The Effect of Lantana camara L. extract and Nano-silver extract of Lantana against Potato Tuber Moth [Phthorimaea operculella (Zeller)]

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Abstract

The widespread use of chemical pesticides has resulted in significant ecological disturbances and adverse effects on non-target organisms globally. In response, nanotechnology has emerged as a promising component of environmentally sustainable pest management strategies, fostering the development of innovative, natural, and safe biopesticides. This study investigates the insecticidal efficacy of ethanol and nano-silver extracts derived from the medicinal plant *Lantana camara* L. against the eggs and larvae of the Potato Tuber Moth (*Phthorimaea operculella* [Zeller]), a critical quarantine pest threatening potato production in Turkey. *The toxicological effects of silver nanoparticles (AgNPs) extracts derived from L. camara were assessed based on the lethal concentration required to achieve 50% mortality (LC_{50}) in third instar larvae and 1-day-old eggs of P. operculella. The LC50–LC90 range was established as 6.56–54.72 for ethanol-based extracts and 1.45–6.59 for AgNp-based extracts. Maximum egg-hatching inhibition was recorded at a 12% ethanol extract concentration (76.5%) and 200 ppm AgNPs treatment (94.9%). The bioassay results indicated that silver nanoparticles formulations of L. camara were significantly more effective than ethanol extracts in controlling both larvae and eggs of the Potato Tuber Moth. Furthermore, treated potato tubers exhibited a marked reduction in adult moth emergence compared to the untreated control*

Introduction

Phthorimaea operculella-Zeller (Lepidoptera:Gelechiidae)-Potato Tuber Moth (PTM) commonly known as the Potato Tuber Moth (PTM), is regarded as one of the most destructive pests affecting potato crops in warm climate regions, leading to substantial economic losses on a global scale. While it infests various host plants within the Solanaceae family, it exhibits a marked preference for potato. The larvae feed on the mesophyll tissue, creating blotch mines within the leaves. Over time, the initially translucent mined areas become necrotic, turning brown and desiccated (Anonymous, 2013; 2020). The larvae occasionally burrow into the petiole and extend their feeding activity into the stem, often penetrating near the buds and excavating shallow galleries beneath the tuber skin. Biopesticides have emerged as effective alternatives to synthetic chemical pesticides in the management of a wide range of agricultural pests. These sustainable, biologically derived, and environmentally benign pest control agents offer numerous advantages over conventional pesticides, including improved soil fertility, reduced environmental contamination, and enhanced safety for non-target organisms and human health.

Nanotechnological formulations offer a significant advantage in pest management by enabling targeted delivery, enhancing biodegradability, and sustaining effective concentrations over extended periods, thereby minimizing the required chemical dosages (Sabbour, 2013, 2015; Sabbour et al., 2015; Rikta & Rajiv, 2021). *Lantana camara*, a species native to South America, demonstrates considerable potential as a biopesticidal agent. In Turkey, it is commonly cultivated as an ornamental plant, particularly in the Mediterranean, Marmara, and Aegean regions (Akkemik, 2014). In addition to its use as an ornamental and medicinal plant, Lantana camara L. has demonstrated insecticidal properties attributed to its phytochemical constituents, particularly the flavonoid compounds Lantaden A and B (Sharma et al.,

