

Development and performance evaluation of solar powered insect trapper in tomato crop using different color light

K. Khan^{1*}, P. R. Sarkar¹, M. Iqbal¹, H. A. Peerzada¹, M. S. Dar², S. A. Mushtaq³, M. Ali¹

(1. Division of Renewable Energy Engineering, Sher-e-Kashmir University of Agricultural Science and Technology, Srinagar-190025, India;

2. Centre for Artificial Intelligence and Machine Learning, Sher-e-Kashmir University of Agricultural Science and Technology, Srinagar-190025, India;

3. Faculty of Farm Machinery and Power Engineering, Sher-e-Kashmir University of Agricultural Science and Technology, Jammu-180009, India)

Abstract: Insect control constitutes one of the primary challenges in agriculture, with chemical pesticide usage adversely affecting soil biota, humans, and animals. To mitigate these impacts, a solar-powered insect trap was developed for the insect control. The device operates using solar photovoltaic technology and incorporates a solar module measuring 1050 cm², which charges the battery during daylight hours from 7:00 a.m. to 6:00 p.m. Evaluation of the trap was conducted utilizing a 5 W compact fluorescent lamp as the light source. The solar panel generated an average current of 0.27 A, with an input power of 32 W and an output power of 4 W. At the optimal temperature of 13°C–17.3°C, the solar-powered insect trapper collected an average of 72 non-favorable insects and 11 crop-friendly insects with the wind velocities between 4.30 and 5.30 km h⁻¹. Illumination with white light produced the highest insect capture rates, as indicated by lux meter readings between 9 and 10, followed by yellow and blue light in decreasing order of effectiveness. This solar insect trap exemplifies an eco-friendly pest management approach by integrating renewable energy with optimized light wavelengths to improve insect trapping efficiency, thereby reducing reliance on harmful chemical pesticides.

Keywords: conversion efficiency, light spectrum, pest management, solar trapper, sustainable agriculture

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1 Introduction

Eco-friendly pest management is a sustainable and chemical-free approach. Solar-powered trap is particularly effective in integrated pest management (IPM) systems, offering continuous operation in remote agricultural fields with low operational costs and zero carbon emissions. Studies have reported improved pest monitoring accuracy, reduced pest incidence, and

enhanced crop yield and quality when solar insect traps are deployed (Saxena et al., 2017; Peerzada et al., 2024).

In contrast, bug traps that ran on solar power emerged as a viable and eco-friendly pest control option. An automated solar-powered light trap was developed and evaluated to detect and capture insect pests in date palm cultivation (Mohammed et al., 2018). Developed and evaluated a solar photovoltaic insect light trap,

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***Corresponding author:** Kalay Khan, Junior Scientist. Division of Renewable Energy Engineering, Sher-e-Kashmir University of Agricultural Science and Technology, Srinagar, India. Email id: khan.kalay93@gmail.com.

comprising a 10 Wp Solar Photo Voltaic (SPV) panel, battery, controller, and light source, and tested its performance in cotton fields. The study recorded insect catches for blue, yellow, and (Ultraviolet-A) UV-A blue light traps, with the UV-A blue light trap capturing the highest number of insects, demonstrating the technical and economic feasibility of solar-powered insect light traps as eco-friendly tools for pest management in agricultural crops (Gavhande et al., 2019).

Evaluated the performance of a solar-powered automatic pest control system in rice yield, after evaluated found that solar-powered pest control devices can improve crop yield while reducing reliance on chemical methods and environmental hazards (Okoronkwo and Onu, 2020).

