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Araştırma
(Research)

Effect of *Trichoderma harzianum* Rifai (Ascomycota: Hypocreales) on the Biological Traits of *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae) Mediated by Pepper Plant

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Abstract

Objective: It has been reported that the colonization of plant roots by the beneficial microorganism *Trichoderma harzianum* triggers the plant's immune system, providing defense against herbivorous insects. In this study, the effects of *T. harzianum* on the biological traits of *Myzus persicae* on pepper plants were investigated under controlled conditions (25±2°C, 65±5 RH, and a 16:8 light: dark).

Materials and Methods: The raw data obtained from daily counts of *Myzus persicae* feeding on pepper plants whose roots were colonized by *Trichoderma harzianum* were subjected to life table analysis.

Results: According to the analysis results, the intrinsic rate of increase (r) was 0.3148 d^{-1} in the control and 0.3304 d^{-1} in the *T. harzianum* treatment, while the finite rate of increase (λ) was 1.3701 d^{-1} and 1.3916 d^{-1}, respectively. The net reproductive rate (R_0) was determined as 68.26 offspring/individual in the control and 65.65 offspring/individual in the *T. harzianum* treatment. The difference in population doubling time between the control (2.2 days) and *T. harzianum* treatment (2.1 days) was found to be statistically insignificant.

Conclusion: As a result of the study, it was determined that there was no effect of *T. harzianum* colonization on the biological traits of *M. persicae* feeding on Demre-type pepper plants.

Keywords: Age-stage two-sex life table, biological traits, *Myzus persicae*, pepper plant, *Trichoderma harzianum*

Trichoderma harzianum **Rifai (Ascomycota: Hypocreales)'nin Biber Bitkisi Aracılı** ***Myzus persicae*** **(Sulzer, 1776) (Hemiptera: Aphididae)'nin Biyolojik Özelliklerine Etkisi**

Öz

Amaç: Faydalı mikroorganizmalardan *Trichoderma harzianum*'un bitki köklerine kolonize olması sonucunda bitkilerin bağışıklık sistemini uyararak herbivor böceklere karşı savunma sağladığı bildirilmiştir. Bu çalışmada, *T. harzianum*'un Demre tipi biber bitkileri üstünde *Myzus persicae*'nin biyolojik özellikleri üzerine etkileri kontrollü koşullar altında (25±2 °C sıcaklık, %65±5 bağıl nem ve 16:8 aydınlık: karanlık) araştırılmıştır.

Materyal ve Yöntem: Köklerine *Trichoderma harzianum*'un kolonizasyonu sağlanan biber bitkileri üstünde beslenen *Myzus persicae*'den günlük sayımlarla elde edilen ham veriler yaşam tablosu analizine tabi tutulmuştur.

Araştırma Bulguları: Analiz sonuçlarına göre, kalıtsal üreme yeteneği (r) kontrol grubunda 0,3148 d^{-1} ve *T. harzianum* uygulamasında 0,3304 d^{-1}, artış oranı hızı (λ) ise sırasıyla 1,3701 d^{-1} ve 1,3916 d^{-1} olarak bulunmuştur. Net üreme gücü (R_0) kontrol grubunda 68,26 yavru/birey, *T. harzianum* uygulamasında ise 65,65 yavru/birey olarak belirlenmiştir. Kontrol (2,2 gün) ile *T. harzianum* uygulaması (2,1 gün) arasındaki popülasyonun ikiye katlanma süresi farkının istatistiksel olarak önemsiz olduğu bulunmuştur.

Sonuç: Çalışmanın sonucunda, köklerine *T. harzianum* kolonize edilen Demre tipi sivri biber bitkileri üzerinde beslenen *M. persicae*'nin biyolojik özellikleri üzerinde herhangi bir etkisinin olmadığı belirlenmiştir.

Anahtar kelimeler Yaş ve döneme özgü iki eşeyli yaşam tablosu , biyolojik özellikler, *Myzus persicae,* biber bitkisi, *Trichoderma harzianum*

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Inroduction

Pepper (*Capsicum annuum* L.) is a plant that can be cultivated wherever climate and soil characteristics are suitable, and it is a significant commercial crop. Worldwide production of pepper, which is a food source rich in vitamins A and C and high in antioxidant content for human health (Liang et al., 2022), reached approximately 44 million tonnes in 2023 (FAO, 2025).