1992; Babu et al., 1994; Ghisalberti, 2000). Similar to *L. camara*, various other plant extracts have been recognized for their ovicidal, repellent, and insecticidal activities (Isman, 2006; Devi & Devi, 2011). Beyond botanical formulations, nanotechnology has increasingly been integrated across diverse sectors —including textiles, food, healthcare, and agriculture—due to its potential for precision delivery and enhanced efficacy. Recent research has increasingly focused on the integration of metallic nanoparticles —such as nano-silver and nano-zinc—with plant-derived extracts for pest control applications. These synergistic formulations have demonstrated promising potential in pest management strategies. Biopesticides developed through green synthesis by combining plant extracts with nanoparticles (NPs) have been effectively utilized for the control of storage pests, including *P. operculella*, as well as other agricultural pests. These formulations offer an environmentally sustainable, cost-effective, and non-toxic alternative to conventional chemical pesticides (Duncan, 2011). Previous studies have demonstrated the efficacy of nanoparticles in pest control. Pandey et al. (2012) reported a 70% mortality rate in *Sitophilus oryzae* following nanoparticle exposure. Similarly, Rouhani et al. (2012) observed 83% toxicity of nano-silver treatments against *Callosobruchus maculatus* larvae. Furthermore, the nanoparticle-induced inhibition of feeding, oviposition, egg hatching, as well as their repellent and fumigant properties, have also been documented by Muhammed (2013), highlighting the multifaceted pest management potential of nanomaterials.

The current study aimed to evaluate the larvicidal efficacy and egg-hatching inhibition potential of ethanol and green-synthesized silver nanoparticles (AgNPs) derived from *Lantana camara* L. against the immature developmental stages of the Potato Tuber Moth (*Phthorimaea operculella*).

Experimental Design and Treatments

Plant Material and Insect Culture

The immature developmental stages (larvae and eggs) of *Phthorimaea operculella* (PTM) were utilized in this study. Potato tubers, serving as a nutritional medium for the insects, were procured from cultivation plots within the research fields of Tokat Gaziosmanpaşa University. Leaves of *Lantana camara* L. were collected during

June and July from the provinces of Yalova and Mersin. The collected plant material was transported to the Entomology Laboratory, where it was dried under controlled laboratory conditions. Adult male and female specimens of *P. operculella* were placed in 1-liter plastic containers, with honey supplied as a nutritional source. The container lids were removed, and sterile blotting paper was positioned over the openings, secured with muslin cloth to permit ventilation while preventing escape. Oviposition by adult females occurred on the sterile paper surface. The *P. operculella* culture was maintained under controlled laboratory conditions 23 ± 2°C, 65 ± 2% relative humidity, and a photoperiod of 12:12 h light:dark.

Extract Preparation and Toxicity of Lantana Plant Extract

Dried Lantana plant material was ground into a fine powder, and 20 grams of the ground sample were extracted with 100 mL of ethanol (w/v). The mixture was agitated on a rotary shaker at 200 rpm for 24 hours. Following extraction, the solution was filtered through sterile filter paper, and the filtrate was allowed to stabilize at room temperature. The resulting stock solution was subsequently diluted with ethanol to obtain the desired concentrations of 3%, 6%, 9%, and 12% (w/mL). Ethanol alone was used as the control treatment (Zamin et al., 2014).

Nano-silver-AgNOPs Green Synthesis

The green synthesis of silver nanoparticles (AgNPs) was carried out using a 6% concentration of *L. camara* extract, previously determined to induce over 50% larval mortality in bioefficacy assays. For the synthesis of 1 mM (168 ppm) AgNPs, 0.02 g of commercially sourced silver nitrate ($AgNO_3$; Nano-Kar) was dissolved in 100 mL of deionized water (w/mL). The Lantana extract was then added to the silver nitrate solution. The mixture was incubated at 30°C for 30 minutes, during which a visible color change from yellow to brown indicated the formation of silver nanoparticles (Fig. 1) (Soni & Prakash, 2014). For this synthesized solution, experimental concentrations were prepared: 0 ppm (control), 50 ppm, 100 ppm, 150 ppm and 200 ppm (Saware et al., 2014; Oluwaniyi et al., 2015, Nartop, 2017).

