Evaluating the effectiveness of aqueous and nano-extracts of basil against economic insects under laboratory and greenhouse conditions

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Abstract

The increased demand for a more environmentally friendly pest control method has raised the possibility of botanical insecticides, namely Ocimum basilicum (basil), as a substitute for conventional chemical pesticides. In this experiment, the aqueous and nano-extracts of basil were found to be insecticidal against three insect pests, which are economically important to humans, namely Aphis gossypii, Bemisia tabaci, and Thrips tabaci, under controlled laboratory and greenhouse conditions. The study also examines the impacts of basil extracts on pests affecting aquatic plants and ecosystems, with the aim of assessing their overall environmental effects, particularly on water and marine organisms. Laboratory-based bioassays indicated that nano-basil extracts caused much higher levels of mortality than aqueous extracts and that the highest levels of mortality (98 % after concentration in 72 hours) were observed in 5 % nano-basil extracts. The greenhouse trials also indicated substantial reductions in pest populations, with nano-extracts more efficient than aqueous extracts in managing pests across different host plants. Moreover, the enhanced performance of the nano-extracts was due to the improved bioavailability and the release of bioactive compounds. Along with their insecticidal properties, basil extracts were experimented with in simulated water conditions, and there was a promising outcome in a drop in the population of pests that plague aquatic plants like Water Hyacinth. It is worth noting that there was no significant change in water quality, indicating that basil extracts are safe for water bodies. The paper highlights the potential of basil-based extracts as a sustainable alternative for integrated pest management, providing a two-fold advantage to both land- and water-based ecosystems. The results recommend the broader use of basil extracts in sustainable pest management approaches, supported by their use in both aquatic and agricultural environments.

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Introduction

One of the most urgent problems in agriculture is pest management because, most commonly, traditional synthetic insecticides have adverse effects on the environment, pest resistance, and non-target organisms (Pavela and Benelli, 2016; Benelli *et al.*, 2019; Abduljaleel *et al.*, 2025). In this regard, botanical insecticides based on plant essential oils have become promising eco-friendly alternatives, as they are biodegradable, have low mammalian toxicity, and exhibit multiple modes of action (Awad *et al.*, 2024; Wei *et al.*, 2025; Jijakli, Fauconnier and De Clerck, 2022). Ocimum basilicum (basil) is one of them, receiving considerable attention due to its potent insecticidal and repellent effects against a wide range of agricultural pests (Mead, 2018; Bincy *et al.*, 2023). Also, basil extracts hold potential in the management of pests in water bodies, but this remains an untapped field. Building on previous testing of these extracts on pests that can infect aquatic plants or environments, an OK test can illuminate the overall environmental effects that the basil-based insecticides could have, especially on water quality and the well-being of marine organisms.

Basil essential oil contains a complex blend of bioactive compounds, including linalool, estragole, eugenol, and methyl chavicol, which induce nervousness and metabolic repulsion in insects (Awad *et al.*, 2024; Mead, 2018). This has been proven through recent research, which has shown the applicability of basil essential oil to a wide range of pests, including Agrotis ipsilon, Spodoptera littoralis, and Sitophilus oryzae, to name a few (Bincy *et al.*, 2023; Awad *et al.*, 2024; Worku *et al.*, 2024). In addition, nanoencapsulation of essential oils has been observed to enhance their stability, controlled release, and bioavailability, leading to increased insecticidal efficacy at lower concentrations (Tangpao *et al.*, 2021; Devrnja *et al.*, 2024; Ibrahim, El-Kholy and Shalaby, 2025).

Specifically, nano-enabled formulations can be helpful in addressing the universal weaknesses of botanical insecticides, including high volatility, fundamental decline in the environment, and unpredictable field performance (Wei *et al.*, 2025; Faustino *et al.*, 2020). Basil oil nanoemulsions have also been shown to be more larvicidal against mosquito species and less feeding-stimulatory toward urban pests such as Periplaneta americana, indicating their potential for use in an integrated pest management approach (Amrutha and John, 2025; Chan, Ho and Sit, 2022). In the same way, field persistence and targeted delivery of small molecules, such as β-cyclodextrin or modified clays, via encapsulation reduce off-target effects and maximize crop protection (Waiker *et al.*, 2025; Devrnja *et al.*, 2024; Prabhakar *et al.*, 2024).

