



Assessing the efficiency and effectiveness of solar-powered insect traps for integrated pest management in cotton fields: A field-based evaluation

Kanishk Verma, Yadvika, Nitin Karwasra*

Department of Renewable and Bio Energy Engineering, CCSHAU, Hisar, Haryana, India

Abstract

This study investigates the efficiency and effectiveness of solar-powered insect traps for integrated pest management (IPM) in cotton fields. Conducted at the Research Farm, Cotton Section, CCS Haryana Agricultural University, and selected farmers' fields in Ludas Village, this field-based evaluation aimed to reduce dependency on chemical pesticides and promote sustainable pest control methods. Ten solar insect trap units were installed at five locations, covering BT Cotton, Desi Cotton, and Non-BT Cotton varieties. The traps were assessed for performance, with the highest solar panel efficiency recorded at 10.50% under a solar insolation of 750 W/m². The traps operated effectively from dusk to dawn, ensuring uninterrupted insect trapping. Insect trapping efficiency varied across cotton varieties, with Coleopteran insects (beetles) showing the highest populations. BT Cotton exhibited the lowest overall pest presence, with an average population of 18,900 insects per day, compared to 33,060 in Non-BT Cotton and 42,720 in Desi Cotton. The use of solar traps significantly reduced the need for chemical pesticides, leading to cost savings and environmental benefits. The findings demonstrate that solar-powered insect traps are an effective tool for managing pest populations in cotton fields. Integrating these traps into IPM frameworks can enhance crop yield, promote sustainable farming practices, and reduce environmental impact.

Keywords: Solar insect trap, renewable energy, cotton, pest management, pest control, integrated pest management

Introduction

Cotton (*Gossypium hirsutum*), often referred to as "White Gold," is a crucial fiber crop globally, with significant economic importance in agriculture, particularly in countries like India, China, and the United States. India leads the world in cotton production and acreage, contributing 26% of global cotton output with 6.05 million metric tons and 41% of the total cotton cultivation area, covering 12.96 million hectares (Swetha *et al.*, 2022). Haryana was a major cotton-producing state, cultivated 5.75 lakh hectares in 2022-23, yielding 10 lakh bales with a productivity of 295.65 kg/ha, significantly below the national average (CITI India, 2024). (Rajendran *et al.*, 2018) Cotton crops face significant challenges that impact productivity and quality. Key issues include pest infestations, such as sap-sucking pests (jassids, aphids, whiteflies, mealybugs, thrips) and bollworms (spiny, spotted, *Helicoverpa*, pink), which cause leaf curling, stunted growth, and damage to fruiting bodies. Other pests like leaf rollers and cotton stainer bugs contribute to defoliation and seed damage. Overuse of chemical pesticides has led to resistance, complicating control efforts. Implementing Integrated Pest Management (IPM) is challenging due to the need for balanced chemical, biological, and cultural methods. Genetically modified (GM) cotton helps manage bollworms but has led to secondary pests like mealybugs and whiteflies, with concerns about BT toxin resistance. Economic losses arise from reduced lint and seed quality, while invasive species and adverse weather further exacerbate challenges. Sustainable cotton farming requires a comprehensive, integrated pest management approach.

Traditionally, chemical pesticides have been the primary method for pest control in cotton fields. Chemical pesticides

have long been the primary method for pest control in cotton fields, but their over-reliance has led to significant challenges. The excessive pesticide use causes environmental degradation by disrupting ecosystems and harming beneficial insects (Rajendran *et al.*, 2018). Additionally, it has resulted in pest resistance, as seen in bollworms like *Helicoverpa armigera*, which have developed resistance to multiple insecticides (Kranthi, 2002)^[5]. Furthermore, pesticide exposure poses health risks to farmers and consumers which make pest management even more challenging, emphasizing the need for sustainable alternatives like Integrated Pest Management (IPM) to mitigate these issues (Rajendran *et al.*, 2018)^[10]

