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ORIGINAL ARTICLE

Evaluating of nano-silver and lavender (*Lavandula angustifolia* Mill) extract efficacy against *Tetranychus urticae* Koch (Acari: Tetranychidae)

Ayşe Yeşilayer[1] · **Sinem Dilibal**[1] · **Kadriye Özlem Saygı**[2]

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Abstract

The use of nanoparticles from plants associated with biopesticides is gaining an increasingly important in agriculture. *Tetranychus urticae* Koch (Acari: Tetranychidae) is an aggressive, invasive species that is harmful to park, forest, ornamental and many cultivated plants. In this study, silver nanoparticles (AgNPs) were synthesized using *Lavandula angustifolia* Mill water extract. The synthesized AgNPs was identified by Ultraviolet–Visible (UV–Vis) spectrophotometer, Fouirer Transform-Infrared Spectroscopy (FTIR), Scanning Electron Microscope, X-Ray Diffraction techniques. AgNPs exhibited a maximum UV–vis absorbance at 480 nm. Hydroxyl group was observed at 3262.97 cm^{-1}in FTIR spectrum. AgNPs were found to be spherical and less than 50 nm in diameter.The acaricidal effect *L. angustifolia* of ethanol extract and AgNPs was investigated using leaf dipping method. Experiments were carried out using (3 cm diameter) leaf disks of *Phaseolus vulgaris L.angustifolia* ethanol extract and silver nanoparticles (AgNP) were compared in 4 different concentrations. The acaricidal effect of ethanol extract was found as 95.46% and 62.24% at the concentration of 12% and 6% for 5 days respectively. AgNPs effect was observed as 98.82% at 336 ppm at the same period. All the extracts exhibited significant mite mortality as compared to control also, AgNPs were the most toxic, based on the LC50 and LC90 values, against the *T. urticae* compared to the other extracts tested. As a result, AgNPs used in this study are thought to be used as an alternative method to pesticides for control of *T. urticae*. However, the impact of these AgNPs effect on *T. urticae* should also be needed further studies.

Keywords Two spotted spider mites · Biyopesticide · Green sythesis · AgNPs · Lavander

Introduction

In recent times, the necessity for the development of alternative control methods has arisen due to the adverse effects of chemical control, including the presence of residues, environmental pollution and the development of resistance. Moreover, these chemicals have been demonstrated to have adverse effects on nontarget organisms, including natural enemies, honey bees, and wildlife (Akyazı et al. 2015). The development of resistance in pests following pest control is a significant issue. In the mean time development of resistance; variations in the population density of *T. urticae* among the studied host plant genotypes and varieties may be attributable to differences in nutritional quality, morphological traits, chemical composition also (Roozbahani et al. 2016). In a research study, Ashtari et al. (2025) have been examined the resistance mechanisms of several chitti beans genotypes to the two-spotted spider mite. Acording to the their findings are revealed that the Dadfar variety and the KS-31286 genotype exhibited antibiosis resistance mechanisms. The term "resistance" is used to describe a decrease in sensitivity to chemicals, except in cases where problems such as incorrect control of insect density, improper applications, and unsuitable environmental conditions have occurred (Ünal and Gürkan 2001).This phenomenon, referred to as insecticide resistance, entails the diminished sensitivity of a pest population to a pesticide due to prolonged and repeated exposure to the same pesticide

✉ Ayşe Yeşilayer
ayse.yesilayer@gop.edu.tr

Sinem Dilibal
sinem.dilibal@gop.edu.tr

Kadriye Özlem Saygı
kadriyeozlem.saygi@gop.edu.tr

[1] Agricultural Faculty, Department of Plant Protection, Tokat Gaziosmapaşa University, Tokat, Türkiye

[2] Faculty of Arts and Sciences, Department of Chemistry, Vocational School, Tokat Gaziosmanpasa University., Tokat, Türkiye

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(Çakır and Yamaner 2005; Demiröz and Tunca 2018). In other words, resistance can be defined as the emergence of resistant races against pesticides as a result of the repeated use of the same pesticide against a pest over an extended period of time (Öncüer and Durmuşoğlu 2008). This problem has been observed in many parts of the world, including our own country Türkiye. *T. urticae* (the two-spotted red spider) is the species that has developed resistance to the greatest number of active substances worldwide (Van Leeuwen et al. 2010). This species has developed resistance to a significant number of chemical agents used to control it. It has been designated the "resistance champion" (Dermauw et al. 2013). The feeding of plant sap by the pest results in the discoloration of leaves and the production of inferior quality products. Given that *T. urticae* has a relatively short life cycle, produces a large number of offspring, and reproduces by arrhenotokous means, it has been observed that they develop resistance at a rapid rate. A study (Whalon et al. 2008) identified *T. urticae* as the most resistant species in the world, demonstrating resistance to 92 different chemicals. The negative effects of chemical agents, the development and implementation of alternative control strategies have become increasingly imperative. The utilization of plant-based compounds as an alternative control method is witnessing a notable surge. The fact that plant extracts are already present in nature and are part of the natural cycle has led to an uptick in the deployment of these compounds for the management of agricultural pests (Yang et al. 2007; Tomczyk and Suszko 2011; Kök et al. 2016). In addition to plant extracts, metal nanoparticles have emerged as a promising alternative for pest control in vegetables, fruits, and crops in agriculture, following the advancements in nanotechnology over recent years. The research on the use of plant extracts and nanomaterials derived from them as biopesticides in pest control is increasing (Raut et al. 2010; Khan et al. 2012; Chrysargyris et al. 2016; Kasap and Kök 2009) It has been reported by many researchers that silver nanoparticles (AgNPs) have insecticidal, pesticidal, antimicrobial and antifungal properties (Xu et al. 2011; Ocsoy et al. 2013; Ali et al. 2015; Le Van et al. 2016; Ayoub et al. 2018; Kung et al. 2018). The objective of in this study was to investigate the acaricidal activity of ethanol extracts from lavender (*Lavandula angustifolia* Mill.) and silver nanoparticles (AgNP) obtained by green synthesis from lavender against the two-spotted spider mite *T. utricae*.