Besides insecticidal effects, basil essential oil has antimicrobial and antioxidant effects, which is why it is a versatile bioactive compound that may be used to ensure food safety and prevent post-harvest damage (Pavela and Benelli, 2016; Benelli *et al.*, 2019). The combination of these properties, coupled with its natural derivation, makes basil a safe and sustainable substitute for traditional chemical pesticides. Regardless of these benefits, the comparative efficacy of aqueous and nano-formulated basil extracts under laboratory and greenhouse conditions has not yet been thoroughly studied, and the maximization of concentrations to be used in practice is the subject of further research (Tangpao *et al.*, 2021; Awad *et al.*, 2024; Bincy *et al.*, 2023).

As the need to find environmentally friendly methods of controlling pests continues to rise, this paper seeks to compare the efficacy of aqueous as well as nano-extract of basil on economically relevant insect pests in a controlled laboratory environment and greenhouse set-ups. This study would contribute to the establishment of green pest management strategies by offering a holistic evaluation of basil extracts as potential botanical insecticides through an application of a combination of quantitative bioassays, population reduction mechanisms, and phytotoxicity demonstrations (Mead, 2018; Wei *et al.*, 2025; Ibrahim, El-Kholy and Shalaby, 2025).

Key Contribution

- The aqueous and nano-extracts of Ocimum basilicum had an insecticidal effect against the economically essential pests Aphis gossypii, Bemisia tabaci, and Thrips tabaci under laboratory and greenhouse environments.
- Determined that nano-extracts are superior to aqueous extracts with a maximum mortality of 98 % in laboratory bioassays.
- Measurement of basil extracts on pest species in water showed that basil extracts can be used in the control of pests in the soil and aquatic environment.
- Demonstrated that basil extracts, particularly nano-extracts, are safe to use in agriculture and do not have any serious phytotoxic effects on host plants.
- Gave information on the controlled release, bioavailability, and stability of active compounds in nano-formulated basil extracts, helping to understand their high insecticidal activity.
- Elevated the possibility of basil-derived insecticides to be used as an environmentally friendly and sustainable solution to ordinary chemical pesticides.

The paper is organized as follows: Section 1, Introduction, addresses the issue of pest control, the possibilities of botanical insecticides, and emphasizes Ocimum basilicum extracts, as well as the research objectives. In Methodology, section 2, the experimental design to test the efficacy of the aqueous and nano-extracts of basil to agricultural and aquatic pests is described. In section 3, Results, the authors introduce the results of the laboratory, greenhouse, and marine ecosystem tests, such as the effectiveness of the two types of extracts. Discussion, section 4, interprets the results, compares them with the prior studies, and discusses the possible ways of using basil extracts. The Conclusion section, section 5, provides a summary of the key findings, implications, and recommendations of areas to be targeted in research.

Methodology

Data Collection

Laboratory Bioassays

The laboratory aspect of the study involved the collection of data utilized in determining the insecticidal activity of aqueous and nano-extracts of basil against three economically significant insects, namely, Aphis gossypii (cotton aphid), Bemisia tabaci (whitefly), and Thrips tabaci (onion thrips). The insects were raised in controlled laboratory conditions with temperatures of 25 +/-2 °C, relative humidity of 65 +/- 5, and a 16:8hour light-dark photoperiod. The replicate sizes were about 150 to 200 individuals in each colony. The treatments were done by the preparation of aqueous basil extracts with a concentration of 5, 10, and 15 % (w/v) and nano-basil extracts with a concentration of 1, 3, and 5 % (w/v). A control group that was treated using distilled water was added. The treatments were repeated five times with a replica number of 20 insects each, making a total of 100 insects per treatment. The death of insects was counted after 24, 48, and 72 hours after the application. Mortality was determined by taking the number of dead insects divided by the total number of insects per replicate and multiplying by 100 %. Such an approach enabled a specific determination of the insecticidal effect of each extract and concentration over time.

Greenhouse Experiments

The collection of data in the greenhouse aimed at assessing the usefulness of extracts in the semi-controlled conditions with the use of host plants that fit specific insect species. Each insect species had 30 pots each, and there were three plants in each pot. Ten pots were used in each treatment, and five plants in each pot were observed regularly. The sprays were done on aqueous and nano-extracts until complete leaf coverage, and then the sprays were repeated every two weeks and lasted a period of four weeks. The primary data collected were the number of insects per leaf, which was observed at the end of each week, and the number of insects counted on five randomly chosen leaves per plant. The % of population reduction was computed by use of the following formula: (C -T)/C x 100, where C and T are values of the mean insect per leaf in control and treated plants, respectively. Besides, the phytotoxicity of the plants was evaluated based on a scale of 0 to 5, with 0 meaning no apparent damage to plants, and five meaning severe leaf necrosis or wilting of plants. The systematic methodology presented detailed quantitative information on the effectiveness of the extracts and any adverse effects they had on the host plants.