In addition to chemical pesticides, a less hazardous method known as the light trap has been developed. This electronic device utilizes phototaxis (attraction to light) and chemotaxis (attraction to energy) to lure pests into touching a high-voltage grid, effectively killing or collecting them in a bag or bowl (Rabbani *et al.*, 2020)^[9]. Most light traps used in agriculture for monitoring and controlling pests are electrically operated and stationary, relying on a consistent power supply (Mamun *et al.*, 2022)^[8]. Reddy *et al.* (2010) introduced a solar-powered trap with a collecting net, which operates independently of external energy sources like wind, fuel, or electricity. This device automatically turns on at night and off at sunrise, offering a sustainable solution. In cotton belt of Haryana, pink bollworm infestations have escalated since 2019, with damage reported in over 90% of Bt cotton fields in some areas (Kumar *et al.*, 2024). Farmers face further challenges as bollworms have developed resistance to costly pesticides. Integrated pest management (IPM) techniques, such as pheromone traps, yellow sticky

traps, and electrically operated light traps, are recommended. However, the lack of electricity in rural areas, especially remote villages, remains a major constraint (Bhamre *et al.*, 2005) [2]. So, the solar-powered traps offer a viable and eco-friendly solution for pest control in regions with limited or unreliable electricity access.

Solar-powered insect traps have shown significant potential in controlling pests like whiteflies, leafhoppers, and thrips in crops such as cotton, as demonstrated by various studies (Gavhande *et al.*, 2019) [4]. These traps can be optimized by adjusting light colour, intensity, and height to target specific pests while minimizing harm to beneficial insects, thereby supporting biodiversity. For example, research highlights their effectiveness in reducing pest populations without disrupting ecosystems (Bhandari *et al.*, 2017) [1].

Despite of the promising results, there is a need for more field-based evaluations to assess the efficiency and effectiveness of solar-powered insect traps. This study aims to evaluate the performance of solar-powered insect traps in managing key pests in cotton crop, with a focus on their integration into an IPM framework. By assessing the impact of these traps on pest populations, crop yield, and overall sustainability, this research seeks to provide valuable insights into the potential of solar-powered insect traps as a viable pest management tool in cotton cultivation.

Material and Method

The study was conducted at the Research Farm, Cotton Section, Department of Genetics and Plant Breeding (GPB), CCS Haryana Agricultural University (CCSHAU), Hisar, and selected farmers' fields in Ludas Village. The research aimed to evaluate the performance and economic viability of a solar insect trap in cotton crops, reducing pesticide use and its associated environmental hazards. The study was carried out under the ICAR-AICRP Scheme on Energy in Agriculture and Agro-based Industries.

Ten solar insect trap units were procured from Dr. Punjabrao Deshmukh Krishi Vidyapeeth (PDKV), Akola, and installed at five different locations. Each hectare was equipped with two solar insect traps, following the recommended installation guidelines provided by the developers at PDKV, Akola. The traps were set at a height of 1 ft above the crop canopy to optimize insect attraction and capture.

The solar insect trap system comprised with Photovoltaic (SPV) Panel for harnessing solar energy, Battery unit for power storage, UV light source to attract nocturnal insects and Collection chamber for trapping the insects. The traps operated from dusk to dawn, with a fully charged battery sustaining operation through the night. Each system was installed and regularly maintained to ensure consistent performance.

Crop and Treatment Details

The crop treatment experiment was conducted at three different locations which are Cotton Section Field at CCSHAU, Hisar, Seed Science Technology Field at CCSHAU, Hisar and farmer's fields in Ludas Village. Each experimental site covered an area of one hectare, and two solar insect traps were installed per hectare to ensure effective pest control within a 50-meter working radius. The study was conducted on cotton crops, focusing on three different varieties i.e. BT Cotton, Desi Cotton, and Non-BT

Cotton. BT Cotton is a genetically modified variety with built-in insect resistance, while Non-BT Cotton lacks genetic modifications, making it more susceptible to pest attacks. Desi Cotton represents traditional indigenous cotton varieties with distinct pest resistance traits. This selection allowed for a comparative analysis of insect infestation levels and trapping efficiency across different cotton types.