Pepper plant is a product produced in greenhouses and open areas and is a host for many herbivorous insects (Balog et al., 2017). One of the most important of these pests, *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae), feeds by sucking plant sap with its sucking mouthparts on the stem, leaves, buds and flowers of the plant. This feeding causes yield loss in the plant and also causes secondary damage to the plant by causing fumagine. *M. persicae* is a phytophagous pest that can feed on more than 400 host plant species from more than 50 families (Biryol et al., 2022). In addition, *M. persicae* is a vector of more than 100 plant viruses, especially cucumber mosaic virus (CMV), which causes serious crop losses in pepper (Verdugo et al., 2012).

Various methods are used to control herbivorous insects. However, chemical control, which should be used as a last resort, is generally preferred due to its low cost, ease of application and rapid results. This situation leads to the use of approximately 2 million tons of pesticides per year worldwide (Aktar et al., 2009) and creates serious problems such as environmental pollution, toxic effects and resistance development. These negative effects and the disruption of the natural balance encourage producers to turn to more environmentally friendly control methods.

In recent years, more environmentally friendly and economical approaches to controlling insects have been developed. These methods aim to trigger the natural resistance mechanisms of plants, making them healthier and more resistant. In particular, applications have been developed that enable plants to gain resistance against herbivorous insects by using beneficial soil-based microorganisms (Noman et al., 2020). In addition, studies are ongoing to determine the role of endophytic fungi naturally found in underground parts in plant defense and their effects in increasing the resistance of plants to diseases and pests (Pieterse et al., 2014; Pineda et al., 2015; Wielkopolan and Obrępalska, 2016; Verma et al., 2019; Woo et al., 2023).

Trichoderma spp. (Ascomycota: Hypocreales), one of the important endophytic fungi, is a microorganism that can be found in almost all natural environments, some of which are free-living and some of which form close relationships with plants (Chaverri et al., 2003; Woo et al., 2023). *Trichoderma* spp. are considered safe and environmentally friendly bio-control agents because they are not pathogenic for plants and animals, do not produce harmful residues or toxic secondary metabolites, and do not cause environmental pollution or resistance development in target pathogens (Bardin et al., 2015).

Trichoderma spp. increases resistance to biotic and abiotic stress conditions by inducing induced systemic resistance (ISR) in plants (Harman, 2006; Verma et al., 2019; Macías-Rodríguez et al., 2020; Noman et al., 2020; Adeleke and Babalola, 2021). Plants stimulated by beneficial soil-borne microorganisms enter a "priming" state when exposed to pathogen or insect attack (Pineda et al., 2010). Priming refers to the preparation of a faster and more effective defense response against future attacks by plants after exposure to biotic or abiotic stress (Aranega-Bou et al., 2014). In order to fully evaluate the effectiveness of these defense responses, it is important to examine the feeding behaviors of phytophagous insect species with different mouthparts on various crop plants.

The defense of plants against insects is a complex process involving biotic and abiotic factors. When an insect comes to feed on a host plant, it first tries to recognize some chemical cues. In response, the plant creates physical structures against the insect and synthesizes some chemical compounds to resist possible insect attacks (Sharma et al., 2021). In insect-plant interactions, insect endosymbionts attempt to detoxify metabolites produced by the plant, while plant-associated microorganisms activate systemic plant defense responses against herbivorous insect attacks (Beck et al., 2018; Sharma et al., 2021). In this context, it is important to determine the interactions of different plant and insect combinations. In this study, it was aimed to determine the effects of *Myzus persicae* feeding on pepper plants whose roots were colonized by *Trichoderma harzianum*. In determining this effect, age stage two sex life table theory was used, which determines the life table parameters of the insect and can analyze them statistically. The results obtained from this study will provide important information to be used in integrated pest management plans.

Materials And Methods

Pepper Plants

In the experiment, Kont F1 (Zeta Tohum, Antalya) Demre type pepper variety was used. This pepper variety has a strong plant structure, high fruit set rate and long harvest period and is declared suitable for open field and greenhouse cultivation.