Chemicals are sometimes applied in excessive quantities or inappropriate types for the target pests, leading to ineffective pest control and high economic losses for farmers (Sarker, 2021). A portable solar-powered Light Emitting Diode (LED) insect traps were tested in a groundnut field. The traps were powered by a solar photovoltaic module and were fitted with colored LEDs (UV-405 nm, blue, green, and red) to evaluate insect attraction. Over a 15-day trial period, the UV LED trap captured significantly higher numbers of insects, including major field pests such as *Spodoptera litura* and *Aphis craccivora*, compared to other light colors. These results indicated that solar-powered LED traps were effective for attracting and monitoring pest populations in agricultural field (Balamurugan and Kandasamy 2021). An automated solar-powered insect trap was designed and fabricated for organic and integrated farming. The trap operated independently of grid power, attracted pests using light sources, and reduced reliance on chemical pesticides. The findings also supported that such systems were low-cost and eco-friendly alternatives for field pest control (Sathya Sai et al., 2021). Improved light trap designed and were evaluated for the early detection of invasive insect pests in shipping containers, and the results demonstrated that optimized light-based trapping systems significantly enhanced pest detection efficiency, thereby supporting their use in biosecurity and phytosanitary monitoring programs (Marchioro and Faccoli, 2021). Thus, the present study aims to develop and evaluate a solar-powered insect trapper Light

Dependent Resistor (LDR) based) as a sustainable pest management solution. The system harnesses solar energy during daylight hours to charge a battery, which subsequently powers a fan and LED lamps at night to attract, draw in, and trap insects automatically.

2 Methodology

The development of the LDR-based solar insect trap was carried out by first constructing a rigid support frame using Mild Steel (MS) angle iron, followed by the fabrication of a weather-resistant trap housing consisting of a funnel-shaped inlet and a detachable insect collection chamber fitted with fine mesh to prevent escape. A solar panel mounting bracket was fabricated and fixed at an optimal tilt angle to maximize energy capture, while a sealed enclosure was prepared to a box on the top for battery, charge controller, and LDR control circuit. A high-intensity LED module was installed. A funnel was used to carry the pests to suction chamber. All electrical components were interconnected using insulated wiring, securely fastened, and waterproofed using sealants and gaskets. Finally, the fully assembled system was tested for mechanical stability, automatic day–night operation, and reliable insect trapping performance under field conditions in tomato fields.

2.1 Components of developed solar trapper

The stand, solar panel, sealed lead acid battery, container, exhaust fan, funnel, charge controller, and LDR circuit are the components (Table 1) that make up the modern solar-powered trapper.

2.1.1 Frame

Frame has four legs made by angle iron, and all the components of trapper are attached to it. A solar panel is attached on the top at 30° angle.

2.1.2 Solar panel

A solar module is an assembly of solar cells mounted in a framework for installation. Solar model generates direct current using sunlight. Specifications of the module are presented in Table 2.

2.1.3 Battery

A 12 V 7.2 Ah rechargeable battery is used to store the electrical energy for later use.

2.1.4 Battery box

Battery box is made of cast iron sheet. The overall

dimension (L×W×T) of box was 350 mm×150 mm×1.75 mm. It was rectangular in shape and connected on top of the frame at 30° angles. Connection of solar panel is

connected to charge controller and battery which is installed in battery box. LDR circuit is also connected to system.

Table 1 Specifications of developed solar powered insect trapper

No.	Specifications	Dimensions
1	Photovoltaic panel	10 Wp
2	Battery	12 V and 7 Ah
3	Battery box	35 cm×18 cm×38 cm
	Container	
4	Height	38.10 cm
	Top diameter	29.00 cm
	Bottom diameter	25.40 cm
5	Bulb (compact fluorescent lamp, CFL)	5 watts
6	Height of leg	131cm
7	Width of frame	40 cm
	Funnel	
8	Height	19 cm
	Top diameter	20.82 cm
	Bottom diameter	15.25 cm
9	Total weight of trapper	20.5 kg.

Table 2 Specifications of the solar panel used in developed trapper

No.	Particular	Dimensions
1	Brand	Sun star
2	Model	SS -1220
3	Type of cell	Mono/Multicrystalline Silicon
4	Front face	Front face
5	Encapsulate	Ethylene vinyl acetate
6	Frame	Anodized aluminum alloy
7	Size	35×30 cm
8	Peak power (watt)	15
9	V _{oc}	22
10	I _{sc}	12
11	Cell conversion efficiency (%)	14%-20%
12	Number of cells	36
13	One cell generates approx.	0.5-0.6 V
14	Total cell area	1050 cm ²
15	Weight	2 kg

2.1.5 Container frame

It was circular in shape and made of cast iron. The diameter of container frame was 28 cm and the height from the bottom of trapper was 8.5 cm. Container of insects was fixed in container frame.