Data Collection and Observations

Observations were recorded to assess the trap's performance and its effectiveness in insect control. The parameters measured for environmental conditions are Solar insolation (W/m^2), Ambient temperature ($^{\circ}C$), Relative humidity (RH, %) and Wind velocity (m/s). For trap performance are SPV panel temperature ($^{\circ}C$), Panel voltage (V), Panel current (A), Panel power output (W), Panel efficiency (%) and Energy efficiency (%). Insect collection and identification were done on the basis of Daily insect count, order-wise sorting of insects (Coleopteran, Hemipteran, Lepidopteran, Orthopteran) and identification of species. Economic threshold level assessment was done on basis of trapped insects were collected manually each morning, dried, and sorted in the entomology laboratory. The identification of insect species was performed under the guidance of an entomologist from the Department of Entomology, CCSHAU Hisar. Performance analysis and the solar insect trap's efficiency was evaluated based on Power generation efficiency of the SPV panel under different weather conditions Insect trapping efficiency, comparing the number and type of insects captured per crop variety Economic viability, comparing cost savings from reduced pesticide use.

Results and Discussion

Performance of Solar Insect Trap in Cotton Crop

The solar insect traps were installed at five locations, covering three cotton varieties: BT Cotton, Non-BT Cotton, and Desi Cotton. The evaluation focused on insect trapping efficiency, solar panel performance, and economic viability. Plate 1 represents the installation of solar-powered insect trap in an agricultural field for sustainable pest management



Plate 1: Installation of Solar-Powered Insect Trap in an Agricultural Field for Sustainable Pest Management

Solar Panel Performance



Plate 2: Laboratory Evaluation of Solar Photovoltaic (SPV) Panel for Performance and Efficiency

The solar photovoltaic (SPV) panel performance was assessed on a sunny day in September 2021 as shown in Plate 2. Table 1 represents performance of SPV panel of solar insect trap. The highest efficiency of 10.50% was recorded at 1:00 PM, with a solar insolation of 750 W/m², generating 0.87 A current, 10.7 V, and 9.1 W power. The lowest efficiency of 8.40% was observed at 10:00 AM with a solar insolation of 587 W/m², generating 0.56 A current, 9.7 V, and 5.7 W power. The battery charging time ranged from 4 to 5 hours when fully depleted effects were similar results were observed for testing performance of solar photovoltaic panel (Shaik *et. Al.*, 2023) [11]. These findings indicate that the solar insect trap operates effectively under normal daylight conditions, ensuring uninterrupted night-time insect trapping.

Table 1: Performance of solar panel of insect trap on normal sunny day

Time	Panel Temperature, °C	Temperature, °C	RH, %	Solar Insolation, W/m ²	Current, Amp.	Voltage, Volts	Power, Watt	Efficienc %
10:00	30	29	87	587	0.56	9.7	5.7	8.40
11:00	33	31	85	667	0.67	9.9	7.15	9.27
12:00	36	32	85	679	0.69	10.3	7.27	9.26
01:00	38	35	83	750	0.87	10.7	9.1	10.50
02:00	38	34	85	776	0.94	10.5	9.3	10.37
03:00	37	34	86	650	0.65	9.9	7.2	9.58
04:00	36	33	87	573	0.54	9.8	6.5	9.81
05:00	36	28	88	450	0.43	9.6	3.8	7.30