Toxicity Assay on Larvae

The larvicidal activity of the plant extract was assessed using 3–4-day-old larvae PTM. Potato tubers of uniform weight were immersed in extract solutions of varying concentrations for 3 to 5 seconds. Subsequently, the treated tubers were air-dried at room temperature for 15 to 20 minutes prior to larval exposure (Prijiono & Hassan, 1993). Dried potato tubers were placed into plastic containers measuring 5 cm in height and 11 cm in diameter. 10 larvae were carefully transferred onto each tuber using forceps. The containers were appropriately labeled and covered with transparent tulle to ensure aeration while preventing larval escape (Oroumchi & Lorra, 1993). The number of live and dead larvae was recorded daily, and observations continued until the larvae progressed to pupal and adult stages. The experimental design included five replications including control and was conducted in two independent trials.

In the other part of the study; In this assay, the dipping-slide method—previously employed for ethanol extract treatments—was utilized to assess the larvicidal effects of green-synthesized silver nanoparticles (AgNPs) derived from *L. camara*. A stock solution of AgNPs at 200 ppm (v/v) was prepared and subsequently diluted to achieve the target concentrations for testing (Munir & Muhammad 2005; Moslemi et al.2011; Sallam et al. 2009). The experiments were arranged in four replications, with ten larvae used per replicate. Control groups received no treatment. Larval mortality was recorded daily, and

observations continued until the seventh day post-treatment. Each treatment was conducted in twice independent repetitions to ensure statistical robustness.

Egg-Hatching Assay; Inhibition with Lantana Extracts

The egg-hatching inhibition effect of plant extracts was evaluated using the dipping-slide method. Filter paper segments containing recently laid or one-day-old PTM eggs, previously used as oviposition substrates, were sectioned into groups containing twenty eggs each. These paper segments were briefly immersed in the prepared extract concentrations, air-dried, and subsequently transferred into sterile Petri dishes with a diameter of 90 mm. Each dish was carefully sealed to maintain consistent conditions throughout the experiment (Oroumchi & Lorra, 1993). Each treatment was conducted with fiver replicates, containing twenty eggs per replicate. Observations were carried out daily until the seventh day, at which point the total number of hatched and unhatched eggs was recorded (Kıvan, 2005).

Egg-Hatching Inhibition Assay; with Nano-Silver Extracts

To evaluate the egg-hatching inhibition effects of nano-silver extracts derived from Lantana camara, eggs were immersed in extract solutions at concentrations of 0, 100, 150, and 200 ppm. Following treatment, the number of unhatched eggs was observed and recorded. Each treatment consisted of twenty eggs, with assessments carried out under controlled laboratory conditions.

Results

The larvicidal toxicity of *L. camara* ethanol extract against *P. operculella* larvae varied significantly over time and across different treatment concentrations. At the lowest concentration, a mortality rate of 14.64% was recorded on the third day, which increased to 36% by the seventh day; this increase was statistically significant ($P < 0.05$). After seven days, the highest larvicidal effect was observed on the seventh day, with a mortality rate of 77.69% (Table 1).

Table 1
The larvicidal activity of ethanol extracts derived from *Lantana camara* on *Phthorimaea operculella* larvae *(mean ± SE)*

Treatment(%)	3th day	5th day	7th day
3	14.64 ± 0.20cd	34.73 ± 0.34d	36,12 ± 0.21d
6	9.83 ± 0.01c	41.13 ± 0.36c	52,37 ± 0.3c
9	16.65 ± 0.57b	52,52 ± 0.18b	63.33 ± 0.20b
12	25.12 ± 0.95a	62.61 ± 0.19a	77.69 ± 0.21a
Control	0.00 ± 0.00d	0.00 ± 0.00e	0.16 ± 0.46e

*Means indicated with different letters in the same row are significantly different (Tukey test, P < 0.05)

On the 5th and 7th days of the experiment, Lantana camara ethanol extracts at concentrations of 6%, 9%, and 12% exhibited larvicidal effects exceeding 50%, with the differences in mean mortality rates found to be statistically significant (P < 0.05). All tested concentrations of nano-silver extracts demonstrated toxic effects on PTMa larvae, with the highest concentration (12%) showing the greatest efficacy. Mortality rates observed at 6%, 9%, and 12% nano-silver concentrations were 55%, 74%, and 84%, respectively, with statistically significant differences across treatments (P < 0.05). Based on comparative mortality rates, the nano-silver formulations were determined to be more effective than the ethanol-based extracts (Table 2).