2.1.6 Trapper container

Trapper container was circular in shape and made of plastic. Top diameter of container was 27.90 cm and bottom 25.40 cm. The container of trapper works like a reservoir which holds the insects with the help of funnels and insect net.

2.1.7 Insect net

An insect net is composed of some sort of net made of cloth or fine mesh that is attached to a funnel and container.

2.1.8 Funnel

A narrow (at bottom) and wide (at top) funnel is used

for guiding insects into a small opening to carry the insects in container.

2.1.9 Compact fluorescent lamp (CFL)

Three CFL used of different color light that is white, blue and yellow, each was 5 watts.

2.1.10 Exhaust fan

A DC exhaust fan is used in trapper for sucking the insects into the container. The main purpose of fan is that it increases the insect collection efficiency of trapper.

2.1.11 Charge controller

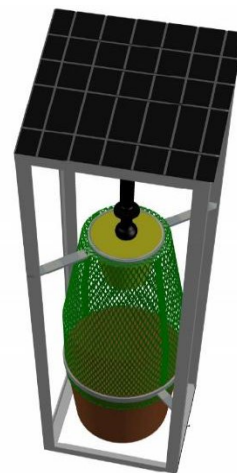
A10A, 12V/24Vcharge controller is used to develop an automated solar insect trap to adjusts the current and voltage that is delivered to the loads. The specifications of used charge controller are described in Table 3.

2.1.12 LDR circuit

A light dependent resistors (LDR) circuit assembled for automatic ON/OFF according to sunrise and sunset. It

is a component that has a resistance that changes with the light intensity that falls upon it means it is used to indicate

the presence or absence of light. Circuit diagram of LDR is shown in Figure 1b.



(A) Physical prototype showing front and side perspectives (B) Complete circuit diagram of the LDR-based automatic switching system

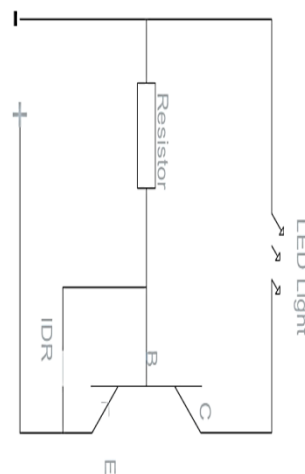


Figure 1 Developed solar-powered insect trapper system

2.2 Working mechanism of the developed trapper

The working principle of the developed prototype is very simple. When the sunlight irradiates on surface of solar panel, parts of the photon are absorbed by the panel which is made of semiconductor (silicon), and are converted into electricity or heat current. Generated current is stored in battery for later use of CFL at night. The CFL light automatically turns ON/OFF with the help of LDR. It automatically turns ON at sunset and automatically turns OFF at sunrise. When CFL is ON at night, different types of insects move towards trapper CFL, exhaust fan sucks these insects from light source into container of trapper through a funnel. The developed trapper is shown in Figure1a.

2.3 Performance evaluation of panel used in solar powered insect trapper

Performance evaluation of solar panel on the basis of

following terminology:

2.3.1 Solar panel input.

The rated voltage of a 12 Volt solar module is generally around 17.0 V, but controller reduces the voltage approximately 13 to 15 V which is required for charging the battery. For finding the solar module input we consider panel current, solar isolation data, cell area and number of cells (Bombale et al., 2010):

$$\text{Average solar input (watt)} = \frac{\text{Total panel area (cm}^2\text{)} \times \text{Solar insolation (mWcm}^{-2}\text{)}}{1000} = A$$

$$\text{Area packing ratio} = \frac{\text{Total panel area (cm}^2\text{)}}{\text{Total area of solar cell (cm}^2\text{)}} = B$$

$$\text{Specific average solar input per cell (watt)} = \frac{\text{Average solar input (A)}}{\text{Area Packing ratio (B)}} =$$