Materials and methods

The lavender (*Lavandula angustifolia* L.) plant was collected from Tokat Gaziosmanpaşa University- Tokat-Türkiye. The two-spotted spider mite species were obtained from the stock culture used in this study were origanated infested of castor bean-'(*Phasaolis vulgaris* L.) in the TOGU University -Tokat-Türkiye Entomology laboratory. Additionally, ethanol extracts of the *L. angustifolia* plant and silver nanoparticles (AgNp) were obtained by green synthesis in the Tokat Gaziosmanpaşa University- Tokat-Türkiye, Chemistry laboratory.

Collection of plants and preparation of extracts

According to (Breuer and Devkota 1990), the above-ground flowers of *Lavandula angustifolia* plants were laid on paper and allowed to dry in room conditions with minimal light and humidity, then the dried plant material was ground into small pieces in a mill. Three hundred milliliters of ethanol were added to 25 g of the ground plant material, which was then shaken on an orbital shaker at 120 rpm for 24 h. Subsequently, the solution was filtered through Whatman filter paper into sterile Erlenmeyers. The resulting extracts were dissolved with ethanol, and target concentrations (1.5%, 3%, 6%, and 12% v/v) were prepared for use in the experiment All of the extracts was stored in the refrigerator at + 4 °C for use in the experiments.

Preparation of silver nanoparticles (AgNP) from lavender water extract

AgNPs were taken 5 g of the powdered form of lavender, 100 ml of deionized water was added and placed in a 500 ml erlenmeyer. This mixture was heated in a heater with magnetic stirrer at approximately 70 °C for 30 min. The resulting water extract was filtered through Whatman filter paper and stored in the refrigerator at + 4 °C degrees for later use (Keratum et al. 2015; Kasmara et al. 2018). To obtain silver nanoparticles, a stock solution was prepared by dissolving 336 mg $AgNO_3$ in 1000 mL deionized water. 95 ml of this solution was taken and 5 ml of *L. angustifolia* aqueous extracts were added dropwise with a dropping funnel. The reaction was carried out in a magnetic stirrer at 50 °C for 2 h. The light yellow plant extract turned brown with the addition of silver nitrate solution. The brown silver solution was prepared for use in the experiments and characterization procedures. Then, the target doses (42, 84, 168 ppm) to be used in the experiment were prepared by diluting the stock solution 336 ppm dose obtained (Keratum et al. 2015; Asha et al. 2016; Kasmara et al. 2018).

Characterization of synthesized nanoparticles

Silver nanoparticles (AgNP) were prepared by adding silver nitrate solution to the plant extract cooled at room temperature. 20 ml of extract was added to 80 ml of silver nitrate solution. This process was carried out at room temperature 50 °C for 3 h on a magnetic stirrer. During this time, a distinct color change occurred from yellow to dark brown, which is explained by the formation of AgNP. The solution was subjected to centrifugation at 10,000 rpm for a period of 15 min in order to precipitate the AgNPs. The precipitated AgNPs were subjected to multiple washes with deionized water and subsequently dried. The characterization of the AgNPs obtained by green synthesis was conducted using appropriate spectroscopic analysis methods. The following techniques were employed: ultraviolet–visible region spectroscopy (UV–vis), Fourier transform infrared spectroscopy (FT-IR), transmission electron microscopy (TEM), scanning electron microscopy (SEM), and dynamic light scattering spectroscopy (DLS). Ultraviolet–visible (UV–vis) spectra were obtained using a Perkin Elmer Lamda 35 UV/VIS Spectrometer. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were conducted using a Tescan Mira3XMU FE-SEM and a Tescan Mira3XMU TEM, respectively. X-ray diffraction (XRD) analysis was performed using an Emprean Malvern Panalytical X'pert PRO diffractometer. FT-IR spectra were obtained using a Shimadzu FTIR 8400 spectrometer (Singh et al. 2014; Ahmed et al. 2016; Saygı and Çaçan 2021).

Bioassay

In the dipping method, separate applications were made for each concentration of both plant extracts and nanoparticulate plant extracts (Jalalizand et al. 2013). The leaves of the beans were cut into circles with a diameter of 3 cm and dipped for 5 s. 5–10 min after dipping, the dried leaves were placed in Petri dishes with a diameter of 6 cm in 2 pieces, and 1–2-day-old adult females were carefully transferred onto each disc. Only 70% ethanol was used in control experiments (Erdoğan et al. 2010; Jalalizand et al. 2013). The experiments were set up in five replicates including the control and each treatment was repeated twice. The same application was made to AgNP methanol extracts synthesized from lavender plants.

