Cureus Journal of Agriculture and Food Science
https://doi.org/10.7759/s44497-026-00311-5

Original Article

Essential Oils as an Eco-friendly Alternative for Managing Pink Bollworm (*Pectinophora gossypiella*) in Cotton

Preethi Bai [1] , P.B. Kavi Kishor [2] , Jawahar Gandra [3,]

1. *Department of Microbiology and Botany, JAIN (Deemed-to-be University) School of Sciences, Bangalore, IND*
2. *Department of Genetics, Osmania University, Hyderabad, IND*
3. *Department of Biotechnology and Genetics, JAIN (Deemed-to-be University) School of Sciences, Bangalore, IND*

Received: May 11, 2026 | Review began: June 04, 2026 | Review ended: September 22, 2026 | Published: October 06, 2026

© **Copyright** 2026
This is an open access article distributed under the terms of the Creative Commons Attribution License CC-BY 4.0., which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Abstract

The pink bollworm (*Pectinophora gossypiella*) poses a significant threat to cotton farming around the world including the genetically modified Bt cotton, which was originally engineered for bollworm resistance. Its increasing global range over the past few years has led to substantial losses beginning at the flowering stage. With an increasing global concern about resistance to pesticides and environmental issues, this research looks into the adult population control of *P. gossypiella* using five different essential oils and their potential eco-friendly fumigant toxicity. The chemical compositions of geranium, thyme, lemongrass, peppermint, and clove oils were analyzed using gas chromatography-mass spectrometry to identify their primary volatile constituents. Geranium oil was primarily composed of citronellol (59.13%) and geraniol (25.53%), while thyme contained phenol (41.99%) and gamma-terpinene (37.23%). Lemongrass comprised mainly 2,6-octadienal (51.40%) and neral (45.40%), peppermint was rich in cyclohexanol (88.25%), and clove oil contained predominantly 3-allyl-6-methoxyphenol (92.75%). Fumigation bioassays were conducted at seven concentrations ranging from 0.02% to 0.5% with an exposure time of 60 minutes. Results revealed that geranium oil demonstrated superior fumigant activity with the lowest LD_{50} value (0.201%), followed by thyme (0.234%), lemongrass (0.252%), peppermint (0.381%), and clove (0.451%). Geranium, thyme, and lemongrass oils achieved complete mortality at 0.5% within the exposure period. These results indicate that plant-based essential oils, especially geranium oil, hold promising potential as environmentally friendly fumigants for controlling pink bollworm infestations in cotton farming. It is concluded that essential oils present a potential and sustainable substitute for traditional chemical insecticides, contributing to a more eco-conscious pest management approach in cotton.

Categories: Plant-pathogen interaction, Disease & pests of crops

Keywords: gas chromatography-mass spectrometry, integrated pest management, fumigation bioassay, pink boll worms, essential oils

Introduction

Cotton (*Gossypium*), originally a perennial plant, is now widely grown as an annual crop in various regions globally. It belongs to the family Malvaceae, and the genus *Gossypium* [1,2]. There are over 50 identified cotton species worldwide, four of which are cultivated. Out of four, *G. arboreum* and *G. herbaceum* are diploid, while *G. hirsutum* and *G. barbadense* are tetraploid [3]. The leading cotton-producing countries include India, China, the United States, Pakistan, Brazil, Australia, Uzbekistan, Turkey, Turkmenistan, and Burkina Faso. Despite India being the top producer, contributing 26% of the global cotton supply, its yield per acre remains relatively low largely because various pests have developed resistance to genetically modified *Bt* cotton, resulting in significant crop damage [4]. Cotton is a highly valuable material and

economic driver, especially in developing nations. It supports over 100 million farmers and contributes $600 billion annually to the global economy. As a major cash crop, it sustains livelihoods, particularly among smallholder farmers, reinforcing its significance in both local and international markets [5].

The cotton ecosystem is home to approximately 1,326 insect species from the time of planting to maturity across various cotton-growing regions worldwide. Even in regions where certain pest species are not affected by *Bt* toxins, genetically modified cotton continues to shape cotton production worldwide. The decreased use of insecticides for bollworms and altered pest management practices in Bt cotton fields have led to an increase in secondary pest populations, which have gradually become significant pests [6]. One of the most significant cotton pests, *Pectinophora gossypiella* (Saund) (Lepidoptera: *Gelechiidae*), is found in all cotton-growing regions of the world [7]. It has recently gained major pest status, causing serious losses. Over the past 2-3-years, it has become a significant threat to *Bt* cotton, leading to considerable yield reductions. Once a major issue for non-*Bt* cotton, especially in the later stages of the crop, pink bollworms are now a major problem for *Bt* cotton hybrids starting from the flowering stage, causing extensive damage. This issue is primarily due to the long duration varieties and the lack of effective control measures [8]. The pink bollworm lays its eggs on flowers or green bolls, and the larvae burrow into cotton bolls to feed on the seeds. This feeding behavior is part of its life cycle, which includes four developmental stages: egg, larva, pupa, and adult. The time required for the life cycle from egg to egg varies with temperature and other conditions [9]. Farmers typically depend on chemicals to combat these significant pests; however, pesticides have not offered a sustainable long-term solution for their management. In contrast to this method, biological control has become a key strategy employed globally in pest management [10]. The discovery of a sex pheromone in female pink bollworms dates back to 1957 and was later characterized as a two-component mixture of Z,Z- and Z,E-(7,11)-hexadecadienyl acetate, known as gossyplure [11]. This sex pheromone has been used for population monitoring and mating disruption in order to facilitate more effective control through the use of insecticides and sterile male releases [12].

