an effective antioxidant enzyme in coping with this stress. According to these results, Safkan and Maraton cultivars could be suitable hosts because they confer high GST activities in *M. persicae*.

Our data on the total thiol content of tested samples of *M. persicae* fed with different Charleston pepper cultures is similar to the GST-CDNB activity results. As the cells use glutathione (GSH) both non-enzymatically and enzymatically (GST) while trying to cope with oxidative stress, the level of GSH in the cells decreases. As a result, the cells enter apoptosis. In other words, reducing the GSH level of cells predisposes those cells to apoptosis and/or directly induces cell death (Yılmaz et al., 2022). When we evaluated our results according to GST-CDNB, and total thiol (GSH) levels, the lowest total thiol, and the lowest GST activity were determined in *M. persicae* individuals fed with the Kanyon cultivar. Consequently, while the Kanyon cultivar may not be a suitable host for *M. persicae*, the Safkan and Maraton cultivars could be a good host because it confers a high level of GSH in *M. persicae*.

Esterases are enzymes that catalyze the conversion of ester-structured compounds to acids and alcohols (Konus, 2014). When the results of EST-PNPA activities are considered, Safkan Maraton, and A3055 showed higher esterase activities than the other two cultivars (Kanyon and Tufan). Furthermore, detoxification with esterases has been reported to be very important in the adaptation of *M. persicae* to cumin, anise, and coriander (Cabrera et al., 2010; Ramsey et al., 2010). Thus, it was concluded that Safkan, Maraton, and A3055 cultivars could be good hosts for the pest because they confer high esterase activities.

To summarize, based on life table parameters, the Kanyon cultivar is less favored by *M. persicae*, while Tufan and A3055 cultivars are deemed more suitable hosts. These findings were supported by enzymatic/nonenzymatic antioxidant levels, as determined by tests. However, as resistance mechanisms were not investigated in this study, the reasons for variation in biological parameters among insects cannot be fully explained, especially the first two resistance mechanisms often overlap and special tests required to distinguish between them (Smith, 2005). The study determined the most and least favored cultivars by *M. persicae* among all the tested cultivars. Conducting additional genetic research to identify the specific genes involved would be advantageous for the development of plant breeding programs and integrated pest management strategies.

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