Table 2
The larvicidal activity of nano-silver extracts of *Lantana camara* on *Phthorimaea operculella* larvae (mean ± SE)

Treatment (ppm)	3th day	5th day	7th day
50	10.79 ± 0,81c	37.39 ± 0.19c	39.89 ± 0.21bc
100	18.35 ± 0,25bc	42.37 ± 0.39bc	55.33 ± 0.31b
150	23,59 ± 0,13b	52.57 ± 0.23b	70.25 ± 0.25ab
200	66.51 ± 0,34a	75.45 ± 0.32a	84.89 ± 1.24a
Control	0.16 ± 0,46d	0.16 ± 0.46d	0.16 ± 0.46d

* Means indicated with different letters in the same row are significantly different (Tukey test, P < 0.05)

Lethal concentration (LC) values were estimated over a seven-day observation period. For the ethanol extract treatments, the LC_{50} and LC_{90} values against Phthorimaea operculella larvae were calculated as 6.56% and 54.72%, respectively, with a heterogeneity value of 0.35 and a slope of 1.39. In comparison, the nano-silver extract treatments demonstrated higher efficacy, with an LC_{50} of 1.45% and an LC_{90} of 6.59%. The associated heterogeneity and slope values were 0.35 and 1.39 for LC_{50}, and 0.36 and 1.95 for LC_{90}, respectively (Table 3).

Table 3
The LC_{50} and LC_{90} values of ethanol and nano-silver extracts treatments

Treatment	LC_{50}(95%CL)	LC_{90}(95%CL)	Slope ± SE	χ2	Heterogeneity
Lantana camara	6.56 (5.04–8.07)	54.72(30.02-200.76)	1.39 ± 0.27	10.49	0.35
L. camara + Ag-Np	1.45(1.10–1.74)	6.59(4.78–12.01)	1.95 ± 0.33	10.89	0.36

Efficiency of Ethanol and Nano-Silver Extracts of Lantana camara against PTM Eggs

At a 6% concentration of ethanol extract from Lantana camara, the egg-hatching inhibition rate of Phthorimaea operculella was recorded as 60.69%, while a 100 ppm concentration of nano-silver extract achieved a slightly higher inhibition rate of 68.82%. In the control group, nearly all eggs successfully hatched. The maximum inhibition was observed at the highest concentration of nano-silver extract (200 ppm), reaching 94.95%. In both treatment types, the inhibition rate increased proportionally with concentration, and the differences among the treatment groups were statistically significant ($P < 0.05$) (Table 4).

Table 4
Toxicity effects of ethanol and nano-silver extracts of *Lantana camara* on *Phthorimaea operculella* eggs (mean ± SE)

Treatment (%)	***Lantana camara* ethanol extracts**	**Treatment (ppm)**	***Lantana camara* nano-silver extracts**
3	46.87 ± 0,05 d	50	54,39 ± 0,06d
6	60.69 ± 0,12c	100	68,82 ± 0,08c
9	73.82 ± 0,06b	150	80,77 ± 0,10b
12	76.51 ± 0,34a	200	94,95 ± 0,80a
Control	0.08 ± 0,02 e	Control	0.08 ± 0,02 e
* Means indicated with different letters in the same row are significantly different (Tukey test, $P < 0.05$)			

Eggs that failed to hatch were monitored through the seventh day of the experiment. The lethal concentration (LC) values for the ethanol extracts of Lantana camara were determined as LC_{50} = 1.71% and LC_{90} = 20.04%, with a slope of 1.99 and a chi-square (χ^2) value of 10.09. In comparison, nano-silver extracts exhibited higher efficacy, with LC_{50} and LC_{90} values of 3.96 ppm and 40.96 ppm, respectively (slope = 1.26, χ^2 = 7.68). These findings indicate that the nano-silver formulations were more effective than ethanol extracts in inhibiting egg hatching (Table 5).

