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COMPARATIVE TOXICOLOGICAL EVALUATION OF SYNTHETIC AND BOTANICAL INSECTICIDES AGAINST COTTON MEALY BUG (*PHENACOCCUS SOLENOPSIS)* UNDER CONTROLLED LABORATORY CONDITIONS IN DISTRICT KHAIRPUR, SINDH, PAKISTAN

Tasneem Kousar[*1], Zaibun-Nisa Memon[2], Shabana Mangi[3], Mansoor Anwar[4], Ranjeet Kumar[5], Sumbul Mureed Mastoi[6], Naveed Ahmed Abbasi[7]

[*1,2]*Department of Zoology, Shah Abdul Latif University, Khairpur Mir's, Sindh, Pakistan*
[3,4]*Assistant Professor Government College University Hyderabad*
[5]*Assistant Professor Govt: Islamia Science College, Sukkur*
[6]*College Of Forestry, Sichuan Agricultural University, Chengdu, China*
[7]*College of Plant Science & Technology, Huazhong Agricultural University, Wuhan China*

[*1]tasneemlarik710@gmail.com

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Corresponding Author: *
Tasneem Kousar

Abstract
Gossypium hirsutum is a major cash crop of Pakistan and contributes substantially to the livelihood of rural communities. In recent years, the cotton mealybug (Phenacoccus solenopsis), has become a persistent invasive pest, posing a serious constraint to cotton production nationwide. The traditional use of synthetic insecticides has brought temporary relief, but also has resulted into development of resistance, contamination of environment and negative impact on useful organisms. However, alternative insecticides, which are environmentally friendly, including botanical insecticides are also being scrutinized with regard to their application in integrated pest management (IPM).The current analysis was carried out in the controlled Entomology Laboratory of the Department of Zoology, Shah Abdul Latif University, Khairpur, Sindh, to assess the comparative toxic effects of three synthetic insecticides profenofos, lambda-cyhalothrin, and imidacloprid and extracts of the botanical plants (neem, tobacco, and garlic) against P. solenopsis. Bioassays were performed under controlled laboratory conditions, and mortality was documented at successive exposure intervals. The findings indicated that profenofos and lambda-cyhalothrin produced the most rapid and substantial mortality, reflecting their strong knockdown capability rates after 24 h. Imidacloprid showed moderate efficacy with a slower toxic response. Among the botanical treatments, neem extract exhibited the greatest effectiveness, followed by garlic and tobacco. The statistical analysis indicated that there were significant differences among all treatments, where the use of botanical extracts particularly neem, may offer viable enviromentally safer options for the sustainable management of the cotton mealy bug. This study presents a scientific basis for promoting eco-friendly control measures that balance efficacy with long-term sustainability, thereby supporting more resilient agricultural systems.

INTRODUCTION

The textile industry of Pakistan is mainly cotton based as it contributes a significant portion of the agricultural exports and rural workforce in the nation. Several insect pests are however becoming a major threat to the production of cotton especially the cotton mealybug (*Phenacoccus solenopsis*), which is now a major invasive pest of cotton in South Asia. *P. solenensis* was first reported in mid 2000s in Pakistan where it was causing immense yield loss along with the economic disturbance (Hodgson et al., 2008; Abbas et al., 2010; Badr et al., 2020).

The cotton mealybug is a sap sucker, which makes the host plants weak, and they spread the toxins which lead to an impaired growth, curling of the leaves, and falling of fruits. It measures its economic risks by virtue of its polyphagous nature, which makes it infest a variety of crops (Ali and Rajabpour, 2024; MamoonurRashid et al., 2024). Many cotton farmers in Sindh especially in the District Khairpur, have been struggling to deal with this pest due to its high reproduction and adaptation ability.

Historically, chemical insecticides were the major control measure. Organophosphates, pyrethroids, and neonicotinoids compounds have proved to be very effective against sucking pests (Ahmad et al. 2007; Asif et al. 2016; Afza et al. 2023). However, mass application has resulted in resistance, diminished field performance as well as ecology. In addition, synthetic chemicals are applied carelessly, which interferes with the population of natural enemies, endangering the biodiversity and health of humans (Padaliya et al., 2022).