2.3.2 Solar panel output

The output of solar module means, total amount of current generated by the module, which is stated watts (W). Solar panel output is expressed in units of watts (W)

(1)

and represents the module theoretical power output under ideal temperature and light intensity (Bombale et al., 2010):

$$\text{Panel output (watt)} = \text{Panel voltage (V)} \times \text{Panel current (I)} \quad (2)$$

2.3.3 Conversion efficiency of panel (%)

It is the ratio of voltage and current developed by solar array system to the input of array (Bombale et al., 2010):

$$\text{Conversion efficiency (CE)} = \frac{\text{Panel Outputs (Watt)}}{\text{Input to Panel (Watt)}} \times 100 \quad (3)$$

2.3.4 Overall efficiency of the trapper (%)

It is the ratio of energy actually used for bulb to the incoming energy from the sun and is expressed as percentage (Bombale et al., 2010):

$$\text{Overall efficiency of system (OE)} = \frac{\text{bulb wattage (Watt)}}{\text{Input energy (watt)}} \times 100 \quad (4)$$

3 Results and Discussion

The experiment was conducted during the month of July 2021 at the experimental research farm of the Division of Vegetable Science, Faculty of Horticulture (FoH), SKUAST–Kashmir, Shalimar Campus, Srinagar, to evaluate the field performance of the developed solar-powered insect trap in a tomato crop. The experimental site was geographically located at approximately 33.9167° N latitude and 76.6667° E longitude, with an average altitude of about 1,587 m above mean sea level. The insect trap was installed within the tomato field, with the compact fluorescent lamp (CFL) positioned at a height of 850 mm above the ground to ensure effective insect attraction and trapping under field conditions.

3.1 Overall performance of solar panel

Monitoring voltage, current, panel input and output power, conversion efficiency, and overall system efficiency allowed for the evaluation of the solar panel's overall performance. The Indian Meteorological Department in Srinagar, J&K, observed ambient conditions including temperature and sun insolation. The average temperature for the three test days (DI, DII, and DIII) was 30°C, 32°C, and 25°C, respectively, with the highest daily temperature peaking at 14:00 hours. 44, 37, and 37 mW cm⁻² were the mean values of solar insolation. The panel had input and output powers of 32 W and 4 W, respectively, and generated an average current of 0.27 A.

The system's overall efficiency was 28.7%, with an average conversion efficiency of 12.5%. These findings support earlier research in which conversion efficiencies ranged from 13.7% to 18.2% and solar insolation ranged from 45 to 80 mW cm⁻² (Bombale et al., 2010). In a similar vein, the output power and current readings match the 2.84–6.34 W and 0.2–0.4 A reported ranges, respectively. Figure 2 shows the solar panel's overall performance data utilized in the test.

3.2 Effect of different light colors on insect Collection

White, yellow, and blue CFL lights were used to test the trap's ability to catch insects. Concurrently recorded were the relative humidity, wind speed, ambient temperature, and light intensity (lux). The Division of Entomology at SKUAST-Kashmir, India identified the different types of insects. With ambient nighttime temperatures averaging 15.16°C, wind speeds ranging from 4.3 to 5.3 km h⁻¹, and light intensity of around 9.66 lux, an average of 72 pests and 11 crop-friendly insects were captured under white light (refer to Table 3). About 89.9% of the insects that were caught were not favourable.

At somewhat higher wind speeds (7.7 km h⁻¹) and lower light intensities (6.16 lux), the trap caught an average of 61.7 non-favourable and 11 crop-friendly insects under yellow light (see Table 4). The percentage of pests trapped was also similar (~93.1%). Under lower temperatures (~13.6°C), larger wind variance, and the lowest light intensity (~3.33 lux), blue light (see Table 5) attracted the fewest insects, with an average of 72 non-favourable and 11 crop-friendly insects, with around 90.2% pests. Light intensity, colour spectrum, temperature, and wind speed all had a significant impact on the quantity of insects captured; lower light lux and less-than-ideal climatic circumstances resulted in decreased catch rates.