Table 5
The LC_{50} and LC_{90} values of ethanol and nano-silver extracts of *Lantana camara*

Treatment	**LC_{50}(95%CL)**	**LC_{90}(95%CL)**	**Slope ± SE**	**χ2**	**Heterogeneity**
Lantana camara	1.71 (1.31–2.07)	20.04(10.84–73.50)	1.99 ± 0.22	10.09	0.33
L. camara + Ag-Np	3.96 (2.80–4.87)	40.96(24.76–11.33)	1.26 ± 0.19	7.68	0.25

DISCUSSION

This study examined the larvicidal and ovicidal effects of ethanol and green-synthesized nano-silver extracts of *L. camara* on the immature stages (eggs and larvae) of PTM. Silver nanoparticles were synthesized via a green method, utilizing *L. camara* extracts as a reducing agent, due to the method's enhanced reliability and environmental compatibility (Mohapatro et al., 2015).

Larval mortality began to manifest by the third day across all concentrations of ethanol extracts, with a mortality rate of approximately 53% recorded at a 6% concentration by day seven. Similarly, Kasmara et al. (2018) reported mortality rates exceeding 55% in *Spodoptera litura* larvae treated with *L. camara* extracts at concentrations ranging from 5–40%. Pavela (2011), investigating methanol extracts from various plant species against *S. littoralis* larvae, found that several—including *Foeniculum vulgare* and *Artemisia campestris*,achieved 100% mortality by the fifth day, while others such as *Lavandula angustifolia* and *Artemisia absinthium* induced 39% mortality. In our study, the highest ethanol extract concentration resulted in 62.6% larval mortality by day five.

In comparison, the nano-silver (AgNPs) extract of *L. camara* demonstrated enhanced toxicity, with larval mortality rates of 75% and 84% on the fifth and seventh days, respectively. The LC_{50} and LC_{90} values for ethanol extracts were calculated at 6.56% and 54.72%, respectively, while those for nano-silver extracts were markedly lower, at 1.45% and 6.59%, indicating higher potency. Supporting findings by Kasmara et al. (2018) demonstrated increased larvicidal activity of nano-formulated *L. camara* compared to crude extracts on third instar *S. litura* larvae. Furthermore, earlier studies have indicated that silver nanoparticles can induce larval mortality by penetrating the cuticle and causing dehydration and cellular disruption (Stadler et al., 2018).

The ovicidal potential of both ethanol (3–12%) and nano-silver (50–200 ppm) *L. camara* extracts was also evaluated. Egg-hatching inhibition at the lowest and highest concentrations ranged from 46.87–98.68% for ethanol and from 54.31–99.92% for nano-silver treatments. Both treatments exhibited significantly greater ovicidal activity than the control group (Table 4). Khani et al. (2013) reported inhibition rates of 59% and 58% at the lowest doses of petroleum ether extracts of *Piper nigrum* and *Jatropha curcas*, respectively. Similar ovicidal effects were also documented using *Allium sativum* and *Curcuma longa* against *Tribolium castaneum*. In a comparative study, *L. camara* and *Solanum nigrum* extracts both inhibited egg hatching, with *S. nigrum* showing higher efficacy (Elsayed, 2020). Additionally, Gülsoy & Yeşilayer (2018) demonstrated that *L. camara* extracts inhibited *P. operculella* egg hatching by 20% more than Salvia spp., a finding reinforced by Yeşilayer & Gülsoy (2018). Deniz (2019) reported that extracts of *Salvia officinalis* achieved egg-hatching inhibition rates of 52.5% at 3% and 62.5% at 5%, with *Thymus vulgaris* and *Lavandula officinalis* reaching up to 73.75% at 10% concentration. Consistent with larvicidal outcomes, nano-silver *L. camara* extracts were more effective in inhibiting egg hatching, with LC_{50} and LC_{90} values of 3.96 ppm and 40.96 ppm, respectively (slope = 1.26, χ^2 = 7.68, heterogeneity = 0.25).