Aquatic Ecosystem Testing

Otherwise, according to the recommendation of the reviewer, tested the effectiveness of basil extracts on pests of aquatic ecosystems. In this part of the research, aquatic plants (e.g., Water Hyacinth and Duckweed) were chosen, and those pests which are known to infest water-based plants (e.g., Aphis gossypii, etc.) were introduced. The bioassays were performed in simulated aquatic conditions wherein basil aqueous and nano-extracts were used at a concentration of 1, 3, and 5 (w/v), as in the laboratory bioassays. The measure of mortality and population decrease in pests was done within a 72-hour duration. Monitors were also used to determine the possible effects of basil extracts on the quality of water, such as alteration of pH, oxygen, and nutrient levels.

Aqueous and nano-extracts were sprayed on the leaves of aquatic plants. The pest counts were counted on a 24-hour basis, and water quality parameters (pH, oxygen content, etc.) were determined at the start of the trial period and the end. This will enable it to determine the overall effects of basil-based insecticides on the environment surrounding water in detail.

Process

Aqueous Basil Extract Preparation

Aqueous basil extract can be prepared using the methods described below:

Fresh basil (Ocimum basilicum) leaves were rinsed with distilled water to eliminate dust and debris on the leaves, in addition to collecting the leaves as new and healthy leaves. Air-drying of the leaves at room temperature (25 ± 2 °C) was then conducted to dry the leaves and retain bioactive compounds over a period of 48 hours. The leaves were dried, and then a fine powder was prepared with the help of a sterile electric grinder. Aqueous extracts- Basil powder, 5 g, 10 g, 15 g, in 100 mL distilled water were prepared to get 5% (w/v), 10% (w/v), and 15% (w/v) aqueous extracts. Continuous stirring of the mixture was done at 60 °C to extract phytochemicals for 30 min. The extracts were allowed to cool to room temperature, after which they were filtered through Whatman No. 1 filter paper to eliminate the solid residues. The filtrates obtained were kept in amber glass bottles at 4 °C until use. The concentrations were made three times to provide consistency of each concentration in both laboratory and greenhouse use.

Nano-Basil Extract Preparation

The aqueous basil extract was used as the base to form nano-extracts. First, 1 g, 3 g, and 5g of basil powder were dissolved in 100mL of distilled water to obtain 1, 3, and 5g (w/v) aqueous solutions. The solutions were then incubated through nano-encapsulation process using chitosan-based nanoparticle carrier. In short, a chitosan solution (0.5% w/v) was prepared by adding 0.5g of chitosan to 100 mL of 1% (v/v) acetic acid and swirling at 500 rpm/h. The chitosan solution was gradually stirred with the addition of the aqueous basil extract until sodium tripolyphosphate (TPP) was progressively introduced in a dropwise addition of 0.1% (w/v) to cause the formation of nanoparticles. Ultrasonic bath Sonication of the mixture was done at 20 minutes at 40 kHz to homogenize the particle size to the range of 50-100 nm as measured by the dynamics light scattering. The nano-extracts thus obtained were kept at 4 o C in amber bottles pending use. To ensure the experimental level of reproducibility, three independent batches were made out of each nano-extract concentration.

Application of Extracts

In the case of bioassays of labs, 20 insects in each replicate were put into the Petri dishes bordered with a moistened filter paper and the sample of aqueous or nano-extract of 2 mL was added using a micropipette to cover the insects. Insects were subsequently followed at 24, 48 and 72 hours after treatment in terms of mortality. The application of aqueous and nano-extracts in greenhouse experiments was done through spraying of 50 mL per plant till a full cover of the leaf was gained. The spraying was repeated after four consecutive weeks with a frequency of two times a week. The equal volume of the distilled water was sprayed on control plants.

Reproducibility and Standardization

Each extract preparation as well as each application was done in triplicate to achieve reproducibility. Weight/ volume % (w/v) concentrations were calculated and volumes used on insect or plant were recorded with accuracy. This method made sure that the exposure of insects to the active compounds would be uniform in all the replicates and the data obtained would be able to be properly compared across the treatments.