Myzus persicae and *Trichoderma harzianum*

Myzus persicae to be used in the experiment was obtained from cultures produced in Van Yüzüncü Yıl University, Faculty of Agriculture, Department of Plant Protection. In order to eliminate the effect of variety, the pepper variety to be used in the experiment was taken into the experiment after at least three generations of pest feeding were ensured.

Trichoderma harzianum was obtained from the Mycology Laboratory of the same department, and the NTC1 isolate of *T. harzianum*, previously demonstrated to be effective on pepper plants, was used (Kara, 2025). In plant protection against diseases and pests, *Trichoderma harzianum* was applied at 10^8 spores/ml, which has been identified as an effective concentration (Abdel-Fattah et al., 2007; Al-Hazmi & TariqJaveed, 2016; Mukherjee & Ghosh et al., 2023). Solutions containing $1x10^8$ spores/ml were prepared by hemocytometer from one-week-old colonies of these fungi on potato dextrose agar (PDA; Merck Ltd., Darmstadt, Germany). A 20 ml aliquot of the prepared solution was transferred into a beaker. During the planting process, the roots of the seedlings were immersed in the solution to ensure thorough penetration. Following planting, the remaining solution in the beaker was added to the root collar of the seedlings.

Life Table Studies

The experiment was initiated with the offspring of a newly mature female adapted to the species used. The study was designed in two groups as control and *T. harzianum* treatment, and 40 replicates were created for each group. In order to prevent aphids from escaping, clips consisting of acetate papers glued to hairpins with a diameter of 2 cm and a height of 2 cm were used. All replicates were distributed equally on the upper and lower surfaces of the plant leaves. One clip was used for each repetition. The experimental pest was followed with daily observations from the beginning of the first stage until the death of the individual in the relevant clip, and data such as molting and the number of offspring were recorded. The experiment was carried out in a climate chamber equipped with plant growth LEDs under 25±2 °C, 65±5 RH and 16:8 light:dark (L:D) conditions.

Statistical Analysis

Raw data for the life table of *M. persicae* were obtained using the Two-sex MSChart (Chi et al, 2022a; Chi, 2024a) program designed with Visual BASIC for the Windows operating system, based on the age and stage specific two-sex life table method (Chi and Liu, 1985; Chi, 1988). The definitions and formulas of each population parameter are given in Table 1. The standard error of the population parameters was calculated using the bootstrap technique (B=2000) (Efron and Tibshirani, 1993), and the Cartesian product of all bootstrap replicates was applied to derive all possible pairwise differences for more precise confidence interval estimation (Chi et al, 2022b).

Table 1. Definition and formulas of population parameters

Parameter	Definition and equations
r	The intrinsic rate of increase (r) was estimated using the iterative bisection method and the Euler–Lotka equation with the age indexed from 0. (Goodman, 1982). $\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$
λ	The finite rate (□) and the mean generation time (T) were calculated as follows: $\lambda = e^r$
R_0	Where □ is the number of life stages. The cumulative reproductive rate (R_x) is the number of offspring produced by an individual from birth to age x, while the net reproductive rate (R_0) is the total offspring produced by an individual during her lifetime. These were calculated according to Chi and Su (2006). $R_0 = \sum_{x=0}^{\infty}\sum_{j=1}^{m} s_{xj} f_{xj} = \sum_{x=0}^{\infty} l_x m_x$
T	It is the time required for a population to increase by R_0- fold of its size, as the population approaches infinity and achieves a stable age-stage distribution. $T = \frac{\ln R_0}{r} = \frac{\ln R_0}{\ln \lambda}$

Cartesian products can be used to include all possible paired comparisons between two parameters (r, λ, R_0 e.g.) (Chi et al. 2022b). The Cartesian product of two sets, e.g., rA and rB, is the set consisting of all ordered pairs whose first element belongs to rA and whose second element belongs to rB (Chartrand et al. 2008). It can be expressed as:

r,A × r,B = {(r,Ax, r,By): r,Ax ∈ rA and rB,y ∈ rB }

The differences of all pairs of the Cartesian products (CPT:4,000,000) will definitely include all possible differences of the bootstrap results of the two parameters. All graphics were created using SigmaPlot 12.0 (Systat Software Inc., San Jose, CA, USA).