Conclusion

In the context of integrated pest management (IPM), there is an increasing emphasis on the development of green nanobiotechnological solutions that are both efficient and environmentally benign. Nanotechnology has progressively found applications in agricultural and agronomic practices (Nair & Laurencin, 2007; Lee & El-Sayed, 2006; Jain et al., 2008). The present study demonstrates the promising insecticidal potential of both ethanol and nano-silver *L. camara* extracts against the pre-imaginal stages of PTM. As this is the first study to document the pesticidal activity of nano-silver Lantana extract against PTM, further investigations under field and semi-field conditions are warranted to validate its stability and efficacy.

Overall, the findings clearly indicate that nano-silver *L. camara* extracts exert superior larvicidal and ovicidal activities compared to ethanol-based formulations. Therefore, both ethanol and nano-silver *L. camara* extracts could serve as effective and sustainable alternatives to synthetic pesticides in the management of PTM and other agricultural pests.

Declarations

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Author Contribution

The idea of the study was conceived by AY. AY and EG designed and performed experiments, analysed data and co-wrote the paper. AY and EG verified the analytical methods. All authors discussed the results and contributed to the final manuscript

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Figures

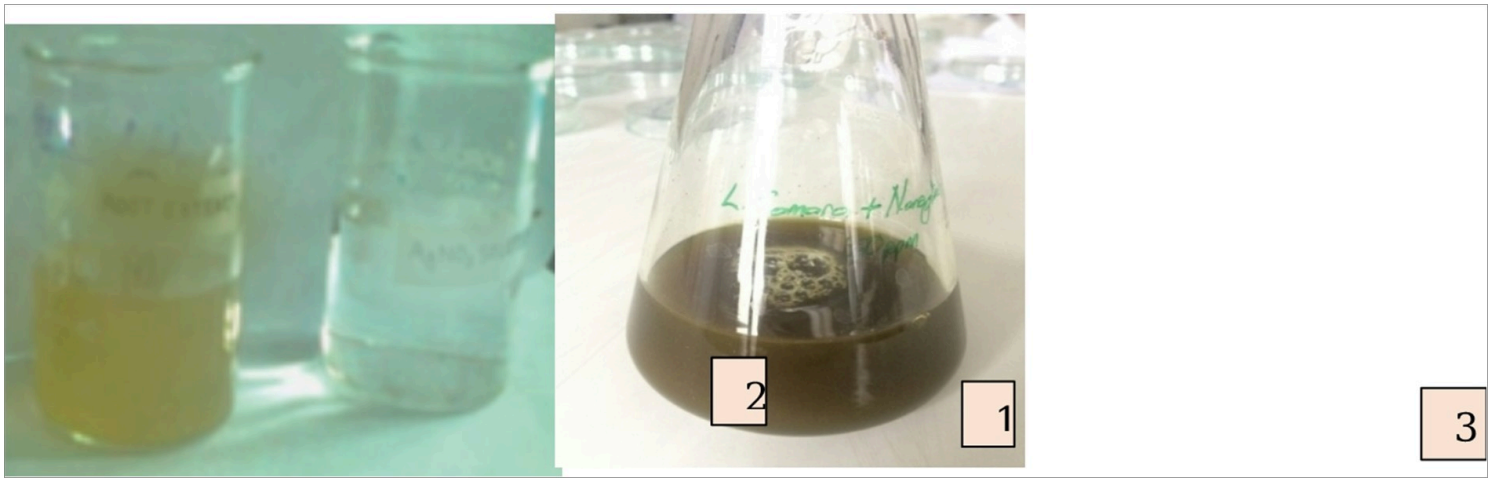

Figure 1

Green-synthesized nanoparticles changes (respectively 1, 2, 3) color after mixing of silver nitrate and *Lantana camara* extract.

Supplementary Files

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