Statistical analysis

One-way analysis of variance (One-Way ANOVA) was applied to the data and means were compared at $p \leq 0.05$. Differences between means were grouped according to Tukey test. All statistical analyses were performed with MINITAB Release 14 (McKenzie and Goldman 2005). package program. Addionaly The LC50 and LC90 values were determined using Probit Analysis, following the methodology of Robertson et al. (2007), and processed with the POLO-PC software developed by LeOra Software (1987).

Results

Ethanol extracts (1.5%, 3%, 6% and 12%) obtained from lavender plants were applied against *T. urticae*, an important pest of the cultivated plant. In the study, the individuals that died on the 1st, 3rd, 5th, 7th and 9th days after the treatment were counted and the average mortality values (%) were recorded (Table 1).

While the mortality rate was 63.87% at the end of the 9th day counts at 1.5% concentration of lavender ethanol extract, it was determined as 81.07% and 99.92% after the application at 3% and 6% concentrations, respectively, and it was found to be statistically significant ($P < 0.05$).

Different concentrations of AgNPs prepared with 12%, the most effective concentration of *Lavandula angustifolia* plant and obtained by green synthesis, were prepared and applied by dipping method as in the ethanol extract of lavender plant. For this purpose, the target concentrations determined against *T.urticae* females and taken from the stock culture; 42 ppm, 84 ppm, 168 ppm and 336 ppm were used. The data obtained were recorded (Table 2).

In the study, while the average mortality rate was 86.45% at the end of the 9th day at the lowest concentration of 42 ppm, it was recorded to be 96.47% and 100% effective at 84 ppm and 168 ppm, respectively. At the maximum concentration in the application, 98.03% mortality was detected on the 7th day and 100% mortality on the 9th day. At 168 ppm, 44.99% mortality was detected on the 3rd day and 79.46%

Table 1 Acaricidal effect of lavender ethanol extract on *Tetranychus urticae* by dipping method

% Dead ± SE*					
Concentration %	1 day	3 day	5 day	7 day	9 day
1.5	0.16 ± 0.46 cd	11.61 ± 0.14d	23.57 ± 0.14c	47.46 ± 0.18d	63.87 ± 0.16c
3	3.25 ± 0.48bc	23.50 ± 0.20c	50.58 ± 0.35b	69,12 ± 0.50c	81.07 ± 0.35b
6	9.04 ± 1.08b	39.84 ± 0.20b	62.24 ± 0.53b	80.38 ± 0.25b	99.92 ± 0.22a
12	28.43 ± 0.20a	68.85 ± 0.20a	95.46 ± 0.75a	100.00 ± 0.00a	100.00 ± 0.00a
Control	0.00 ± 0.00d	5.31 ± 0.99d	18.42 ± 0.58c	25.60 ± 0.50e	33.81 ± 0.63d

*There is a statistical difference between different lowercase letters following the same column (Tukey test, $p < 0.05$)

Table 2 Acaricidal effect of silver nanoparticles (AgNPs) at different concentrations on *Tetranychus urticae* by dipping method

Dead % ± SE*					
Concentration ppm	1 day	3 day	5 day	7 day	9 day
42	7.10 ± 1.01c	25.63 ± 0.48c	49.37 ± 0.35c	69.76 ± 0.38d	86.45 ± 1.03c
84	11.77 ± 0.05b	32.40 ± 0.11c	60.01 ± 0.03c	83.19 ± 0.04c	96.47 ± 8.10b
168	15.50 ± 0.07b	44.99 ± 0.05b	79.46 ± 0.06b	98.03 ± 0.48b	100.00 ± 0.00a
336	30.69 ± 0.05a	75.93 ± 0.18a	98.82 ± 0.82a	100.00 ± 0.00a	100.00 ± 0.00a
Control	0.00 ± 0.00d	3.69 ± 0.56d	13.67 ± 0.04d	20.48 ± 0.10e	29.92 ± 0.09d

*There is a statistical difference between different lowercase letters following the same column (Tukey test, $p < 0.05$)

Table 3 Acaricidal effect of silver nanoparticles (AgNP) and ethanol extract on *Tetranychus urticae* on day 1 and day 9

Silver nanoparticles (AgNp) extract			Ethanol extract		
Concentration ppm	1 day	9 day	Concentration %	1 day	9 day
42	7.10 ± 1.01c	86.45 ± 1.03c	1.5	0.16 ± 0.46 cd	63.87 ± 0.16c
84	11.77 ± 0.05b	96.47 ± 8.10b	3	3.25 ± 0.48bc	81.07 ± 0.35b
168	15.50 ± 0.07b	100.00 ± 0.00a	6	9.04 ± 1.08b	99.92 ± 0.22a
336	30.69 ± 0.05a	100.00 ± 0.00a	12	28.43 ± 0.20a	100.00 ± 0.00a
Control	0.00 ± 0.00d	29.92 ± 0.09d	Control	0.00 ± 0.00d	33.81 ± 0.63d

*There is a statistical difference between different lowercase letters following the same column (Tukey test, $p < 0.05$)

Table 4 LC_{50} and LC_{90} values for extract of Lavender against *Tetranychus urticae*