Insect Trapping Efficiency in Cotton Varieties

The daily insect collection from the traps varied across different cotton varieties. The captured insects were categorized into four major orders: Coleoptera (beetles), Hemiptera (bugs), Lepidoptera (moths), and Orthoptera (grasshoppers). The table 2 provides a comparative analysis of the total population of different insect orders in BT Cotton, Non-BT Cotton, and Desi Cotton. The insect orders examined include Coleopteran, Hemipteran, Lepidopteran, and Orthopteran, with their respective populations recorded in each cotton type was similar to the findings of earlier study done (Kranthi, 2005). Coleopteran insects, which include beetles, have the highest population across all cotton types, with 15,600 in BT Cotton, 25,500 in Non-BT Cotton, and 31,920 in Desi Cotton, indicating their significantly higher presence in Desi and Non-BT Cotton fields. Hemipteran insects, known for their sap-sucking feeding habits, show a much lower presence compared to Coleopterans, with 540 in BT Cotton, 1,560 in Non-BT Cotton, and 2,040 in Desi Cotton, highlighting that BT Cotton has the lowest infestation among the three types. Lepidopteran insects, which include moths and caterpillars, are of particular concern in cotton farming as they are major pests. Their population is 2,520 in BT Cotton, 5,760 in Non-BT Cotton, and 8,400 in Desi Cotton, reinforcing the fact that BT Cotton is highly effective in controlling Lepidopteran pests due to its genetically modified pest-resistant traits. Orthopteran insects, which include grasshoppers and crickets, are present in relatively low numbers across all cotton types, with 240 in both BT and Non-BT Cotton, and a slightly higher 360 in Desi Cotton, indicating that Orthopteran populations are less influenced by the type of cotton cultivated. The total insect population across all orders and cotton types highlights a clear trend that BT Cotton has the lowest total insect population at 18,900 per day, Non-BT Cotton has a significantly higher

population at 33,060, while Desi Cotton records the highest overall infestation at 42,720 insects per day. Plate 3 showing insects collected using solar-powered light trap.

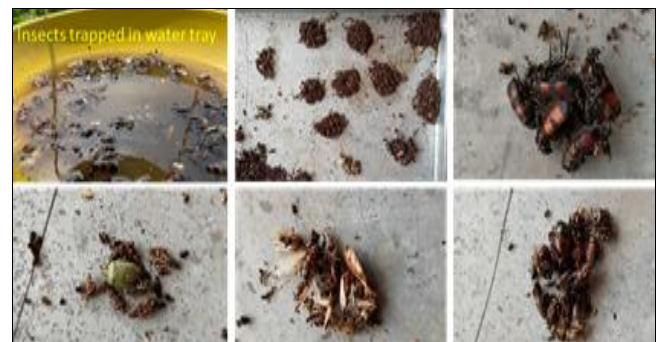


Plate 3: Insects Collected Using Solar-Powered Light Trap

Table 2: Population details of different order insects from BT, Non-BT and desi cotton field

Sr. No.	Order of insect	Total Population in BT Cotton	Total Population in Non-BT Cotton	Total Population in Desi Cotton
1.	Coleopteran	15600	25500	31920
2.	Hemipteran	540	1560	2040
3.	Lepidopteran	2520	5760	8400
4.	Orthopteran	240	240	360
Total		18900	33060	42720

The table 3 presents data on the average population of different insect orders trapped per day in BT Cotton, Non-BT Cotton, and Desi Cotton fields. The data is categorized by insect order, specifically Coleopteran, Hemipteran, Lepidopteran, and Orthopteran, and highlights their varying population densities across different cotton types. Among the Coleopteran insects, five different species are listed,

showing significant variation in population. The highest population recorded for Coleopterans is 200 in BT Cotton, 350 in Non-BT Cotton, and 450 in Desi Cotton, indicating that these insects are more abundant in Desi Cotton and Non-BT Cotton fields, whereas their numbers are relatively lower in BT Cotton. Other Coleopteran species have lower populations, such as 13, 18, 21, and 8 in BT Cotton, which also follow a similar trend of increasing population in Non-BT and Desi Cotton fields. For the Hemipteran order, two species are reported, with populations ranging from 4 to 5 in BT Cotton, 8 to 18 in Non-BT Cotton, and 10 to 24 in Desi Cotton, suggesting that Hemipteran insects, though fewer in number, are significantly more prevalent in Non-BT and Desi Cotton than in BT Cotton. The Lepidopteran order,

known for its pest species that cause damage to cotton crops, has a notable population increase across cotton types. One species shows 12 in BT Cotton, 26 in Non-BT Cotton, and 30 in Desi Cotton, while another species has a much higher population of 30 in BT Cotton, 70 in Non-BT Cotton, and 110 in Desi Cotton, reinforcing the observation that Lepidopteran insects are more abundant in Non-BT and Desi Cotton fields, where pest resistance is lower. Lastly, Orthopteran insects, which include grasshoppers and crickets, are absent in BT Cotton, while their population in Non-BT Cotton is 4 and in Desi Cotton is 6, showing that these insects are not a major concern compared to other pest orders.