Numerous insect species were observed, including fruit worms, tree crickets, beetles, moths, mosquitoes, and whiteflies. These results are consistent with the larger body of research showing that spectral characteristics and light color have a significant impact on insect behaviour and trap effectiveness. Due to its wide spectrum emission and higher intensity, white light usually draws a wider variety and more pest species. Yellow light comes in second in terms of attractiveness, and blue light draws fewer insects, probably as a result of its lower intensity and shorter wavelength (Ananya et al., 2020; Bombale et

al., 2010).

Furthermore, recent studies highlight those environmental parameters like temperature and wind speed, as well as trap installation (height and position), have a significant impact on capture rates in addition to color spectrum tuning (Marchioro and Faccoli, 2021). Research conducted in rice, tea, and greenhouse settings shows that solar LED traps decrease the need for chemical pesticides while simultaneously increasing the effectiveness of pest capture (Balamurugan and

Kandasamy, 2021; Marchioro and Faccoli, 2021) for instance, discovered that improving catch efficiency and specificity required careful consideration of installation height and trap wavelength.

Together, the study's findings support these findings and emphasize the significance of carefully choosing LED colors (white light is best) and creating ideal environmental conditions for sustainable, environmentally friendly pest management with solar-powered light traps.

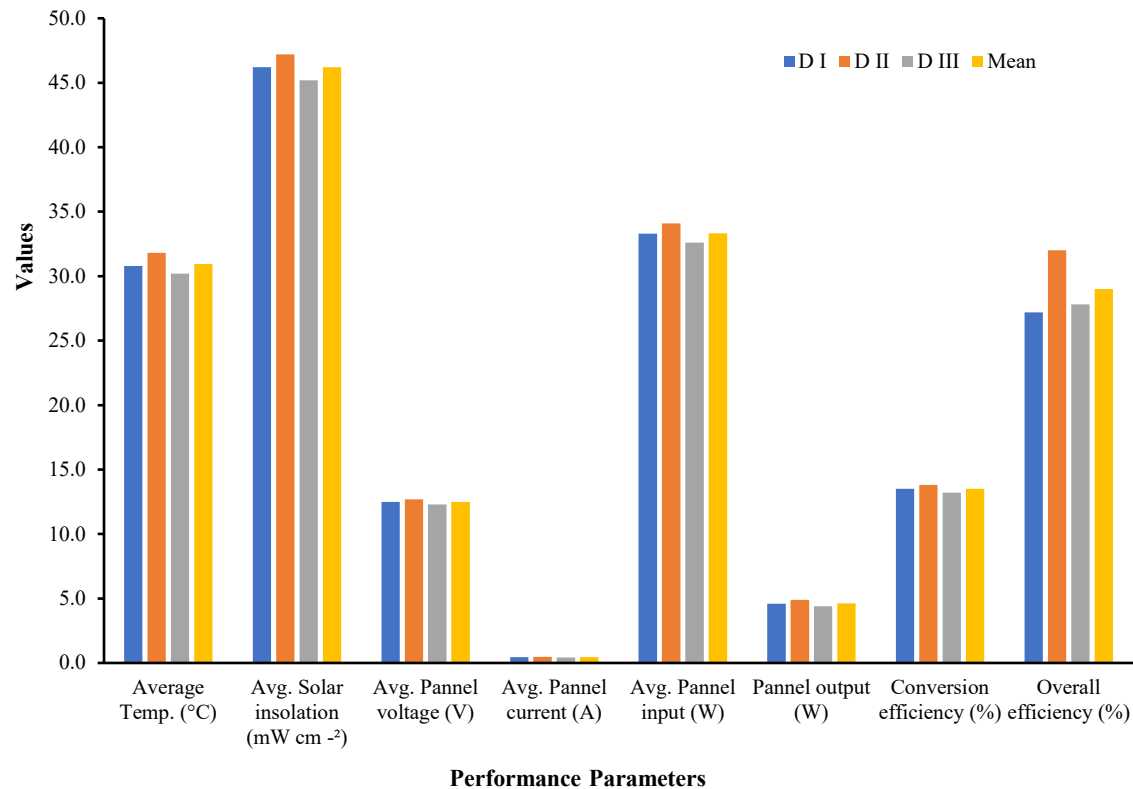


Figure 2 Overall performance of solar panel when trapper used in tomato field

Table 3 Number of insects collected (non-favorable insects and crop friendly insects) in trapper while using white light and other observations