Recent studies on essential oils (EOs) have emphasized their extensive bioactivities against pests and disease-causing organisms, suggesting their potential as substitutes for synthetic pesticides in crop protection and other pest control applications [13,14]. EOs are aromatic oily liquids, extracted from various parts of plants such as flowers, buds, seeds, leaves, twigs, bark, herbs, wood, fruits, and roots. They consist of complex mixtures of volatile compounds such as sesquiterpenes, monoterpenes, aldehydes, alcohols, esters, and ketones. These oils play a crucial role in protecting plants from pests, herbivores, fungi, and bacteria [15]. In 1996, the Environmental Protection Agency determined that specific ingredients posing minimal risk to users no longer required approval for marketing as insecticides [16]. Many of these ingredients are essential oils, which disrupt an insect neurotransmitter, but are essentially absent in humans, pets, and other vertebrates. These oils can act as fumigants, contact insecticides, antifeedants, or repellents. Because of their low toxicity to mammals, they represent promising alternatives for pest control. Building on this potential, the present study aimed to evaluate the chemical composition of five EOs using gas chromatography-mass spectrometry (GC-MS) analysis and to assess their effectiveness as fumigants in paralyzing or killing *P. gossypiella*, a major pest of cotton.

Materials And Methods

Insect culturing

Larval stage of the *P. gossypiella* were obtained from ICAR-National Bureau of Agricultural Insect Resource (NBAIR), Bengaluru, Karnataka 560024, India, and Cotton Board, Coimbatore. The larvae were maintained in a controlled environment within a BOD incubator at a temperature of 24 ± 2°C to ensure consistent growth conditions. Each individual was reared separately in a small plastic container measuring 3 × 4 cm. They were provided with an artificial diet that was prepared according to the protocol recommended by NBAIR to culture larvae. The diet primarily consisted of chickpea powder, yeast, and wheat gram powder, supplemented with other minor components to provide optimal nutritional support. Upon pupation, the pupae were carefully transferred to test tubes and kept at room temperature. After emergence, the adult moths were introduced into a plastic jar, providing them with an artificial environment.

How to cite this article:
Bai P, Kishor P, Gandra J (October 06, 2026) Essential Oils as an Eco-friendly Alternative for Managing Pink Bollworm (*Pectinophora gossypiella*) in Cotton . Cureus J. Agri. Food Sci 2 : es44497-026-00311-5. DOI https://doi.org/10.7759/s44497-026-00311-5

Cotton swabs soaked with honey and water were offered as food sources, and cotton leaves were provided as substrates conducive to mating and egg-laying. The jar was covered with black cotton cloth to allow ventilation. Some of the adult moths were used in the above experiment (Figure *1*).

Essential oils and their GC-MS analysis

EOs were purchased in pure form from Lakshmi traders, Bengaluru 560053, India. The five EOs used were the geranium (*Pelargonium graveolens*), thyme (*Thymus vulgaris*), lemongrass (*Cymbopogon flexuosus*), peppermint (*Mentha piperita* L), and clove (*Syzygium aromaticum*). The sample was prepared by dissolving 1 ml of the EO with 3 ml of the ethyl acetate and was injected into the injector. The GC-MS analysis was conducted using a Shimadzu QP2010 series GC-MS system, equipped with an AOC-20i auto-sampler. The injector temperature was set at 280°C, and the analytical column used was an Rtx-5MS (30 m length, 0.25 mm ID, 0.25 µm df), featuring a cross bond of 5% diphenyl and 95% dimethyl polysiloxane. The oven temperature was initially maintained at 60°C and then increased to 300°C at a rate of 30°C/min, with a total run duration of 15 min. Helium served as the carrier gas with a total flow rate of 1.20 ml/min and a split ratio of 10:1, while a sample volume of 1 µL was injected. The single quadrupole mass spectrometry detector operated with an ion-source temperature of 220°C and an interface temperature of 280°C. The sample was introduced via the injector in split mode, allowing for effective separation and identification of various components based on their retention times and peak enhancements through standard samples and mass spectral library searches. The total runtime for the analysis was set to 15 minutes, ensuring comprehensive profiling of the EO's components.

Fumigation assay

Vapor toxicity of various EO and their constituents against the adult insects were determined via an impregnated paper assay following the method of [17,18]. A reagent bottle of 250 ml capacity with screw lids was used as an exposure chambers. EOs of different concentrations (0.02, 0.04, 0.06, 0.08, 0.1, 0.25, 0.5%) were dissolved in acetone and applied to Whatman No. 1 filter paper (2 × 5 cm) with the concentration was adjusted according to the internal surface area of the container. After solvent evaporation (10-15 minutes), treated filter papers were placed inside the bottles. Ten adult insects were introduced into each jar, while control groups received filter papers treated with acetone alone. Insect mortalities were determined and calculated after 60 min of exposure and were recorded at different concentrations. All experiments were conducted in biological triplicates and technical duplicates. LD_{50} values were calculated for all measurements.