Population Projection

Population simulation was performed to estimate the future size of a population initiated with 10 first instar nymphs. In this process, population projection was calculated using age-stage specific two-sex data. Calculations were performed using the TIMING-MSChart (Chi, 2024b) program, in accordance with the methods developed by Chi (1990).

Results

Developmental Period, Fecundity and Survival Rate of *M. persicae*

It was observed that the development period of *M. persicae* fed on plants whose roots were colonized by *T. harzianum* was shorter than that of control plants (P=0.003). When their total longevity were compared, the difference between the means was not found to be significant (P=0.06). It was determined that the total pre-reproduction period (TPRP) data of aphids feeding on plants treated with *T. harzianum* were shorter compared to the control and the difference was statistically significant (P=0.002). Although the oviposition days of aphids feeding on *T. harzianum*-treated plants were significantly longer, when evaluated in terms of fecundity, the difference between the two groups was not significant (P=0.45). The survival rate was determined as 100% in both trial groups (Table 2).

Table 2. Fecundity, development, longevity, and survival rate of *Myzus persicae* feeding on *Trichoderma harzianum*-treated pepper plants.

	Control		***T. harzianum***		
	N	**Mean±SE***	**N**	**Mean±SE**	***P* value**
Nymph I (d)	38	1.66±0.09b	40	1.90±0.05a	0.02
Nymph II (d)	38	1.66±0.08a	40	1.15±0.06b	0.000
Nymph III (d)	38	1.87±0.09a	40	1.75±0.10a	0.41
Nymph IV (d)	38	1.79±0.07a	40	1.48±0.14b	0.04
Preadult duration (d)	38	6.97±0.14a	40	6.28±0.18b	0.003
Total longevity (d)	38	48.97±1.11a	40	46.20±0.96a	0.06
TPRP (d)	38	7.00±0.15a	40	6.28±0.18b	0.002
Fecundity (nymph/female)	38	68.26±2.33a	40	65.65±2.51a	0.45
Oviposition days (d)	38	23.21±0.64b	40	25.48±0.73a	0.02
Survival rate (%)	38	100	40	100	

*Values in each row followed by the same letter are not significantly different from each other at the 0.05 level, based on pairwise comparisons of group means conducted using the Cartesian product approach.

The age-stage survival rate graph is given in Figure 1. Age-stage survival rate graphs (s_{xj}) are graphs showing the survival rate of a newborn nymph at age x and stage j and the transition between periods. All *M. persicae* individuals feeding on control and *T. harzianum*-treated plants in the study reached the adult stage, and after surviving for a while, deaths began, which was similar. In the following days, the first death was observed (day 32) in *T. harzianum* (Figure 1).

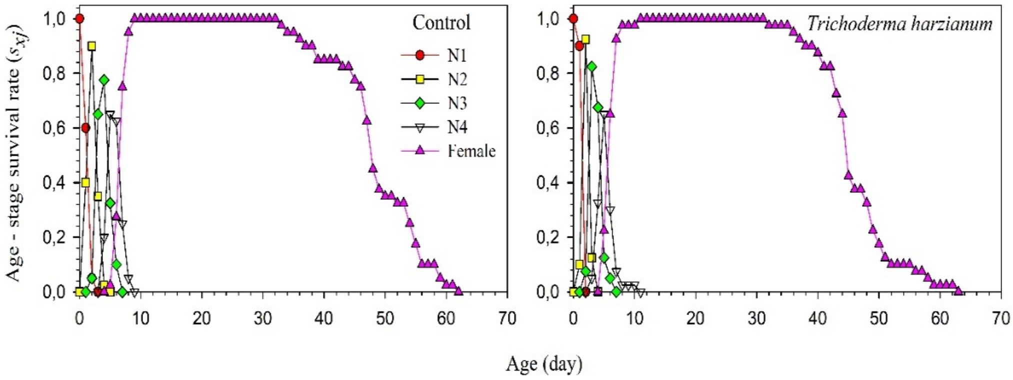

Figure 1. Age- stage specific survival rate of *Myzus persicae* feeding on *Trichoderma harzianum*-treated pepper plants.