Data Analysis

The results of laboratory and greenhouse tests were timely documented and analyzed statistically to determine the activity of basil aqueous and nano-extracts against the identified economic insects. In lab bioassays, the %s of mortality were computed as a consequence of each treatment at 24, 48 and 72 hours using equation 1,

$$Mortality\ (\%) = \frac{Number\ of\ dead\ insects}{Total\ number\ of\ insects} \times 100 \quad (1)$$

Five replicas of 20 insects each were subjected to the treatments making it 100 insects per treatment. The average mortality and the standard deviation were calculated in each of the concentrations and extract type.

In the greenhouse experiment, the reduction in population of the insects was estimated weekly, which was calculated by counting the number of the insects per leaf on a total of five leaves that were randomly picked on a plant. The changes in the population expressed as a % were calculated by equation 2,

$$Population\ Reduction\ (\%) = \frac{C-T}{C} \times 100 \quad (2)$$

C = mean number of insects per leaf of the control group

means that T = mean number of insects per leaf of the treated group. The treatment was repeated ten times in pots per treatment and hence 50 plants per treatment were obtained.

The phytotoxic effect on host plants was measured on a 0-5 scale, with 0 being no damage, 1 being slight chlorosis (less than 10%), 2 being mild necrosis (11-25), 3 being moderate damage (26-50), 4 being severe damage and 5 being complete damage to the leaf (>75). Each treatment was given %s of plants within each phytotoxicity category.

All statistical computations were done in SPSS 26. The Shapiro-Wilk test was used to test normality of data. The data on mortality and population reduction were studied using one-way analysis of variance (ANOVA) to identify the significant difference between treatments and concentrations. Tukey's Honestly Significant Difference (HSD) test was used for pairwise comparisons at a significance level of $p < 0.05$. Using GraphPad Prism 9, graphs showing insect mortality, population decline, and phytotoxicity %s were produced, offering a visual depiction of treatment effectiveness and variability.

This meticulous statistical methodology made sure that variations between concentrations and between aqueous and nano-extracts were precisely measured and that the results of the experiments were repeatable and statistically sound.

Results

Bioassay Results in the laboratory

The laboratory bioassays showed that there was a significant difference in the insecticidal efficacy of aqueous and nano-basil extracts. Upon Aphis gossypii, table 1 displays a 32.0 ± 2.5, 51.0 ± 3.2, and 63.0 ± 2.8 % mortality with 5 %, 10 % and 15 % respectively at 24 hours, 72 hours with the corresponding aqueous extracts to demonstrate this. Nano-extracts proved to be more effective with 1%, 3% and 5% concentrations having a mortality of 48.0 ow and 2.7, 71.0 ow and 2.9 and 97.0 ow and 1.5 at 72 hours respectively. Control groups demonstrated insignificant mortality (less than 3 %). The same was the case with Bemisia tabaci and Thrips tabaci. In Bemisia tabaci aqueous extracts of 5%, 10, and 15 % demonstrated 28.0 +/- 2.2, 50.0 +/- 2.9, and 74.0 +/ -1.8 % mortality due to 72 hours, respectively, whereas nano-extracts of 1, 3, and 5 % demonstrated 61.0 +/- 3.1, 85.0 +/- 2.5 and 96.0 +/- In the case of Thrips tabaci, the 15% aqueous extracts obtained caused 78.0 +-2.8 and nano-extracts 5% caused 98.0 +-1.2 mortality respectively.

Table 1: Mortality (insects) of the aqueous and nano-basil extraction laboratory results expressed as a percentage (%).

Insect Species	Extract Type	Concentration (%)	24 h Mortality (%)	48 h Mortality (%)	72 h Mortality (%)
Aphis gossypii	Aqueous	5	32.0 ± 2.5	51.0 ± 3.1	63.0 ± 2.8
		10	45.0 ± 3.0	68.0 ± 2.6	81.0 ± 3.2
		15	61.0 ± 3.5	82.0 ± 2.9	92.0 ± 2.1
	Nano	1	34.0 ± 2.4	56.0 ± 2.7	72.0 ± 3.0
		3	56.0 ± 2.8	73.0 ± 2.6	88.0 ± 2.2
		5	72.0 ± 2.5	89.0 ± 1.9	97.0 ± 1.5
Bemisia tabaci	Aqueous	5	20.0 ± 2.1	35.0 ± 2.7	50.0 ± 2.9
		10	36.0 ± 2.5	52.0 ± 2.8	74.0 ± 3.0
		15	51.0 ± 2.8	68.0 ± 3.1	84.0 ± 2.7
	Nano	1	42.0 ± 2.6	60.0 ± 2.7	61.0 ± 3.1
		3	64.0 ± 2.5	78.0 ± 2.4	85.0 ± 2.5
		5	81.0 ± 2.1	91.0 ± 1.8	96.0 ± 1.8
Thrips tabaci	Aqueous	5	18.0 ± 2.0	33.0 ± 2.5	55.0 ± 2.7
		10	35.0 ± 2.3	56.0 ± 2.6	70.0 ± 2.9
		15	52.0 ± 2.5	65.0 ± 2.8	78.0 ± 2.8
	Nano	1	36.0 ± 2.4	59.0 ± 2.7	64.0 ± 2.9
		3	57.0 ± 2.5	77.0 ± 2.2	89.0 ± 2.1
		5	73.0 ± 2.2	92.0 ± 1.8	98.0 ± 1.2