Statistical analysis

The mortality data obtained from each tested concentration in the bioassay were statistically analyzed to determine lethal dose values. Regression analysis using probit analysis was employed to calculate LD_{50}, providing a quantitative measure of toxicity. In addition, the relationship between concentration levels and mortality percentages was examined through two-way analysis of variance (ANOVA), allowing assessment of both main effects and interactions.

Results And Discussion

The pink bollworm has become a significant pest threatening cotton production in India, resulting in substantial yield reductions in recent years. To manage this pest, farmers have mostly relied on synthetic insecticides such as beta-cyfluthrin and indoxacarb. However, the effectiveness of these chemicals is limited because the larvae develop entirely within cotton bolls, shielding them from direct contact with insecticides [19]. The widespread adoption of Bt cotton, engineered to produce insecticidal proteins from *Bacillus thuringiensis*, initially reduced pink bollworm damage. However, resistance emerged by 2014, which led to a drastic reduction in crop production [20]. Recent studies on EOs have emphasized their extensive bioactivities against pests and disease-causing organisms, suggesting their potential as substitutes for synthetic pesticides in crop protection and other pest control applications [12]. They also exhibit diverse pesticidal properties, [21,22] and their chemical composition was characterized using GC-MS analysis in recent studies.

How to cite this article:
Bai P, Kishor P, Gandra J (October 06, 2026) Essential Oils as an Eco-friendly Alternative for Managing Pink Bollworm (*Pectinophora gossypiella*) in Cotton . Cureus J. Agri. Food Sci 2 : es44497-026-00311-5. DOI https://doi.org/10.7759/s44497-026-00311-5