The age-specific survival rate (l_x), age-specific fecundity (m_x), and age-specific maternity (l_xm_x) of *M. persicae* on treatment is presented in Figure 2. The age-specific survival rate (l_x) is the curve showing the overall survival without taking into account the periods. In the general view, it is seen that the aphids feeding on control and *T. harzianum*-applied plants maintained their vitality for a long time. It is observed that the survival rate of the population drops below 50% after the 48th day in control and after the 45th day in *T. Harzianum*..

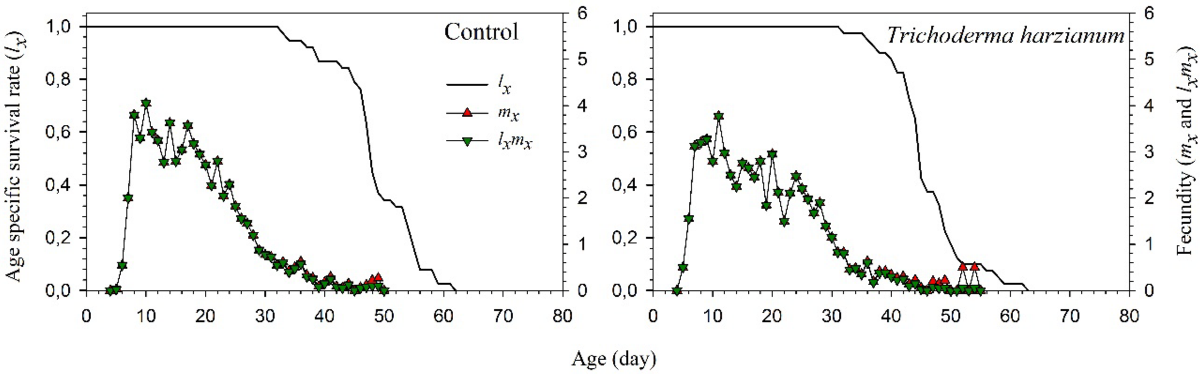

Figure 2. Age-specific survival rate (l_x), fecundity (m_x) and maternity (l_xm_x) of *Myzus persicae* feeding on *Trichoderma harzianum*-treated pepper plants.

Life Expectancy and Reproductive Value

Life expectancy graphs of plants whose roots were colonized by *T. harzianum* and *M. persicae* fed on control plants are given in Figure 3. The life expectancy graph (e_{xj}) shows the total time an individual aged x and in stage j is expected to live as a result of different applications. Accordingly, the longest expected lifespan was calculated as 48.97 days for aphids fed on control plants, while the expected lifespan for aphids fed on plants to which *T. harzianum* was applied to their roots was calculated as 46.20 days (Figure 3). Age-stage-specific reproductive value (v_{xj}) shows the future contribution of an individual at age x and in stage j to the growth of the population. It was observed that female individuals provided the greatest contribution to population growth for both groups. While the highest fecundity was observed in the *M. persicae* population feeding on the plants in the control group (13.29 at age 8 day), this value was determined to be lower in the plants whose roots were treated with *T. harzianum* (11.32 at age 7 day) (Figure 4)..

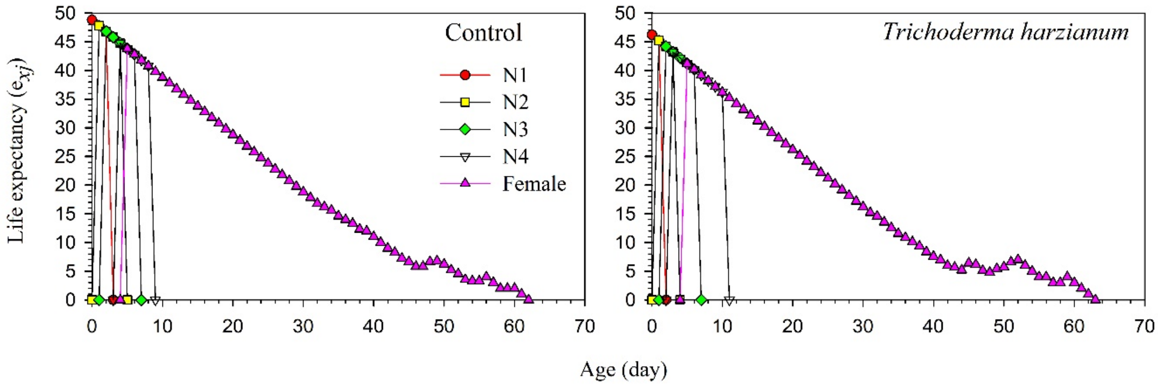

Figure 3. Age-stage life expectancy (e_{xj}) of *Myzus persicae* feeding on *Trichoderma harzianum*-treated pepper plants.