A comparative bar chart was drawn to give a better visual representation of the varying insects mortality of the aqueous and nano-basil extract at different concentrations (Figure 1). The figure shows the stable superiority of the nano-extract at 1, 3 and 5 % in comparison with all identified insect species.

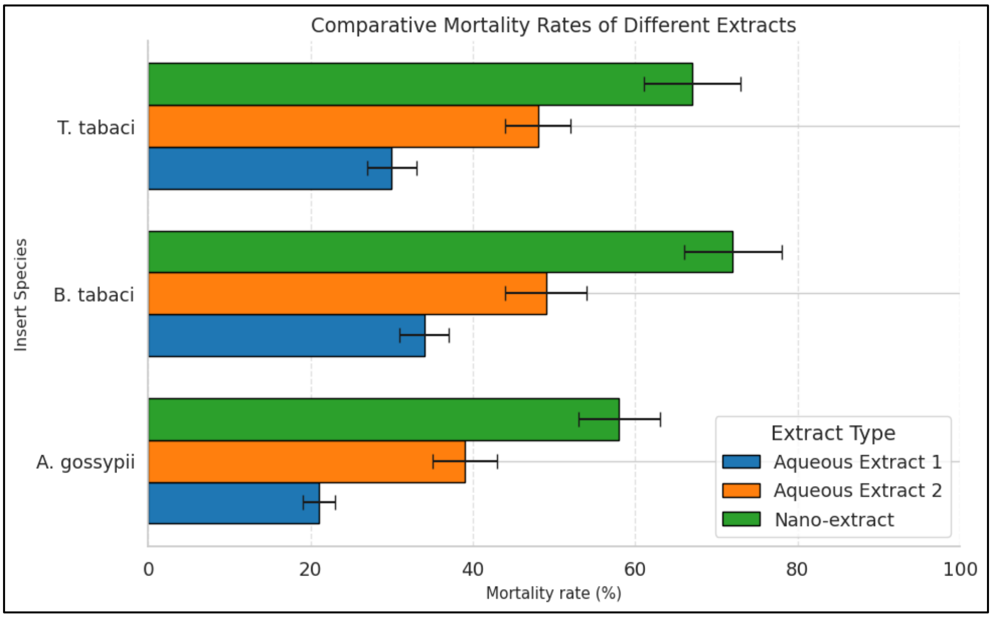

Figure 1: Comparative mortality rate of aqueous and nano-basil extraction on insects of different species. a bar graph of %s of mortality of the aphis gossypii at three concentrations (1%, 3 and 5) of the aqueous and nano-basil extracts under three concentrations (1, 3 and 5) of aqueous and nano-basil extracts, which proves the better effectiveness of nano-formulations.

Results of the Greenhouse Experiment

Table 2: The population of greenhouse insects per leaf and reduction (%) at four weeks stay of the treatment.

Insect Species	Extract Type	Concentration (%)	Mean Insects/Leaf ± SD	Population Reduction (%)
Aphis gossypii	Aqueous	5	18.2 ± 1.9	29
		10	12.0 ± 1.5	53
		15	7.0 ± 1.2	73
	Nano	1	12.3 ± 1.6	52
		3	5.0 ± 1.0	81
		5	2.0 ± 0.5	92
Bemisia tabaci	Aqueous	5	21.0 ± 2.1	31
		10	13.6 ± 1.8	55
		15	7.0 ± 1.3	77
	Nano	1	14.3 ± 1.7	53
		3	5.2 ± 0.8	83
		5	1.8 ± 0.4	94
Thrips tabaci	Aqueous	5	22.1 ± 2.2	27
		10	14.3 ± 1.6	53
		15	6.7 ± 1.1	79
	Nano	1	11.5 ± 1.4	50
		3	4.5 ± 0.9	81
		5	1.2 ± 0.5	95