Day	LC_{50}(95%CI)	LC_{90}(95%CI)	Slope ± SE	χ2	Heterogenity
5d	05.24–09.47	50.47–627.31	01.12 ± 00.18	07.57	0.24
7d	02.67–04.87	37.36–505.19	00.93 ± 0.17	08.87	0.32
9d	00.54–01.41	07.23–17.33	1.28 ± 0.20	11.92	0.8

*χ2, calculated chi-square value; and CI, confidence interval

Table 5 LC50 and LC90 values for silver nanoparticles (AgNPs) of Lavender against *Tetranychus urticae*

Day	LC50 (95%CI)	LC 90 (95%CI)	Slope ± SE	χ2*	Heterogenity
5d	47.07–85.35	570.25–3199.89	02.45 ± 0.18	11.46	0.38
7d	15.33–39.78	187.33–418.19	02.39 ± 0.29	18.62	0.62
9d	4.74–23.77	91.63–168.60	03.45 ± 0.46	20.48	0.68

*χ2, calculated chi-square value; and CI, confidence interval

mortality on the 5th day, but there was no statistical difference, while 100% mortality was observed on the 9th day of the same dose.

In the experiment, plant-ethanol and AgNPs extracts applied by dipping method were found to be effective against red spider mite on the 1st and 9th day after both applications (Table 3).

The experimental results demonstrated, the highest effect after 7 and 9 d, based on LC50 and LC90, were with Lavandula ethanol extract and silver nano particles with *T. urticae* adults, respectively (Tables 4 and 5). These results showed that the acaricidal activities increased with increasing dose and depending on exposure time. In accordance with the findings of Salman et al. (2013), the efficacy of the extracts on adults *T. urticae* was positively correlated with both the duration of the observation period and the concentration. Morover as shown these tables for dipping method LC50 and LC90 values of ethanol extracts were obtained lower than silver nanoparticles (AgNPs) extracs on adult stages.

Synthesis and characterization of silver nanoparticles (AgNPs)

AgNPs were synthesized from lavender plant extracts and plant extracts during the study. Structural analysis of the obtained AgNPs was first performed using UV–Vis spectroscopy. Considering UV–Vis, the band seen in the 450–480 nm range, where Ag (I) cations are reduced to neutral Ag (0) species, was determined in the specific range for AgNPs in solution (Korkmaz et al. 2020; Saygı 2021). When the same process was repeated for the water extract of the plant, no band was observed. This comparison is given in detail in Fig. 1.

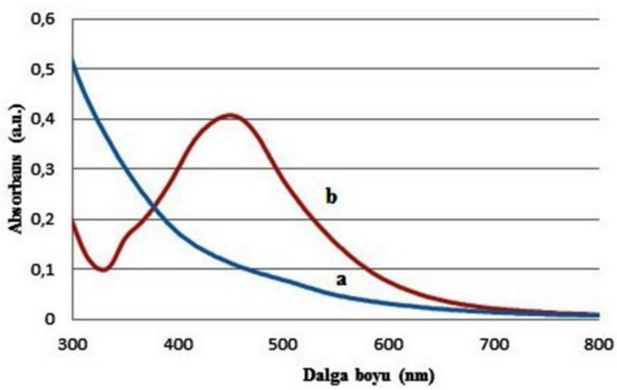

Fig. 1 UV–vis spectra of water extract (**a**) and synthesized AgNPs (**b**)

Considering the previous studies on this subject, when plant extract is added to AgNO3 solution, the vibrational movements of AgNPs in the solution according to the principle of surface plasmon resonance with the increase in concentration over time can be detected qualitatively by taking a color from yellow to brown. According to surface plasmon resonance; this color change is a physical phenomenon that occurs due to the vibrational movements occurring on the metal surface during the reflection of plane polarized light hitting a metal surface. During our studies, the plant extract, which was initially yellow in color, changed color from yellow to brown with the addition of AgNO3 solution (Zargar et al. 2011; Awwad et al. 2013). AgNPs obtained by green synthesis were analyzed in the wavelength range 250–800 nm with a resolution of 1 nm between 0 and 2 min. AgNPs have strong absorption in the 400–500 nm range due to surface plasmon resonance (SPR) (Fig. 1).

The surface morphology of the particles was realized using scanning electron microscopy. STEM images of the prepared AgNPs show that they have a very smooth surface morphology. STEM images of AgNPs were taken by applying voltage in the range of 200 kV-300 kV. In the study, STEM analyzes of AgNPs obtained from lavender plants were also performed and it is thought that the nanoparticles obtained from plants such as thyme and mint are dense and therefore phenols or phenolics are high in terms of chemical content and are thought to have a significant effect on pest control (Ayyıldız and Karaca 2018; Kasap and Kök 2009).

Figure 2 shows that AgNPs have a specific morphological shape 'spherical' and are not aggregated. Their average size was found to be less than 50 nm. FTIR analysis was used to identify the biomolecules responsible for the reduction and effective stabilization of Ag(I) cations in AgNO3 solution to the neutral Ag(0) species. Trace amounts of samples were taken and spectra were performed at room temperature.

AgNPs are surrounded by these bio-molecules, reducing the potential of metal particles to come together and form clusters and increasing their stability in solution. The peak at 3262.97 cm-1 in the water extract obtained from Lavender plant rich in secondary metabolites shows the presence of -OH and -NH (amine and polyphenols) groups. Similarly, 2923.56 cm-1 indicates -CH and -CH2 aliphatic groups, 1590.02 cm-1 C = C groups, 1026.91 cm-1 C-O carbohydrate groups.