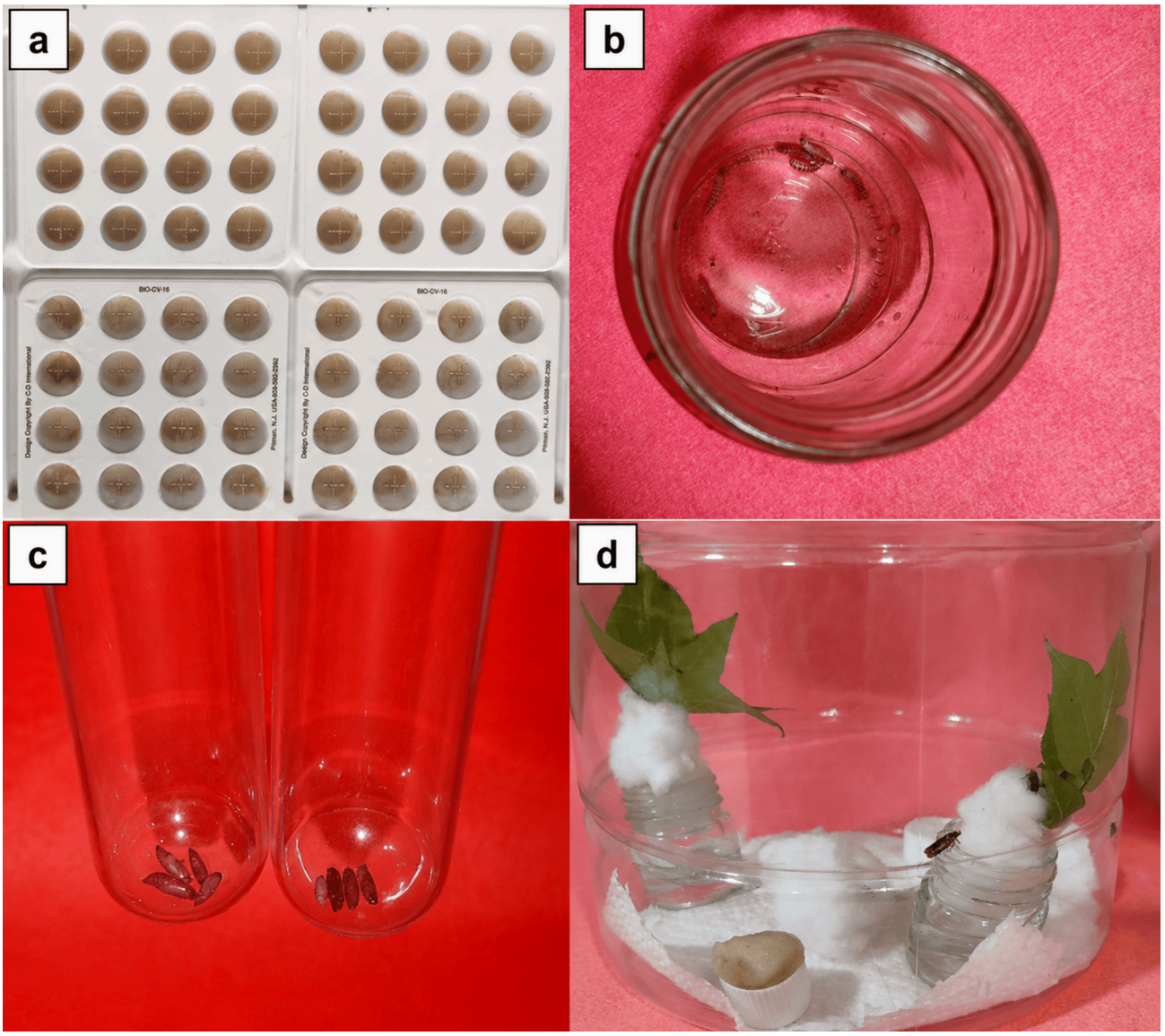

FIGURE 1: Different stages of pink bollworms (a) 1st stage larvae (b) 3rd stage larvae (c) pupae (d) adult moth

How to cite this article:
Bai P, Kishor P, Gandra J (October 06, 2026) Essential Oils as an Eco-friendly Alternative for Managing Pink Bollworm (*Pectinophora gossypiella*) in Cotton . Cureus J. Agri. Food Sci 2 : es44497-026-00311-5. DOI https://doi.org/10.7759/s44497-026-00311-5

Chemical composition of the oils

Essential oil	Compound name	Retention time (min)	Area %
Geranium oil	Linalool Cyclohexanone, 5-methyl-2-(1-methylethyl)-, (2R-cis) Citronellol Geraniol 6-Octen-1-ol, 3,7-dimethyl-, formate	4.945, 5.392, 5.718, 5.853, 5.924	6.64, 3.62, 59.13, 25.53, 5.09
Thyme oil	β-Pinene, p-Cymene, γ-Terpinene, Phenol, 2-methyl-5-(1-methylethyl)-, Thymol	4.093, 4.458, 4.704, 6.035, 6.081	0.24, 14.96, 37.23, 5.57, 41.99
Lemon grass oil	α-Pinene Neral 2,6-Octadien-1-ol, 3,7-dimethyl-, (Z) 2,6-Octadienal, 3,7-dimethyl-, (E) Diethyl Phthalate	3.723, 5.804, 5.847, 5.962, 7.411	0.52, 45.40, 1.41, 51.40, 1.27
Peppermint oil	l-Menthone Cyclohexanone, 5-methyl-2-(1-methylethyl)-, (2R-cis) Cyclohexanol, 5-methyl-2-(1-methylethyl), (-)-Carvone Anethole	5.337, 5.391, 5.513, 5.853, 6.066	3.87, 0.68, 88.25, 0.44, 6.76
Clove oil	3-Allyl-6-methoxyphenol, Caryophyllene, Humulene, Caryophyllene oxide	6.457, 6.733, 6.885, 7.454	92.75, 6.63, 0.54, 0.08

TABLE 1: Essential oil compositions obtained from geranium, thyme, lemongrass, peppermint, and clove oils

Gas chromatography (GC)-mass spectroscopy (MS) was used to identify the saturated and unsaturated hydrocarbons present in essential oil extracts [23]. An analysis was carried out to identify the volatile constituents of various essential oils. A list of the identified volatile constituents, the percentage of each volatile component, their experimental retention indices are summarized in Table 1. Geranium oil primarily consists of citronellol (59.13%) and geraniol (25.53%), with smaller amounts of linalool (6.64%), cyclohexanone (3.62%), and 6-octen-1-ol formate (5.09%). Thyme oil contains a significant amount of phenol (41.99%) and gamma-terpinene (37.23%), alongside minor components such as beta-pinene (0.244%), p-cymene (14.96%), and another phenolic compound (5.57%). Lemongrass oil primarily comprises 2,6-octadienal (51.40%) and neral (45.40%), with trace amounts of 2,6-octadien-1-ol (1.41%), alpha-pinene (0.52%), and diethyl phthalate (1.27%). Peppermint oil is rich in cyclohexanol (88.25%), with minor components like anethole (6.76%), l-menthone (3.87%), cyclohexanone (0.68%), and carvone (0.44%). Clove oil predominantly consists of 3-allyl-6-methoxyphenol (92.75%), along with small amounts of caryophyllene (6.63%), humulene (0.54%), and caryophyllene oxide (0.08%).

In the present study, GC-MS analysis was carried out for phytochemical screening of geranium oil. It exhibited the presence of five peaks representing major constituents such as citronellol (59.13%) and geraniol (25.53%), along with minor components such as linalool (6.64%), cyclohexanone, 5-methyl-2-(1-methylethyl)-, (2R-cis) (3.62%), and 6-octen-1-ol, 3,7-dimethyl-, formate (5.09%), respectively. GC-MS analysis of geranium was carried out and similar constituents were reported by previous researchers, whereas citronellol (38.0%) and geraniol (16.0%) were found to be present in the