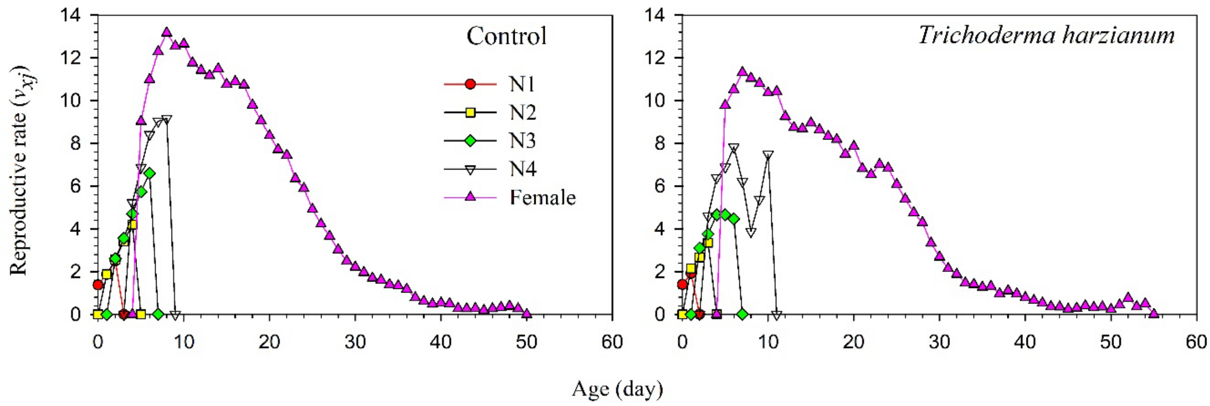

Figure 4. Age-stage specific reproductive value (v_{xj}) of *Myzus persicae* feeding on *Trichoderma harzianum*-treated pepper plants.

Life Table Parameters

Age-stage two-sex life table parameters of *M. persicae* on *T. harzianum* treatments and control are shown in Table 3. From the life table parameters, it was observed that the difference in the intrinsic rate of increase (*r*) between the populations fed on *T. harzianum*-treated plants and control plants was insignificant (P=0.09). Likewise, it was determined that the difference between the finite rate of increase (P=0.09) and net reproductive rates (P=0.45) of the populations was statistically insignificant. When the mean generation time was compared, it was determined that the aphids feeding on plants whose roots were colonized by *T. harzianum* had a shorter time than the aphids on the control plant and this difference was statistically significant (P=0.02). Although it was concluded that the time required for population doubling was shorter in *T. harzianum*-treated plants, this difference was not statistically significant.

Table 3. Life table parameters of *Myzus persicae* feeding on *Trichoderma harzianum*-treated pepper plants.

	Control		***T. harzianum***		
Life Table parameters	**N**	**Mean±SE***	**N**	**Mean±SE**	***P* value**
Intrinsic rate of increase r (d^{-1})	38	0.3148±0.006a	40	0.3304±0.007a	0.09
Finite rate of increase λ (d^{-1})	38	1.3701±0.008a	40	1.3916±0.01a	0.09
Net reproductive rate R_0 (offspring/individual)	38	68.26±2.34a	40	65.65±2.54a	0.45
Mean generation time T (d)	38	13.41±0.23a	40	12.66±0.23b	0.02
Doubling time DT (d)	38	2.20±0.04a	40	2.10±0.04a	0.09

*Values in each row followed by the same letter are not significantly different from each other at the 0.05 level, based on pairwise comparisons of group means conducted using the Cartesian product approach.

Population Projection of *M. persicae*

The estimated number of aphids feeding on plants with *T. harzianum* applied to their roots and on control plants at the end of 45 days is shown in Figure 5. Based on the analysis results for populations initially started with 10 first-stage nymphs, it was determined that the *T. harzianum* application would increase the aphid population on the plants to 10,699,166 individuals, while the total number of aphids on the control plants was estimated to be 4,933,017 (Table 4)..