The crystal structure of the obtained silver nanoparticles was analyzed by X-ray diffraction (XRD) method. The analysis was performed using CuKα radiation and measurements

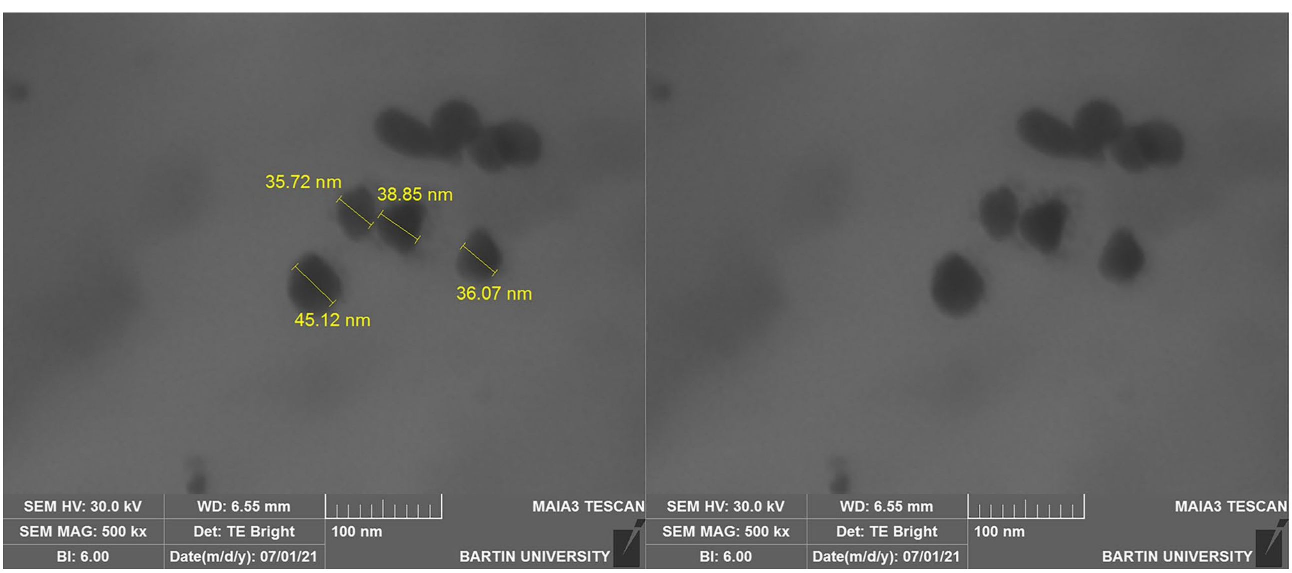

Fig. 2 STEM analysis results of AgNPs

were taken in the range of 2Θ angle 1–60. X-ray diffraction pattern of silver nanoparticles synthesized using plant extract is given in Figs. 3 and 4 Accordingly, characteristic peaks (2θ = 38.04 (111), 44.17 (200), 64.43 (200) and 77.35 (311)) were observed in the XRD pattern of AgNPs (Jayaseelan and Rahuman 2011).

The elemental composition of the synthesized nanoparticles is also determined by EDS analysis. While working with EDS, many regions were scanned and the region where the nanoparticles obtained could be the best was analyzed. Strong signals in the silver region (~3 keV) during the analysis is another indication that silver nanoparticles are formed (Fig. 5). Other weak elemental peaks are due to the functional groups of the plant.

Discussion

In our study, conducted under laboratory conditions in Tokat-Türkiye Province, the acaricidal effect of ethanol extract and silver nanoparticles (AgNPs) obtained from lavender plant against *T.urticae* was determined. It was