Table 3: Insects trapped from solar insect traps installed at different locations from cotton crop per day

Sr. No.	Insects Trapped	Order of insect	Average Population in BT Cotton per day	Average Population in Non-BT Cotton per day	Average Population in Desi Cotton per day
1.		Coleopteran	13	18	22
2.		Coleopteran	18	21	24
3.		Coleopteran	200	350	450
4.		Coleopteran	21	26	25
5.		Coleopteran	8	10	11
6.		Hemipteran	4	8	10
7.		Hemipteran	5	18	24
8.		Lepidopteran	12	26	30
9.		Lepidopteran	30	70	110
10.		Orthopteran	0	4	6

Economic and Environmental Benefits

The installation of solar insect traps significantly reduced the dependency on chemical pesticides, leading to cost savings for farmers. Since chemical pesticides are toxic to the soil and the environment, the use of solar-powered traps provides an eco-friendly alternative. Additionally, reduced pesticide use enhances soil health and biodiversity, promoting sustainable cotton farming practices. Studies have shown that solar insect traps reduce pesticide dependency by 30-50%, thereby cutting costs while maintaining pest control efficiency, similar effects were observed in earlier findings (Kumar *et al.*, 2021). By using solar traps in cotton fields, farmers can lower pesticide expenses, reduce chemical residues in the environment, and promote sustainable agriculture. The net present value (NPV) for the 12-year cash flow analysis was calculated to be Rs. 10000. The financial system's benefit-cost ratio over the period was determined, resulting in a benefit-cost ratio of 1.93 for the solar photovoltaic (SPV) insect light trap, with a payback period of 2 years and 1 month. The SPV light trap operated for 10 to 13 hours, and the battery achieved a full charge in 6 hours using the SPV panel similar was in findings of Gavhande *et al.*, 2019 [4]. The UV-A blue light trap covered an area of 2.5 acres per two traps. The solar insect light trap proved to be an eco-friendly and effective solution for controlling various insect pests across different crops, eliminating the need for chemical pesticides in agricultural fields.

Conclusion

The data collected showcases a clear reduction in pest populations across BT Cotton, Non-BT Cotton, and Desi Cotton, with BT Cotton exhibiting the lowest overall pest presence. This result is consistent with earlier studies, such as Rajendran *et al.* (2018) [10], which highlighted the challenges of pest management in cotton crops and the potential of Integrated Pest Management (IPM) strategies. In comparing the effectiveness of different cotton varieties, the study reinforces the findings of Kranthi (2005), who reported the benefits of genetically modified (GM) cotton in controlling major pests like bollworms. The lower pest populations observed in BT Cotton further validate the efficacy of GM traits in reducing pest infestations. Additionally, Kumar *et al.* (2021) [6] emphasized the economic and environmental benefits of reducing pesticide use, a goal achieved through the use of solar-powered insect traps in this study. The integration of solar-powered traps into the IPM framework offers a sustainable solution for pest management, especially in regions with limited access to electricity. The traps' ability to operate independently of external power sources, such as wind, fuel, or electricity, aligns with the observations of Bhamre *et al.* (2005) [2], who highlighted the potential of such traps in enhancing pest control without disrupting ecosystems. The use of solar traps reduces the dependency on chemical pesticides, contributing to cost savings for farmers and promoting soil health and biodiversity, as demonstrated by the reduced pesticide use and enhanced ecological balance reported by Kumar *et al.* (2021) [6]. Moreover, the comparative analysis of insect orders across different cotton varieties provides