In line with this, researchers have researched botanical insecticides (as a response) in place of synthetic insecticides since they are eco-friendly. The extracts of neem (*Azadirachta indica*) include the compound called azadirachtin which is a strong antifeedant and insecticidal compound (Agbo et al., 2023; Sinha and Ray, 2024; Agbo et al., 2019; Koul et al., 2004). There has been pesticidal activity of tobacco (*Nicotiana tabacum*) alkaloids especially nicotine on a variety of insect pests (Chen et al., 2022; Chen et al., 2020). Garlic (*Allium sativum*) essential oils possess an insecticidal effect and repelling one, and therefore, they should be used in managing pests (Chaubey, 2017; Giuliano et al., 2024). These botanicals are biodegradable, they are less toxic to the nontargets and can be integrated with integrated pest management (IPM) strategies. Plant-based compounds and essential oils are increasingly being seen as possible agents of pest control that can help decrease the usage of synthetic chemicals (Pavela, 2016; Campolo et al., 2017; Zhang et al., 2020; Hikal et al., 2017; Lengai et al., 2020).

Although, comparative research on synthetic and botanical insecticides against *P. solenensis* under in situ conditions is paucate. This gap is filled by this study, whereby controlled laboratory bioassays are performed in the Khairpur, District of Sindh. This research project aimed at comparing the toxicological efficacy of the selected synthetic insecticides (profenofos, lambda-cyhalothrin and imidacloprid), and botanical extracts (neem, tobacco, and garlic) on the cotton mealybug. The findings will help to offer information on sustainable pest control methods that consider effectiveness and sustainability.

Methodology

This research work has been done under Entomology Laboratory, Department of Zoology, Shah Abdul Latif University, Khairpur, Sindh. The drug infested cotton fields were where the cotton mealybugs (*Phenacoccus solenopsis*) were harvested and they were nurtured provided with laboratory facilities. Three synthetic insecticides (profenofos, lambda-cyhalothrin, and imidacloprid) and three botanical extracts (neem, tobacco and garlic) were tested.

The bioassays were conducted in the modes of leaf-dip and topical application by using conventional entomological procedures (Lengai et al., 2020). The mortality was counted at 24, 48 and 72 hours after treatment. All treatments were done in three replicas, and with proper controls.

Statistical Analysis

Abbott formula was used to correct the mortality data. The experiment was a three-replicate, entirely randomized design (CRD) experiment. ANOVA was used to compare the treatment and exposure time (24, 48, and 72 h) two-way ANOVA was used to compare the difference. In cases where a lot of variation was observed, means of treatments were separated with Least Significant Difference (LSD) test at the 5% significance level $p \leq 0.05$. The SPSS (version XX) was used to conduct all the analyses and results are presented as mean percentages ± standard errors.

Results

The bioassays were conducted in the laboratory showed clear differences in the toxicity of insecticides that were used as synthetic insecticides and those found in botanical extracts against *Phenacoccus solenopsis.*

Mortality under Synthetic Insecticides

Artificial insecticides caused high and fast death. The most effective was profenofos with the highest mortality of 85% at 24 h and 98% at 72 h. Lambd-cyhalothrin came next 80% and 96% death occurred at 24 and 72 hours respectively. Imidacloprid was a slower but more constant agent put at 65% expression and 85%t by 72h.

Table 1. Mortality (%) of P. solenopsis under synthetic insecticides

Treatment	24h Mortality	48h Mortality	72h Mortality
Profenofos	85%	95%	98%
Lambda-cyhalothrin	80%	92%	96%
Imidacloprid	65%	78%	85%

Mortality under Botanical Insecticides

Moderate but significant levels of toxicity were observed in botanical extracts. The most effective was neem extract with a mortality rate of 55% at 24 h and a mortality rate of 82% at 72 h. Garlic extract induced 45% mortality at the start which raise to 75% percent at 72 h. The least effective was tobacco extract, having a mortality percentage of 40% and 70% after 24 and 72 hrs respectively.