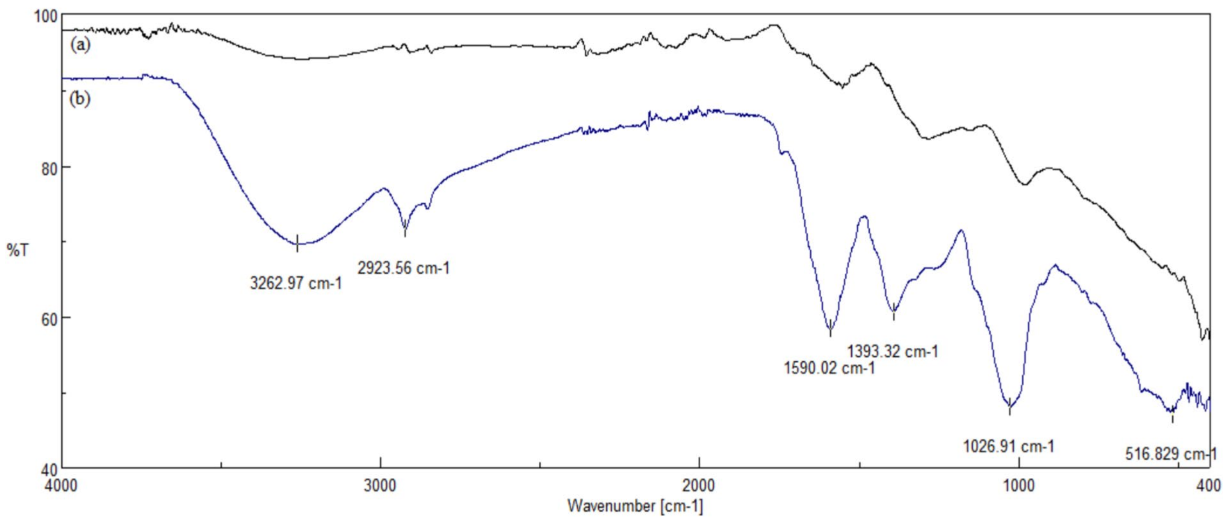

Fig. 3 FTIR spectra of **a** AgNPs **b** water extract

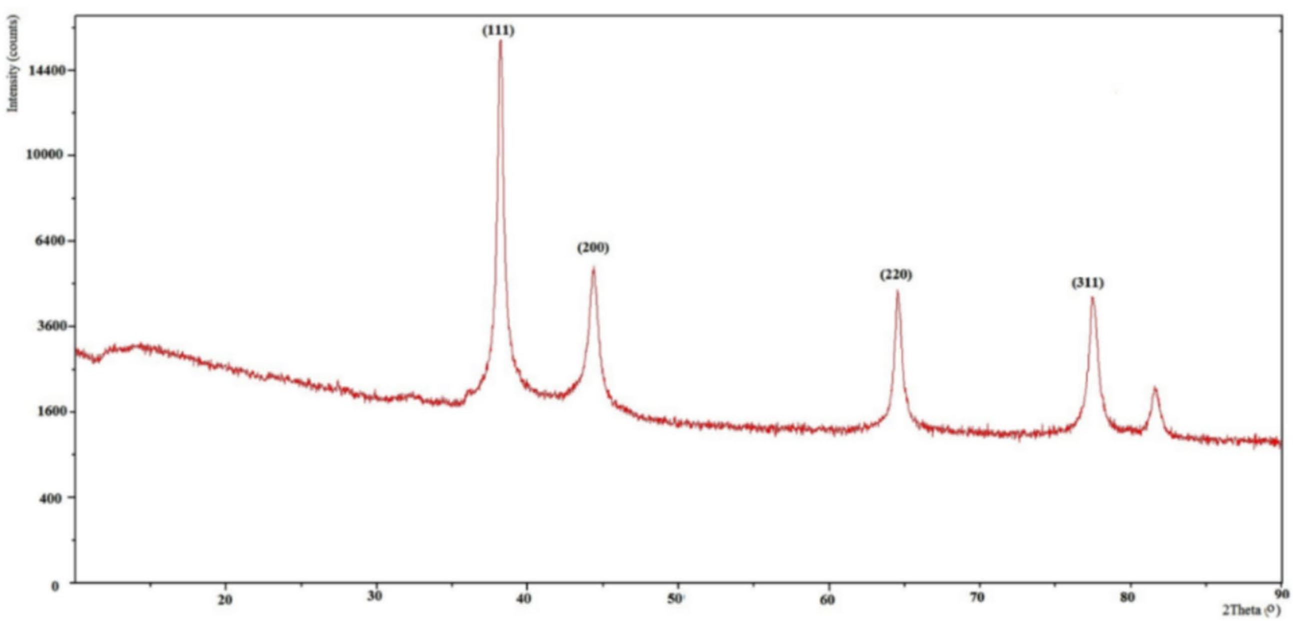

Fig. 4 XRD diffraction pattern of silver nanoparticles prepared by green synthesis

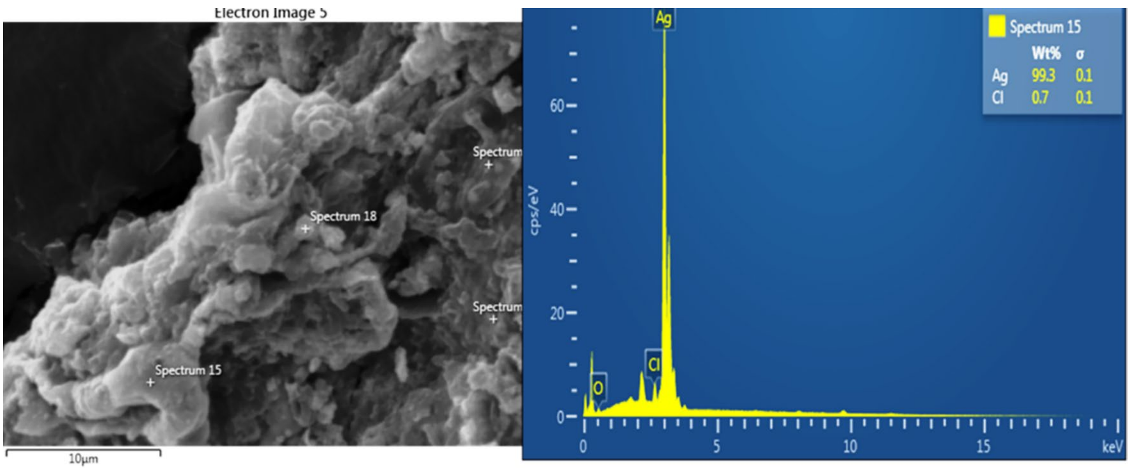

Fig. 5 EDS analysis of silver nanoparticles obtained by green synthesis

observed that the acaricidal activity of lavender with silver nanoparticles obtained from lavender plant was higher than ethanol extract.