How to cite this article:
Bai P, Kishor P, Gandra J (October 06, 2026) Essential Oils as an Eco-friendly Alternative for Managing Pink Bollworm (*Pectinophora gossypiella*) in Cotton . Cureus J. Agri. Food Sci 2 : es44497-026-00311-5. DOI https://doi.org/10.7759/s44497-026-00311-5

highest concentration [24]. Our findings corroborate those obtained by others [24]. In the current study, thyme oil analysis showed significant levels of thymol (41.99%) and γ-terpinene (37.23%), along with minor components like β-pinene (0.244%), p-cymene (14.96%), and phenol, 2-methyl-5-(1-methylethyl)- (5.57%) [25]. Al-Asmari et al. reported similar compounds from thyme oil which was obtained from the steam distillation process. In lemongrass oil, the major compounds found were 2,6-octadienal, 3,7-dimethyl-, (E) (51.40%) and neral (45.40%), with minor components including 2,6-octadien-1-ol, 3,7-dimethyl-, (Z) (1.41%), α-pinene (0.52%), and diethyl phthalate (1.27%). Mohamed Ali found similar compounds in lemongrass oil samples obtained via steam distillation [26]. Peppermint oil mainly contains cyclohexanol, 5-methyl-2-(1-methylethyl) (88.25%), along with smaller amounts of anethole (6.76%), l-menthone (3.87%), cyclohexanone, 5-methyl-2-(1-methylethyl)-, (2R-cis) (0.68%), and (-)-carvone (0.44%). Desam et al. analyzed peppermint oil using GC-MS after hydrodistillation and reported some overlapping compounds with the current findings [27]. In previous work, clove oil obtained from hydrodistillation process revealed the presence of eugenol (59.87%) and caryophyllene (23.58%) as major components, along with some minor components [28]. In the present study, the major components of clove essential oil were 3-allyl-6-methoxyphenol (92.75%), along with minor constituents such as caryophyllene (6.63%), humulene (0.54%), and caryophyllene oxide (0.08%). Variations in results across studies may be due to differences in geographic origin of oil, genetic diversity of plants, soil fertility, seasonal variation, harvesting time, and extraction methods. In this study, however, commercially purchased pure oils were analyzed (Table *1*).

Fumigation assay

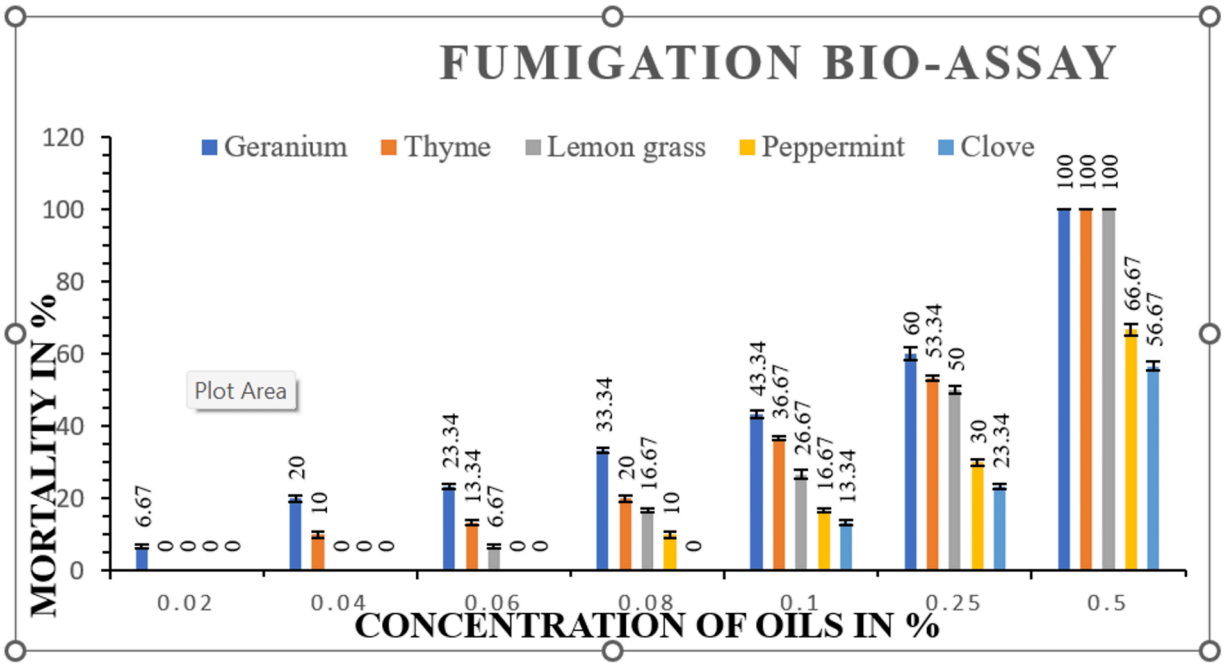

FIGURE 2: Graph representing fumigation bioassay of Pectinophora gossypiella against various concentration of essential oil

The essential oils exhibited varying levels of efficacy against the tested parameter. Geranium oil showed the highest effectiveness, followed by thyme, lemongrass, peppermint, and clove oils, while clove oil exhibited the lowest efficacy. In general, increasing the oil concentration resulted in higher insect mortality rates. Geranium, thyme, and lemongrass oils achieved 100% mortality within 60 minutes at higher concentrations. However, peppermint and clove oils did not reach complete mortality within this timeframe. This pattern further emphasizes the uneven potency of various essential oils, highlighting geranium oil as an effective and potent fumigant against *Pectinophora gossypiella*, the major pest currently devastating the cotton crop