Table 2. Mortality (%) of P. solenopsis under botanical insecticides

Treatment	24h Mortality	48h Mortality	72h Mortality
Neem	55%	70%	82%
Garlic	45%	62%	75%
Tobacco	40%	58%	70%

Comparative Toxicity

Synthetic insecticides always consistently exhibited higher efficacy compared to botanical formulations across all exposure periods. At 24 h, synethetic treatments produced a mean mortality of 77% which increased to 88% at 48 h, and 93% at 72h. In contrast, botanical treatments recorded lower mortality rates of 47%, 63%, and 76% at the same time intervals.

Table 3. Comparative toxicity (synthetic vs botanical)

Category	Mean Mortality (24h)	Mean Mortality (48h)	Mean Mortality (72h)
Synthetic	77%	88%	93%
Botanical	47%	63%	76%

Discussion

These findings proved that synthetic insecticides had both high and rapid mortality rates against *phenacoccus solenopsis*, with profenofos and lambda-cyhalothrin being the most effective ones. These data are connected to the previous experience on the high efficacy of organophosphates and pyrethroids in the presence of sucking pests (Ahmad et al., 2007; Afza et al., 2023; Asif et al., 2016). Imidacloprid worked, although more slowly, which is consistent with the activity of neonicotinoides and their mechanism of action on the systemic level (Ali and Rajabpour, 2022; Ali and Rajabpour, 2024).

Insecticides made out of botanical foliage had medium and high rates of intoxication. The best botanicals were neem extract and other researchers have confirmed this fact through previous research on the use of azadirachtin as an insecticide (Michel et al., 2023; Sinha and Ray, 2024; Agbo et al., 2019; Koul et al., 2004; KilaniMorakchi et al., 2021). Promising outcome was also demonstrated by the garlic essential oils, which are in line with the existing studies emphasizing their bioactivity in reducing pests in stored grains and fields (Chaubey, 2017; Giuliano et al., 2024; Singh et al., 2023). The pesticidal properties of tobacco extracts were also reported, even though the weak toxicity had been reported in relation to alkaloid toxins (Chen et al., 2022; Chen et al., 2020).

The slower activity of botanicals is indicative of its mode of action that is typically not a direct knockdown but the interference with feeding, growth and reproduction. Such an attribute predisposes them to the inclusion into IPM programs, where long-term suppression and environmental safety are eminent. According to Isman (2006), botanical insecticides have deterrent, repellent and insecticidal properties and mostly less harmful to the nontarget than the conventional chemicals. The reviews of essential oils and plant -derived compounds also indicate the potential of their application in IPM (Pavela, 2016; Campolo et al., 2017; Zhang et al., 2020; Hikal et al., 2017; Lengai et al., 2020; Lalruatsangi, 2022; Saikumar et al., 2025).

Another important factor in this respect is the resistance management. The unnecessary dependence on synthetic pesticides has caused resistance among cotton pests, which reduce the effectiveness of fields and cause a higher cost of production. The use of botanicals in controlling pests can also help alleviate the resistance because there is a variation in the control measures and such differentiation leads to a decrease in the selection pressure. The given method indicates the general concepts of sustainable pest management that are outlined in contemporary agricultural sources (Isman, 2006; Jayswal, 2021; Vijay et al., 2025).

The adoption of botanicals as the favorite way to curb pesticide resistance is a workable solution in the case of Khairpur District in the Sindh region where cotton is a significant crop. This will allow farmers to have fewer chemicals, increased sustainability, and less risk to the environment. Although the synthetical insecticides that are employed cannot be ignored because they are necessary in clearing the immediate infestation of pests, botanicals offer alternative solutions, which are in tandem with the world trends regarding sustainable farming.

Overall, the results endorse a middle way, synthetic insecticides in case of extreme influxes and botanicals in long-term environmentally friendly control of pests. This bi-directional approach has the potential of improving the strength of the cotton production systems, in terms of productivity as well as environmental protection.

Conclusion

It is concluded that synthetic insecticides profenofos, lambda-cyhalothrin, and imidacloprid are the ones that lead to rapid and high toxicity to cotton mealybug, whereas botanical extracts, neem, garlic, and tobacco are the ones which are meeting moderate but significant toxicity. Synthetics are still functional but their sustainability in long-term is not good due to resistance and ecological hazards. Neem and botanicals are eco-friendly modes of alternative. The application of botanicals in pest management in Bhopal, Sindh, can increase sustainability, cut down reliance on chemicals.

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