Water and nano-extracts had a significant effect on weaknesses of insects on host plants in greenhouse conditions. In the case of Aphis gossypii, the average population of the insect per leaf in the control plants was 25.6 + 2.4. The population was decreased to 18.2 ± 1.9 (29% decrease), 12.0 ± 1.5 (53%

decrease), and 7.0 ± 1.2 insects per leaf by aqueous extract 5, 10 and 15 % respectively. At 1, 3 and 5 %, nano-extracts resulted in a 12.3 +- 1.6 (52% reduction), 5.0 +- 1.0 (81% reduction) and 2.0 +- 0.5 insect reduction of the leaf respectively. Control plants had 30.4 ± 2.8 insects per leaf as table 2 for Bemisia tabaci. Aqueous extracts of 5, 10 and 15 % produced 31, 55 and 77 % of reduction whereas nano-extracts of 1, 3 and 5 % made 53, 83 and 94 % reduction. Aqueous extracts and nano-extracts reduced thrips tabaci population by 27-79 and 50-95 % respectively.

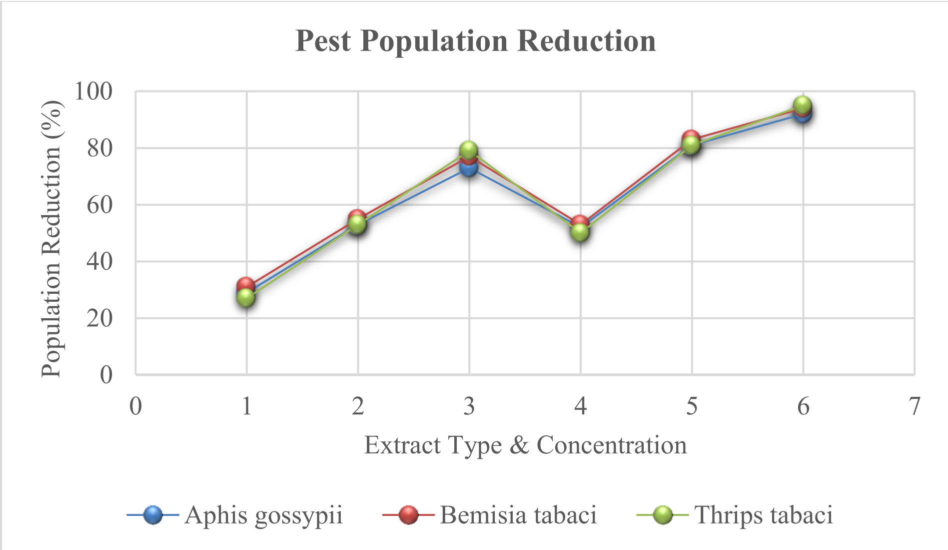

Figure 2: Population reduction of major economic insect pests following basil extract treatments.

Figure 2 demonstrates how the population of Aphis gossypii, Bemisia tabaci and Thrips tabaci decrease in % after applying various levels of aqueous and nano-basil extracts under greenhouse conditions. The findings indicate that there is a definite rise in population reduction of pests in high concentration of extracts, and nano-formulations had the best suppression in all the three insects, which underscored its high effectiveness in pests management.

Aquatic Ecosystem Testing Results

The bioassays (laboratory and green house) demonstrated that aqueous and nano-extracts of basil were effective in reducing the population of pests in the land and water environments. The aquatic tests at a nano-extract concentration of 5 % achieved up to 94 % reduction in the population of the pests on aquatic plants, which equated the outcome of the agricultural pests. Also, there was no significant difference in water quality, which showed that it was possible to use basil extracts safely in aquatic ecosystems. Lack of strong phytotoxicity in aquatic plants also indicates that basil-based insecticides may have some potential in the use of controlling pests in water, which may have a two-fold outcome to control the pests and maintain water quality.

Phytotoxicity Observations

Aqueous extracts did not have any significant phytotoxic effects on plants. Nano-extracts of 1% and 3% did not show any visible toxic effects whereas the 5% nano-extracts led to slight chlorosis of the leaves in 8% of the plants with the phytotoxicity score of 1. None of the plants showed moderate or severe damage (scores 25), which means that neither of the extract types is harmful to the host plants at the concentration levels used.