valuable insights into pest dynamics. The higher presence of Coleopteran insects in Non-BT and Desi Cotton fields, as compared to BT Cotton, underscores the importance of genetically modified traits in pest control. The study's findings on Hemipteran and Lepidopteran populations also reflect the observations of Rajendran *et al.* (2018) [10], who noted the challenges posed by sap-sucking pests and moths in cotton farming. In conclusion, the study demonstrates that solar-powered insect traps are effective in managing pest populations in cotton fields, particularly in reducing the reliance on chemical pesticides. By integrating these traps into IPM frameworks, farmers can achieve sustainable pest management, enhancing crop yield and reducing environmental impact. Future research should focus on optimizing trap design and deployment strategies to further improve efficacy and adoption rates.

Acknowledgement

We extend our heartfelt gratitude to the ICAR-AICRP Scheme on Energy in Agriculture and Agro-based Industries for providing the necessary funding and resources for this research project. We are deeply grateful to Dr. Punjabrao Deshmukh Krishi Vidyapeeth (PDKV), Akola, for supplying the solar insect traps and offering technical support throughout the research.

Reference

1. Bhandari GS, Jha SK, Giri YP, Manandhar HK, Jha PK, Devkota N, *et al.* Performance evaluation of locally developed black light trap for *maize* insects monitoring in Chitwan, Nepal. *Journal of Maize Research and Development*,2017;3(1):98-107.
2. Bhamre V, Sarkate MB, Wadnerkar DW, Ramtake RT. A solar light trap for monitoring and controlling of insect pests of *cotton*. *National Conference on Applied Entomology*, Udaipur,2005:26-28:20-21.
3. CITI India. CICI 2024 March Report. CITI India, 2024.
4. Gavhande A, Kalbande S, Khambalkar V. Development of eco-friendly solar photovoltaic insect light trap for pest control. *International Journal of Current Microbiology and Applied Sciences*,2019;8(07):95–101.
5. Kranthi KR, Jadhav DR, Kranthi S, Wanjari RR, Ali SS, Russell DA. Insecticide resistance in five major crop pests of *cotton* in India. *Crop Protection*,2002:21:449-460.
6. Kumar R, Sharma P, Singh V. Sustainable pest control using solar insect traps: A step towards eco-friendly farming. *Journal of Agricultural Innovations*,2021:18(3):145-162.
7. Kumar A, Kumar V, Chetna N, Ghalawat S, Kaur J, Kumari K, *et al.* Forecasting *cotton* (*Gossypium* spp.) prices in major Haryana markets: A time series and ARIMA approach. *The Indian Journal of Agricultural Sciences*,2024:94(9):1013–1018.
8. Mamun MRA, Keya AC, Alim MS, Hossen MA, Mondal MF, Soeb MJA. Potentiality assessment of solar-based LED light trap as pest management tool in *tea* (*Camellia sinensis* L.). *Smart Agricultural Technology*,2023:5:100304.

9. Rabbani MAER, Basir MS, Aliuzzaman M, Rahman A. Optimization of a solar light trap for controlling the pest in *rice* field. *Agricultural Engineering International: CIGR Journal*,2022;24(2):43-50.
10. Rajendran TP, Birah A, Burange PS. Insect pests of *cotton*. In: Springer eBooks, 2018, 361–411.
11. Reddy HL, Reddy AV, Hemanth S, Durga Prasad PJ. Modelling and optimization of solar light trap for reducing and controlling the pest population. *International Journal of Engineering Technology, Management and Applied Sciences*,2015;3(4):224-234.
12. Shaik F, Lingala SS, Veeraboina P. Effect of various parameters on the performance of solar PV power plant: A review and the experimental study. *Sustainable Energy Research*, 2023, 10(1).
13. Shwetha MN, Devi IS, Lavanya T, Suhasini K, Meena A. Growth in area, production, and productivity of *cotton* crop in India: A state-wise analysis. *International Journal of Environment and Climate Change*, 2022, 51–57.