How to cite this article:
Bai P, Kishor P, Gandra J (October 06, 2026) Essential Oils as an Eco-friendly Alternative for Managing Pink Bollworm (*Pectinophora gossypiella*) in Cotton . Cureus J. Agri. Food Sci 2 : es44497-026-00311-5. DOI https://doi.org/10.7759/s44497-026-00311-5

Oil	LD_{50} value (in %)	95% confidence limit Upper limit Lower limit	Regression equation	R^2 value	X2 value
Geranium oil	0.201111	0.32834935 0.07387264	y = 177.02x + 14.399	0.9501	3.6420111
Thyme oil	0.23477	0.36200871 0.107531999	y = 196.61x + 3.8418	0.9652	4.7376617
Lemon grass oil	0.252793	0.38003156 0.125554849	y = 208.47x - 2.6998	0.9838	7.3111656
Peppermint oil	0.381114	0.50835248 0.253875766	y = 140.11x - 3.3979	0.979	9.2897396
Clove oil	0.451856	0.57909478 0.32461806	y = 121.47x - 4.887	0.9712	14.969757

TABLE 2: LD50, 95% confidence limits and regression equations of essential oils to adult Pectinophora gossypiella after 60 min fumigation treatment

The toxic effects of essential oils applied via fumigation are shown in the Table 2. Adult moths of *Pectinophora gossypiella* were exposed to fumigation with five different essential oils at seven different concentrations (0.02, 0.04, 0.06, 0.08, 0.1, 0.25, and 0.5%). After 60 minutes of exposure, geranium oil was identified as the most effective, achieving a lethal dose of 50 (LD_{50}) value of 0.201%. The LD_{50} values for the other oils were as follows: 0.234% for thyme oil, 0.252% for lemongrass oil, 0.381% for peppermint oil, and 0.451% for clove oil.

Two-way factorial ANOVA demonstrated that both essential oil type and concentration significantly affected insect mortality. Concentration exerted the greatest influence on mortality ($F_{6,70} = 237.12$, $P < 0.0001$). Essential oil type also significantly influenced mortality ($F_{4,70} = 49.49$, $P < 0.0001$). Furthermore, a significant Oil × Concentration interaction ($F_{24,70} = 2.86$, $P = 0.00035$) indicated that mortality responses to increasing concentrations differed among oils. Probit analysis revealed that geranium oil exhibited the highest fumigant toxicity with the lowest LD_{50} value (0.201%), whereas clove oil showed the lowest toxicity ($LD_{50} = 0.451\%$).

The study reports the fumigation effect of five plant-derived essential oils against adult *P. gossypiella*. Findings highlight the distinct toxic effects of these oils, with notable differences in efficacy among them. Geranium oil stands out as the most effective fumigant, exhibiting an LD_{50} value of 0.201% and achieving complete mortality within 60 minutes at higher concentrations. Thyme and lemongrass oils, while slightly less effective than geranium oil, also showed strong fumigant properties with LD_{50} values of 0.234% and 0.252%, respectively. Both oils achieved complete mortality at higher concentrations, indicating their potential viability as alternative sources to synthetic pesticides. Peppermint and clove oils, however, were comparatively less effective, with higher LD_{50} values of 0.381% and 0.451%, respectively (Table 2). Their inability to achieve 100% mortality within the 60-minute timeframe highlights their weaker potency and limits their application as standalone fumigants. The findings also underscore a clear dose-dependent relationship, where increasing concentrations of the essential oils resulted in higher mortality rates among the moths. Interestingly, most essential oils exhibited good toxicity towards *P. gossypiella*. Large number of studies were performed using plant essential oils against the greater wax moth (*Galleria mellonella*), a significant pest affecting honeybee colonies [29], third instar larvae of *Trichoplusiani* [30]. Limited studies have investigated the effectiveness of essential oil-based fumigation

assays against *P. gossypiella*. No researches have carried out the effectiveness of essential oil-based fumigation assays against *P. gossypiella.* This study examines the pesticidal activity of various essential oils through fumigation assay, testing a range of concentrations (0.02%-0.5%) against adult *P. gossypiella.* This trend not only reinforces the importance of optimizing oil concentrations for pest control but also emphasizes the differential potencies of the essential oils tested. The rankings of efficacy are geranium > thyme > lemongrass > peppermint > clove which provides a useful framework for selecting essential oils-based on their effectiveness (Figure *2*).