Acaricidal activity was observed after counting on the 1st, 3rd, 5th and 9th days of the study. On the 7th day, 100% mortality was detected at 12% concentration of lavender ethanol extract applied to adult female individuals by dipping method. Erdoğan et al. (2010) revealed that in similar concentration (12%) of ethanol extract obtained from *Capsicum annuum* (hot pepper) caused 95.46% mortality in adults. Almansour and Akbar (2012) found that the lethal effect of *Nicotiana tabacum* L. and *Pegunum harmala* L. aqueous plant extracts against *T. urticae* caused 82% mortality at the highest dose (100%). In our study, 80.38% mortality rate was observed at 6% dose at the end of the 7th day. Similarly, Yeşilayer and Deniz (2019) found that Lavender plant extract can cause 62% mortality at a concentration of 5% ml/L on day 7 against the pre-adult stages of *P. operculella*, an important quarantine pest. Another with nanoparticles study on the *P. operculella* the highest mortality rate for *P. operculella* larvae was observed to be 69.04% with the only application of nanosilver extract, compared to a mortality rate of 67.69% with the only application of *Lantana* spp. Extract (Gülsoy and Yeşilayer 2018). In the acaricidal efficacy trial, it was observed that there was an increase in dose and time-dependent mortality rates of mites in both applications as the concentration increased from low to high. In the study conducted by Tomczyk and Suszko (2011) with red spider, it was stated that the increase in mortality rate was parallel due to the high concentration of phenolic compounds in high concentration plant extracts. It is thought that the increase in mite mortality may be due to the higher concentration of phenolics in higher concentrations. Yorulmaz et al. (2014) determined the highest mortality rates in nymph and adult stages of *T. urticae* in 4 different concentrations (1%, 3%, 6% and 12%) of extracts obtained from sage and rosemary at 12% dose of both rosemary and sage extracts. In the other application of the study, the acaricidal effect of silver AgNPs obtained from *L. angustifolia* on two-spot red spider by dipping method, 98.82% mortality occurred at the maximum concentration of 336 ppm. Similarly, Abd El-Raheem and Eldafrawy (2016) found that AgNPs killed 100% of *Blattella germanica* (L.) (Dictyoptera: Blattellidae) at a concentration of 300 ppm after 72 h. In another study, Jalalizand et al. (2013), They found that the mortality rate at the maximum concentration was 90% against *T. urticae* using leaf dip method at different concentrations on adult mites. Al-Azzazy et al. (2019), who showed similar results, examined the mortality effect of four different silver concentrations (53.94, 107.88, 161.82 and 215.7 ppm) against mites. In the treatment, On the 5th day of extract application, 23.57% mortality was observed at the lowest concentration (1.5%), while 47.49% mortality was observed at the lowest concentration of AgNP (42 ppm).

In lavanduda ethanol extracts and AgNPs bioassays, the LC50-LC90 were (95%CI) (47.07–85.35)- (570.25–3199.89) and (05.24–09.47)-(50.47–627.31), respectively, determined 5d h after treatment. Similarly, after 7 d and 9d, a significant increase was recorded in these lethal concentrations.

these toxic effects depended on the concentration (Lavandula ethanol extract $X^2 = 20.48$ $p < 0.01$; AgNPs $X^2 = 123$, $p < 0.01$).

In our study, different analyzes were also performed for the characterization studies of nanoparticles obtained from lavender by green synthesis. The biggest feature that makes the produced nanomaterials different from other macro-sized materials is the high surface area / volume ratio. Thus, some of the properties of the material itself are changed and new properties are gained (Genç et al. 2021). Various spectroscopic methods are used in metal nanoparticle analysis and characterization. UV–visible spectroscopy (UV–visible spectroscopy) is a simple and useful method that can measure the concentration of AgNPs according to the Lambert–Beer law and is a technique used to measure the light scattered and absorbed by a sample. FTIR analysis has been used to identify biomolecules responsible for the reduction and effective stabilization of the synthesized silver nanoparticles (Korkmaz et al. 2020). X-ray diffraction (XRD) provides information about the crystal structure of the synthesized AgNPs. The most widely used technique for visualization and characterization of AgNPs is electron scanning microscopy (SEM). Depending on this technique, properties such as aggregation, dispersion, size, structure and shape can be observed as well as visualization at nanometer resolution. Energy dispersive X-ray spectroscopy (EDS) is used for elemental analysis.