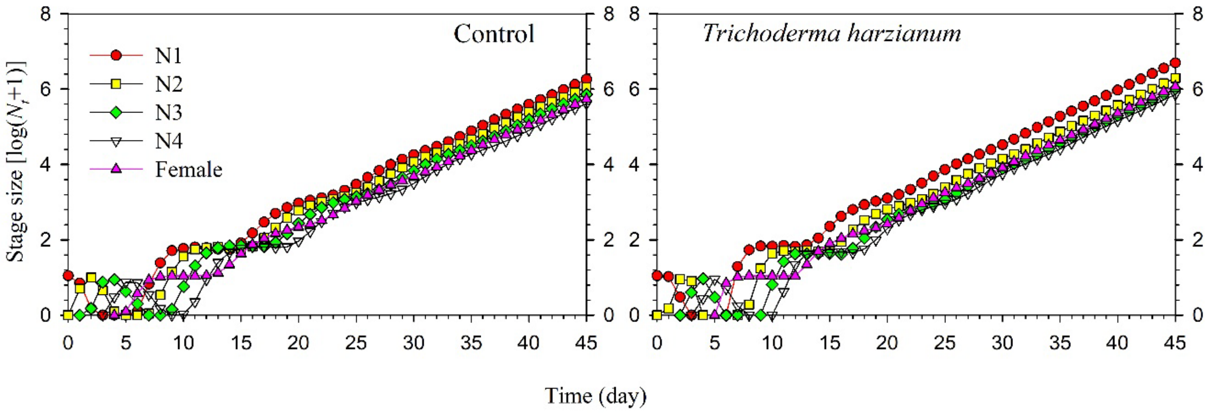

Figure 5. Population projection of *Myzus persicae* feeding on *Trichoderma harzianum*-treated pepper plants over a 45-day period.

Table 4. Population projection of *Myzus persicae* on *Trichoderma harzianum*-treated pepper plants: values at the 45th day

	Nymph I	Nymph II	Nymph III	Nymph IV	Female	Total
Control	1 959 145	1 186 324	764 712	440 908	581 928	4 933 236
T. harzianum	4 961 403	1 801 439	1 674 143	844 935	1 417 246	10 699 166

Discussion

Many soil-borne fungi belonging to the genus *Trichoderma* have played a remarkable role in agricultural production in recent years due to their versatile benefits such as promoting plant growth and activating plant defenses against abiotic and biotic stress factors (Battaglia et al., 2013; Contreras-Cornejo et al., 2024; López-Bucio et al., 2022). These fungi are known to strengthen plant structure and accelerate plant growth by increasing root development and biomass accumulation through mechanisms such as nutrient solubilization and modulation of phytohormone signaling (Contreras-Cornejo et al., 2024; López-Bucio et al., 2022). In addition to these, *Trichoderma* spp. are also known for their ability to systemically prime plant defenses and thereby increase resilience to a wide range of abiotic and biotic challenges, including disease and phytophagous insects (Battaglia et al., 2013; Contreras-Cornejo et al., 2018; Coppola et al., 2019; Alınç et al., 2021; Trotta et al., 2024; Dilmen, 2025). The effects of *Trichoderma* inoculation on phytophagous insects are not universally negative but can be variable, contrary to expectations (Battaglia et al., 2013; Contreras-Cornejo et al., 2018; Dilmen, 2025; Özgökçe et al., 2025a; 2025b). Both plant nutritional changes and the triggering of inducible defenses shape these outcomes, often working in opposition and thereby generating contradictory results (Hermosa et al., 2013).

According to the results obtained in this study, *T. harzianum*, as a biological agent, was found to have no suppressive role in the Demre F1 variety. No statistically significant differences were found between the *T. harzianum*-treated group and the control group for the most important life table parameters [the intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0), and doubling time (DT). Although statistically insignificant, these small differences in these parameters were found to be higher in the *T. harzianum*-treated group than in the control group. These small differences can lead to significant changes in population size in the long term. Even small differences in population growth rates that initially appear insignificant can have significant ecological effects over time due to their increasing effects with each generation (Carey, 1993). Therefore, caution should be exercised when interpreting small effect sizes, as they may still have significant ecological significance (Dilmen, 2025).