Conclusions

The fumigation bioassay experiments demonstrated that plant-derived EOs possess significant insecticidal activity against adult *P. gossypiella* infesting cotton. Among the tested oils, geranium oil exhibited the highest potency, with an LD_{50} value of 0.201%, followed by thyme (0.234%) and lemongrass (0.252%), both of which also achieved complete mortality within 60 minutes at a 0.5% concentrations. These quantitative findings highlight geranium oil as particularly promising for integrated pest management, offering a natural and environmentally sustainable alternative to conventional synthetic insecticides. Future research should focus on validating these laboratory results under greenhouse and field conditions, optimizing nano-formulations for improved stability and delivery, and investigating mechanistic pathways underlying insect mortality to strengthen the scientific basis for essential oil-based biopesticides.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Preethi Bai, P.B. Kavi Kishor, Jawahar Gandra

Acquisition, analysis, or interpretation of data: Preethi Bai, Jawahar Gandra

Drafting of the manuscript: Preethi Bai, P.B. Kavi Kishor, Jawahar Gandra

Critical review of the manuscript for important intellectual content: P.B. Kavi Kishor, Jawahar Gandra

Supervision: P.B. Kavi Kishor, Jawahar Gandra

Disclosures

Plant subjects: All authors have confirmed that this study did not involve any herbarium specimen.

Human subjects: All authors have confirmed that this study did not involve human participants or tissue.

Animal subjects: All authors have confirmed that this study did not involve animal subjects or tissue.

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following:

- **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work.
- **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work.
- **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

How to cite this article:
Bai P, Kishor P, Gandra J (October 06, 2026) Essential Oils as an Eco-friendly Alternative for Managing Pink Bollworm (*Pectinophora gossypiella*) in Cotton . Cureus J. Agri. Food Sci 2 : es44497-026-00311-5. DOI https://doi.org/10.7759/s44497-026-00311-5

Data Availability Statements

The datasets (and/or code) supporting this study are available from the corresponding author upon reasonable request. All data generated or analyzed during this study are included in this published article and/or its appendices.

Acknowledgements

The authors acknowledge the support extended by the management, JAIN Deemed to be University.

References

1. Egbuta M, McIntosh S, Waters D, Vancov T, Liu L: Biological importance of cotton by-products relative to chemical constituents of the cotton plant. Molecules. 2017, 22:93. 10.3390/molecules22010093
2. Fang DD: General description of cotton. Cotton Fiber: Physics, Chemistry and Biology. Springer International Publishing, Cham; 2018. 1-11. 10.1007/978-3-030-00871-0_1
3. Khadi BM, Santhy V, Yadav MS: Cotton: An Introduction. Cotton. Biotechnology in Agriculture and Forestry. Springer, Berlin, Heidelberg; 2010. 65:1-14. 10.1007/978-3-642-04796-1_1
4. Khan MA, Wahid A, Ahmad M, Tahir MT, Ahmed M, Ahmad S, Hasanuzzaman M: World Cotton Production and Consumption: An Overview. Cotton Production and Uses. Springer, Singapore; 2020. 1-7. 10.1007/978-981-15-1472-2_1
5. Malinga L: The importance and economic status of cotton production. Academia Letters. 2021, 10.20935/al2317
6. Dhawan AK: Integrated pest management in cotton. Integrated Pest Management in the Tropics. 2016, 16:499-575.
7. Muralimohan K, Kamath SR, Mohan KS, Ravi KC, Deeba F, Sivasupramaniam S, Head GP: Mass rearing diet for the pink bollworm Pectinophora gossypiella (Lepidoptera: Gelechiidae) and its susceptibility to insecticidal Bt proteins. International Journal of Tropical Insect Science. 2009, 29:102-107. 10.1017/s1742758409990129
8. Narayanamma LV, Ratnakar V, Veeranna G: Management of pink bollworm Pectinophora gossypiella (Saunders) in cotton. Indian Journal of Entomology. 2022, 84:1-3. 10.55446/ije.2022.161
9. Sarwar M: Biological parameters of pink bollworm Pectinophora gossypiella (Saunders)(Lepidoptera: Gelechiidae): a looming threat for cotton and its eradication opportunity. International Journal of Research in Agriculture and Forestry. 2017, 4:25-36.
10. Mohamed HO, El-Heneidy A, El-Heneidy AH, Abd-Elalim AG, Awad A: Non-chemical control of the pink and spiny bollworms in cotton fields at Assuit Governorate, Upper Egypt, II—utilization of the egg parasitoid, Trichogrammatoidea bactrae Nagaraja. Egyptian Journal of Biological Pest Control. 2016, 26:807-813.
11. Bierl BA, Beroza M, Staten RT, Sonnet PE, Adler VE: The pink bollworm sex attractant. Journal of Economic Entomology. 1974, 67:211-216. 10.1093/jee/67.2.211
12. Byers JA, Naranjo SE: Detection and monitoring of pink bollworm moths and invasive insects using pheromone traps and encounter rate models. Journal of Applied Ecology. 2014, 51:1041-1049. 10.1111/1365-2664.12270
13. Isman MB: Bioinsecticides based on plant essential oils: a short overview. Zeitschrift Fur Naturforschung C. 2020, 75:179-182. 10.1515/znc-2020-0038
14. Jyotsna B, Patil S, Surya Prakash Y, Rathnagiri P, Kavi Kishor PB, Jalaja N: Essential oils from plant resources as potent insecticides and repellents: current status and future perspectives. Biocatalysis and Agricultural Biotechnology. 2024, 61:103395. 10.1016/j.bcab.2024.103395
15. Tohidi B, Rahimmalek M, Trindade H: Review on essential oil, extracts composition, molecular and phytochemical properties of Thymus species in Iran. Industrial Crops and Products. 2019, 134:89-99. 10.1016/j.indcrop.2019.02.038
16. Federal Register: Exemption of Certain Pesticide Substances From Federal Insecticide, Fungicide, and Rodenticide Act Requirements. A Rule by the Environmental Protection Agency on 03/06/1996. 1996,
17. Wang X, Li Q, Shen L, et al.: Fumigant, contact, and repellent activities of essential oils against the darkling beetle, Alphitobius diaperinus. Journal of Insect Science. 2014, 14:75.
18. Brari J, Thakur D: Insecticidal efficacy of essential oil from Cinnamomum zeylanicum Blume and its two major constituents against Callosobruchus maculatus (F.) and Sitophilus oryzae (L.). Journal of Agricultural Technology. 2015, 11:1323-1336.