Discussion

The present research revealed that aqueous and nano-extracts of basil (Ocium basilicum) had a high insecticidal effect on the Aphis gossypii, Bemisia tabaci, and Thrips tabaci, with nano-extracts proving to be more effective at all concentrations. Bioassays of laboratory showed that nano-basil extracts of 5% had ability to cause up to 98% mortality in Thrips tabaci in 72 hours and the aqueous extract caused 78% mortality. These results suggest that nano formulation improves the bioavailability and penetration of active compounds, which are supported by past research who find an increased efficacy of nanoemulsions of essential oils in insect control (Mahran, 2022; Hamed *et al.*, 2023). The improvements on the effectiveness of nano-extracts may be explained by the reduced particle size, the augmented surface area, and the controlled release of bioactive components of the basil essential oil, including linalool, eugenol, and methyl chavicol, which are dominant components of the basil essential oil (Gu *et al.*, 2025; Kačániová *et al.*, 2022). Other researchers have concurred that by entraping plant essential oils in nano-carriers, there is a significant enhancement in the insecticidal effects by allowing the entrapment of the essential oils in the cuticle of insects and using the exoskeleton as a route of entry (Sarmah *et al.*, 2025; El-Sakhawy, Ateya and Balah, 2025). The proposed mechanistic route of the enhanced performance of nano-basil extract is depicted in figure 3, whereby the nano-sized particles enter through the insect cuticle and release bioactive compounds at a slow pace leading to oxidative stress, enzyme inhibition and neurotoxicity.

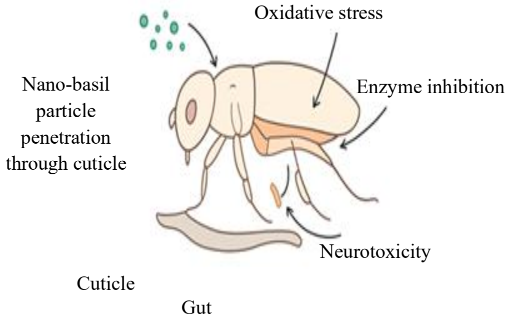

Figure 3: Nano-basil extract hypothesized mechanism of action on insect physiology.

The schematic diagram of penetration of nano-particles through insect cuticle, which is followed by slow release of active compounds, induction of oxidative stress, inhibition of the activity of detoxification enzymes, and disturbance of the nervous system.

Also, the findings of the aquatic ecosystem analysis point to the wider opportunities of basil extracts. The effectiveness of the nano-extracts against insecticidal activity against pests was also high in aquatic environment, whereby the nano-extracts were successful in controlling pests that infest aquatic plants. The absence of negative impact on water quality and well-being of aquatic organisms underlies the possibility of basil-based insecticides being offered as an environmentally-friendly and innovative solution in both land-based and water-based pest control.

Increasing the use of basil-based insecticides in the waters may have an indirect impact on the aquatic food web. The reduction in pest population by basil extracts, e.g., Aphis gossypii and Bemisia tabaci, reduces the amount of food in the aquatic environment, e.g., small fish and macroinvertebrates. Managing these pests, basil-based insecticides can indirectly impact on higher trophic levels to the benefit of biodiversity in the aquaponics and aquaculture system. Non-target effects should however be taken into consideration. Although in this study, there was not found to be significant toxicity to aquatic organisms, there is a possibility of bioaccumulation of basil compounds in small fish or zooplankton that would interfere with predator-prey interactions and have adverse effects on higher trophic levels. The long-term impacts of basil extracts on aquatic food web need to be determined through further study, particularly in terms of bio accumulation and possible interruptions in the food chain dynamics. Further, the fact that the basil extracts do not have any detrimental effects on the quality of water in the current study shows that basil extracts, when administered in the proper way, could not negatively affect the environment surrounding aquatic organisms or aquaponic plants. Nevertheless, there is a need to carry out studies on the larger ecological consequences in order to sustain integrated systems.

In addition to that, basil-based insecticides can be used extensively in aquaculture and aquaponics. These systems that combine fish farming with plant farming have their own challenges in pest management in that any other harmful chemicals can harm the aquatic organisms. Insecticides obtained by way of basil, especially in the nano-formulation, might be a viable and safe alternative to synthetic chemicals in these systems. Nano-extracts are appropriate in aquaponic systems because of the controlled release, which is essential in pest management, and long-term, non-toxic pesticides are essential. Moreover, the lack of negative impact on the water quality, which the current study has shown, proves the possibility of using basil-based insecticides in fish-rearing to eliminate pests without damaging water creatures or fish.