When combined with TEM (transmission electron microscopy), they provide information about the elemental composition of the sample (Pang et al. 2010). In the study, the crystal structure of the nanoparticles was investigated using X-ray diffraction (XRD). The analysis was performed using CuKα radiation and measurements were taken in the range of 2Θ angle 1–60. The X-ray diffraction pattern of silver nanoparticles synthesized using plant extract is given in Fig. 4. Accordingly, characteristic peaks ($2\theta = 38.04$ (111), 44.17 (200), 64.43 (200) and 77.35 (311)) were observed in the XRD pattern of AgNPs. When the nanoparticles are amorphous, no diffraction peak can be observed and the appearance of broad peaks indicates that nanosized particles are formed. Similarly, Jayaseelan and Rahuman (2011) observed peaks at $2\theta = 27.71°$, 32.16°, 38.08°, 46.15°, 54.70° and 57.35°. The results reported by many researchers are similar. The XRD diffraction patterns of AgNPs synthesized by Saygı and Çaçan (2021) from water extract of linden flower and Saygı and Usta (2021) from waste rosehip seeds were found to be compatible with the presented study. In addition, no impurity peak was observed (Fig. 1). TEM is another technique used to characterize the morphology of nanoparticles through direct imaging. This method is based on electron microscopy and provides several benefits for morphological and size analysis; however, it is also associated with several drawbacks, such as the ability to provide limited information on size distribution and true dispersion averaging (Dam et al. 2017). The instrument has an electron gun, vacuum system and condenser lenses. TEM produces three types of images; external X-ray maps, backscattered electron images and secondary electron images (Gupta et al. 2013). For SEM analysis, the nanoparticle solution is dried into a powder, mounted on a sample holder and coated with a conductive metal such as gold, gold/palladium alloy, platinum, osmium, iridium and chromium using a sputter coater (Suzuki 2002). After this process, a beam of high-energy electrons is directed at the sample to produce various signals on the surface of the samples (Jones et al. 2004). The signals from the sample exposed to the electron beam are recorded by the detector, which provides information about the samples, including the external morphology, crystal structure and the chemical composition and orientation of the materials in the sample Accordingly, it is shown in Fig. 2 that L-AgNPs were synthesized in a uniform spherical shape without aggregates and their average diameter size was less than 50 nm. In our study, SEM analysis of AgNPs obtained from lavender showed a strong absorption peak in the range of 400–500 nm in UV–vis. The observation of an absorption band around 450 nm after a period of time when silver nitrate was added to the water extract of the plant (40–50 min at room temperature) from a very light yellow color to brown confirms the production of these nanoparticles (Fig. 1.) For the structure analysis of the obtained nanoparticles, UV–vis spectra were applied and the spectra were evaluated. As can be seen in Fig. 1, the broad band observed in the 400–500 nm range is characteristic for silver nanoparticles in colloid structure in solution. In the analysis of aqueous extract of lavender plant, no distinct band formation was observed in this region. Accordingly, it was determined that Ag(I) cations were reduced to neutral Ag(0) species and the targeted AgNPs were formed. Similarly, Some et al. (2019) reported that green synthesized AgNPs from *Morus indica* L. exhibited a maximum UV–vis absorbance of 460 nm. In another study, Jayaseelan and Rahuman (2011) reported that AgNPs synthesized from Ocimum canum exhibited a UV–vis absorbance of 426 nm. Zahir and Rahuman, (2012) synthesized AgNPs from Euphorbia prostrata plant exhibited absorbance at 420 nm. As shown in Fig. 4.2, the spectra of the water extract of the plant and the synthesized silver nanoparticles were compared.

Fourier Transform Infrared Spectroscopy (FT-IR) proved that $AgNO_3$ was reduced due to the presence of -OH group in silver nanoparticles as shown in Fig. 3. According to the results of this analysis, the amine groups bind strongly to the metal nanoparticles, preventing aggregation and making the medium more stable. In the EDS analysis of silver nanoparticles obtained by green synthesis from various plant extracts in the literature, there are peaks associated with strong signals (~ 3 keV) (Hemmati et al. 2019). Based on this analysis, the amount of silver in the particles is 99.3.

Due to the excessive use of pesticides in our country, the residue in products poses a significant risk to the environment and human health. Nowadays, in order to create alternative control methods to classical control methods, the use of extracts prepared from plants that exist in nature has gained importance in pest control (Ertürk 2006). In previous studies, it is known that many plants have insecticidal effects (Karakaş, 2018). Since phytochemicals in plant extracts are of biological origin, they do not cause water or soil pollution and thus do not form residues harmful to human health

(Topuz and Madanlar 2006). Plant extracts slow down and stop the resistance development of pests and diseases compared to chemicals (Tolga 2010).

Conclusion

In our study, we investigated the efficacy of lavender extract and nanosized particles against *T. urticae*, which is a problem in many plants under cover and in the open field in Türkiye and causes economic losses and it was determined that both plant extracts and nanoparticulate extracts were effective in pest control. As a result of the study, it is thought that nanosilver particles obtained by green synthesis will make important contributions to the control of pests other than red spiders. The widespread development of such studies is very important for both the world and our country. Increasing green synthesis for synthesizing silver nanoparticles is a reliable method for biotechnological research. Plants provide a better working area for synthesizing nanoparticles without being toxic.

In the one-step mechanism of obtaining silver nanoparticles by green synthesis as in this study, these phenolic compounds are responsible for the reduction of Ag (I) ions in silver nitrate solution to Ag(0). While obtaining silver nanoparticles by physical and chemical methods is time-consuming, expensive and laborious, green synthesis is fast, cheap and easy. It is thought that this study will shed light on future biopesticide studies in terms of both laboratory and field studies.

Author contributions For research articles with several authors, a short paragraph specifying their individual contributions A.Y. conceived of the presented idea. A.Y. developed the theory and performed the computations. A.Y. and K. S. verified the analytical methods. A.Y. and K. S. encouraged S.B. to investigate [a specific aspect] and supervised the findings of this work. All authors discussed the results and contributed to the final manuscript. S.B. carried out the experiment. A.Y. wrote the manuscript. Both A.Y., K. S. and S. B.C. authors contributed to the final version of the manuscript. A. Y. supervised the project.

Declarations

Conflicts of interest The authors declare no conflicts of interest.

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