How to cite this article:
Bai P, Kishor P, Gandra J (October 06, 2026) Essential Oils as an Eco-friendly Alternative for Managing Pink Bollworm (*Pectinophora gossypiella*) in Cotton . Cureus J. Agri. Food Sci 2 : es44497-026-00311-5. DOI https://doi.org/10.7759/s44497-026-00311-5

19. Busnoor AV, Wadaskar RM, Fand BB, et al.: Laboratory evaluation of toxicity of selected insecticides against egg and larval stages of cotton pink bollworm, Pectinophora gossypiella (Saunders) (Lepidoptera: Gelechiidae). Journal of Cotton Research. 2024, 7:2. 10.1186/s42397-023-00163-w

20. Kumar R, Bhede BV, Paul D, et al.: Resistance development in pink bollworm (Pectinophora Gossypiella Saunders) against Bt cotton and its' establishment as mid season pest in India. Scientific Reports. 2025, 15:7012. 10.1038/s41598-025-89575-z

21. Kumar S, Mahapatro GK, Yadav DK, et al.: Essential oils as green pesticides: An overview. The Indian Journal of Agricultural Sciences. 2022, 92:1298-1305. 10.56093/ijas.v92i11.122746

22. Garrido-Miranda KA, Giraldo JD, Schoebitz M: Essential oils and their formulations for the control of Curculionidae pests. Frontiers in Agronomy. 2022, 4:876687. 10.3389/fagro.2022.876687

23. Nirmala MJ, Durai L, Gopakumar V, Nagarajan R: Preparation of celery essential oil-based nanoemulsion by ultrasonication and evaluation of its potential anticancer and antibacterial activity. International Journal of Nanomedicine. 2020, 15:7651-7666. 10.2147/ijn.s252640

24. Gallardo A, Picollo MI, González-Audino P, Mougabure-Cueto G: Insecticidal activity of individual and mixed monoterpenoids of geranium essential oil against pediculus humanus capitis (Phthiraptera: Pediculidae). Journal of Medical Entomology. 2012, 49:332-335. 10.1603/me11142

25. Al-Asmari AK, Athar MT, Al-Faraidy AA, Almuhaiza MS: Chemical composition of essential oil of Thymus vulgaris collected from Saudi Arabian market. Asian Pacific Journal of Tropical Biomedicine. 2017, 7:147-150. 10.1016/j.apjtb.2016.11.023

26. Ali MM, Yusuf MA, Abdalaziz MN: GC-MS analysis and antimicrobial screening of essential oil from lemongrass (Cymbopogon citratus). International Journal of Pharmacy and Chemistry. 2017, 3:72. 10.11648/j.ijpc.20170306.11

27. Desam NR, Al-Rajab AJ, Sharma M, Mylabathula MM, Gowkanapalli RR, Albratty M: Chemical constituents, in vitro antibacterial and antifungal activity of Mentha×Piperita L. (peppermint) essential oils. Journal of King Saud University - Science. 2019, 31:528-533. 10.1016/j.jksus.2017.07.013

28. Ahamad J: Characterization of essential oil composition of Syzygium aromaticum Linn. (clove) by GC-MS and evaluation of its antioxidant activity. Journal of Angiotherapy. 2023, 7:1-5. 10.25163/angiotherapy.719358

29. Su XL, Huang ZC, Chen L, Chen DY, Zhao DX, Zeng ZJ: Active components of 16 essential oils and their fumigation effects on Galleria mellonella (Lepidoptera: Pyralidae). Insects. 2024, 15:977. 10.3390/insects15120977

30. Tak JH, Jovel E, Isman MB: Contact, fumigant, and cytotoxic activities of thyme and lemongrass essential oils against larvae and an ovarian cell line of the cabbage looper, Trichoplusia ni. Journal of Pest Science. 2016, 89:183-193. 10.1007/s10340-015-0655-1

How to cite this article:
Bai P, Kishor P, Gandra J (October 06, 2026) Essential Oils as an Eco-friendly Alternative for Managing Pink Bollworm (*Pectinophora gossypiella*) in Cotton . Cureus J. Agri. Food Sci 2 : es44497-026-00311-5. DOI https://doi.org/10.7759/s44497-026-00311-5