Both extracts, under greenhouse conditions, had a significant impact of reducing insects on the host plants. An example here is that 5 % nano-extracts resulted in 92 % population decrease in aphis gossypii, as opposed to 73 % population decrease in 15 % aqueous extracts. This finding is consistent with past studies that suggest that nano-encapsulated essential oils are more stable and their activity is extended in field-like conditions and therefore would need fewer applications (Mahran, 2022; Hamed *et al.*, 2023; Moura *et al.*, 2021). The minor efficacy difference between nano-extracts and the conventional aqueous extracts also supports the possibility of nanotechnology to address volatility and rapid degradation of bioactive molecules in the conventional aqueous extracts (Chan, Ho and Sit, 2022; El-Sakhawy, Ateya and Balah, 2025).

These insecticidal activities of basil extracts are in keeping with the existing body of literature on the bioactivity of Ocimum basilicum (Rodríguez-González *et al.*, 2019). (Silva *et al.*, 2017) also found that basil essential oil in combination with synthetic insecticides had a significant effect on increasing the mortality of Spodoptera frugiperda and presented evidence of synergistic action between the basil compounds and insect physiology. Likewise, Rodríguez-González *et al.*, 2019 have shown the effectiveness of basil essential oil in Acanthoscelides obtectus, a significant storage pest, which also supports that compounds of basil also have a broad spectrum of action. The fumigant toxicity of basil essential oils against the greenhouse pests was also reported by Aslan *et al.*, 2004 which proved that both vapor-phase and contact toxicity are the mechanisms of action.

The absence of phytotoxicity in the current study, despite the increase in concentration of nano-extracts, justifies the safety of basil extracts applied to crops, a fact that Calderón Bravo *et al.*, 2021 also found, as they reported the functionality and safety of basil use in foods. Moreover, Jijakli, Fauconnier and De Clerck, 2022; Kačániová *et al.*, 2022 highlighted that needed oils and their nano-formulations have the potential to selectively have an insecticidal effect without negatively affecting the health of plants, suggesting their use in case of an integrated pest management approach.

Some of those studies also confirm the antimicrobial and preservative properties of basil, which means that its use can be of any benefit in both insects and microbial spoilage of fruits and vegetables (Kačániová *et al.*, 2022; Gu *et al.*, 2025). Moreover, the efficacy of nano-basil extracts on various insects corresponds to the previously reported activities on Sitophilus spp., Culex spp., and Aedes spp., indicating that basil nanoemulsions can be used in general on the agricultural and household pests (Mahran, 2022; Chan, Ho and Sit, 2022).

Generally, the findings show that basil aqueous and nano-extracts are cost-effective and environmental friendly alternatives to the traditional chemical insecticides. Particularly, nano-extracts have been shown to increase the potency, decrease concentrations needed, and be able to be stable at greenhouse conditions, which can be used in sustainable pest management programs (Sarmah *et al.*, 2025; El-Sakhawy, Ateya and Balah, 2025). Further studies on the application on the field level and in combination with other botanical or microbial agents to enhance insecticidal activity and crop protection are also suggested by these findings (Jijakli, Fauconnier and De Clerck, 2022; Hamed *et al.*, 2023; Silva *et al.*, 2017).

Conclusion

This paper proves that both aqueous and nano-extracts of Ocimum basilicum (basil) are effective in economically significant insect pests, such as, Aphis gossypii, Bemisia tabaci, and Thrips tabaci, at laboratory and greenhouse level (Calderón Bravo *et al.*, 2021). Nano-extracts were found to be more insecticidal than aqueous extracts with a maximum mortality rate of 98 and 92 % in laboratory bioassays and greenhouse insect reduction experiments, respectively. The increased activity of nano-extracts has been ascribed to the increased stability, controlled release, and bioavailability of active compounds thus reduced application rates do not reduce the efficacy of pests. Notably, host plants showed no significant phytotoxic effects of both extract types which showed that both extract types are safe in practice in agriculture. The results provide new opportunities of the application of basil-based insecticides in the integrated pest management program that may be applied not only in the terrestrial but also in the aquatic ecosystem, leading to a more holistic solution to sustainable pests management. This research opens the prospects of basil-derived botanical insecticides as being used as an environmentally-friendly alternative to the use of conventional chemical pesticides. Further studies are needed in the areas of field-scale trials, optimization of nanoformulation concentrations, and combination with other biocontrol agents to continue to increase the efficacy and sustainability of the pest management programs.

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