The only parameter that showed a statistically significant difference was the mean generation time (*T*) (*P*=0.02). The mean generation time was significantly shorter in the *T. harzianum*-treated group (12.66 days) compared to the control group (13.41 days). The shorter generation time means that aphids are progressing in their life cycle and are reproducing more rapidly. This is a surprising result, as an effective biological control agent is generally expected to prolong development time or reduce growth rates. This suggests that the effectiveness of *Trichoderma* is largely dependent on plant genotype, and these results are supported by data from other studies. Bataglia et al. (2013) reported that inoculation with *T. afroharzianum* T22 affected the behavior and population growth of the aphid and its endoparasitoid, and therefore, the use of this fungus should be discussed in terms of sustainable pest management strategies. They reported that *Aphis gossypii* fertility, population abundance, and aphid dispersal rate were statistically higher in *Trichoderma*-treated plants compared to the control group.

Özgökçe et al. (2025a) reported that life table parameters of *M. persicae* were statistically higher in the *T. harzianum*-treated Kapia İmbat F1 pepper cultivar compared to the control group. In another study, Özgökçe et al. (2025b) reported that *M. persicae* population parameters in *T. viride*-treated plants of four different pepper cultivars (Avşar, İmbat, Argeto, HT-70) were highly variable compared to the control group. For example, in the Avşar cultivar, the intrinsic rate of increase was significantly reduced in the *T. viride*-treated plants compared to the control group (0.322 day^{-1} vs. 0.372 day^{-1}), while in the İmbat cultivar, the intrinsic rate of increase was significantly increased (0.367 day^{-1} vs. 0.378 day^{-1}). This shift from a potential positive to a negative effect on aphid demography depending on the cultivar highlights the complex and unpredictable nature of these interactions.

Dilmen (2025) emphasized that *M. persicae* population parameters on *T. harzianum*-treated and *T. asperellum*-treated plants on the Mazomort F1 pepper variety were again variable. The results of this study showed that while there was no significant difference in the *T. harzianum*-treated plants compared to the control group among the important population parameters (0.377 day^{-1} vs. 0.386 day^{-1}), a significant difference was found in T. asperellum-treated plants (0.426 day^{-1}). These results suggest that *T. harzianum* slightly, though statistically insignificantly, reduces the aphid population, while the excessive increase in *T. asperellum* suggests that different species of the *Trichoderma* genus do not respond equally to the same plant variety. Kara (2025) applied *T. harzianum* and *T. viride* to the bell pepper cultivar Kasırga F1 and reported that both *Trichoderma* species caused reductions of varying degrees in the population size of *M. persicae*. The observation that different *Trichoderma* species produced distinct outcomes on the same pepper cultivar suggests that these fungi may likewise exert variable effects on different pepper types and cultivars.

Conclusion

The findings of this study demonstrate that the effects of *Trichoderma* spp. on the population dynamics of *Myzus persicae* are highly variable and strongly influenced by both the plant genotype and the fungal species involved. While *T. harzianum* inoculation did not suppress aphid populations on the Demre F1 pepper cultivar, it unexpectedly shortened the mean generation time, thereby accelerating population development. This result, together with evidence from previous studies, emphasizes that *Trichoderma*–plant–insect interactions are complex and cannot be generalized across cultivars or fungal species. Indeed, studies have shown both suppressive and enhancing effects of different *Trichoderma* strains on aphid demography, sometimes even within the same host plant variety. Such inconsistencies highlight the importance of carefully selecting microorganism–plant–insect combinations when considering *Trichoderma* spp. as components of integrated pest management (IPM) strategies. Future research should focus on unraveling the molecular and physiological mechanisms underlying these variable outcomes, particularly the trade-offs between improved plant nutrition and the activation of inducible defenses. Moreover, a better understanding of tritrophic interactions involving plants, beneficial microbes, and herbivorous insects is essential to determine under which ecological contexts *Trichoderma* spp. can serve as effective allies in sustainable pest management programs.

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Conflict of Interest

The authors declare no conflicts of interest.

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