No.	Parameters	N-I	N-II	N-III	Avg.
1	Date of test	02/07/2021	05/07/2021	06/07/2021	-
2	Net test duration, h	9.50	9.50	9.50	9.5
3	Name of Crop	Tomato			
4	Height of crop, mm	1110	1110	1110	1110
5	Crop Season	Kharif			
6	Ambient Temperature, °C (night)	17.3	15.2	13	15.16
7	Relative Humidity	65	68.5	71	68.16
8	Wind speed, km h ⁻¹	5.30	4.50	4.30	4.7
9	Lux Meter Reading (one meter from light)	10	9	10	9.66
10	Number of insects trapped and Species (Non-favorable insets)	123	61	32	72
11	Number of insects trapped and Species (Crop friendly insets)	7	12	3	7.3
12	Percentage of non-favorable insects trapped	94.61	83.56	91.42	89.86

Table 4 Number of insects collected (non-favorable insects and crop friendly insects) in trapper while using yellow light and other observations

No.	Parameters	N-I	N-II	N-III	Avg.
1	Date of test	15/07/2021	16/07/2021	17/07/2021	-
2	Net test duration, h	9.50	9.47	9.48	9.48
3	Name of Crop	Tomato (Another field)			
4	Height of crop, mm	1240	1240	1240	1240
5	Crop Season	Kharif			
6	Ambient Temperature, °C (night)	16	14.53	17.5	16.01
7	Relative Humidity	68	72	62	67.33
8	Wind speed, km/h	7.30	8.20	7.60	7.70
9	Lux Meter Reading (one meter from light)	6	6	6.5	6.16
10	Number of insects trapped and Species (Non-favorable insects)	53	88	44	61.66
11	Number of insects trapped and Species (Crop friendly insects)	4	7	3	4.67
12	Percentage of non-favorable insects trapped	92.98	92.63	93.61	93.07

Table 5 Number of insects collected (non-favorable insects and crop friendly insects) in trapper while using blue light and other observations.

No.	Parameters	N-I	N-II	N-III	Avg.
1	Date of test	24/07/2021	25/07/2021	26/07/2021	-
2	Net test duration, h	10.20	10.20	10.20	10.20
3	Name of Crop	Tomato (another field)			
4	Height of crop, mm	1520	1520	1520	1520
5	Crop Season	Kharif			
6	Ambient Temperature, °C (night)	15	13.40	12.50	13.63
7	Relative Humidity	74	78	80	77.33
8	Wind speed, km/h	8.44	5.33	7.55	7.13
9	Lux Meter Reading (one meter from light)	4	3	3	3.33
10	Number of insects trapped and Species (Non-favorable insects)	45	39	57	47
11	Number of insects trapped and Species (Crop friendly insects)	3	7	5	5
12	Percentage of non-favorable insects trapped	93.75	84.78	91.93	90.15

4 Conclusion

The development and field testing of the solar-powered insect trapper demonstrate its versatility and efficiency as a sustainable pest control method for tomato crops. By combining automated control, sustainable solar energy, and optimal light selection, the device minimizes environmental and health hazards by reducing the need for chemical pesticides. Due to its greater intensity and wider spectrum, white CFL light outperformed yellow and blue lights in the field, capturing almost 90% of less-than-ideal insects. The solar panel demonstrated dependable performance in mild agroclimatic conditions with a conversion efficiency of 12.5% and an overall system efficiency of 28.7%. Accordingly, solar insect traps can be very helpful in sustainable agriculture by promoting integrated pest management techniques that

preserve soil health and crop productivity. Future studies focused on improving solar hardware, optimizing the light spectrum, and adjusting installation parameters will increase the systems' versatility and effectiveness in a range of agricultural contexts.

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