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Designing Solar Power Plants as a Source of Electricity for Insect Traps

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Abstract

This study proposes the design and evaluation of a solar-powered insect trapping system as an environmentally friendly solution for pest control in agricultural fields. The system integrates a photovoltaic (PV) module as the primary energy source with a microcontroller-based control unit. A Passive Infrared (PIR) sensor is employed to detect insect movement, while an electric grid mechanism is used for pest eradication. The system is controlled using an Arduino microcontroller to ensure synchronized operation between detection and execution components. The research methodology involves system design, hardware and software implementation, and field testing in rice cultivation areas. Experimental results indicate that the device provides an effective illumination radius of approximately 5 meters and successfully captured 87 insect pests within two days of operation. Furthermore, the system demonstrates stable energy performance, with efficient battery charging during the daytime and reliable operation at night. These findings confirm that the proposed solar-powered insect trap is a viable, sustainable, and eco-friendly alternative to conventional pesticide-based pest control methods. Future work will focus on optimizing light intensity, improving sensor accuracy, and integrating ultraviolet light to enhance insect attraction.

Keywords: Microcontroller; Solar Panel; Insect Pests; insect trap

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1. Introduction

The food sector in the agricultural aspect in Indonesia is generally dominated by the commodity of rice (Oryza sativa), which is the main food source for the majority of the population[1-3]. Rice plays an important role in national food security. Based on data President Director of Perum Bulog, the national rice consumption requirement in 2024 is projected to reach 31.2 million tons, as stated in the national food balance prognosis prepared by BAPENAS for the period from

January to December 2024 [4]. However, rice productivity still faces various challenges, one of which is the attack of plant-disturbing organisms (OPT) [5-7]. Among these OPTs, insect pests pose a serious threat, particularly the brown planthopper, which is classified as difficult to control [8-9]. The pests generally attack of rice (Oryza sativa) during the first growth by sucking rice stems that has the potential to transmit diseases such as tungro and dwarf virus. Moreover, several cases such as attack of planthoppers that can make the condition as hopper burn, which is characterized by damage to the plant's cell tissues, indicated by a change in leaf color to yellowish-brown, leading to plant death and posing a risk of crop failure [10-12]. To overcome this situation, chemical, such as pesticides, is commonly used to eliminated pests with the consequences such as less optimal in the long term, as it can have negative impacts on the agricultural environment, particularly in the form of pollution in the rice field ecosystem[13-15].

Several less chemical alternatives have been proposed [13-15], the innovative approaches that can be applied is the utilization of pest repellent devices that operate with a lighting system. Lighting system using phototaxis as light trap that can attract pests effectively. In field practice, the use of light traps can reduce pesticide use by up to 83%, representing an effective suppression of pest attacks that drive chemical use. In addition to providing energy independence, the use of solar panels also supports efforts to achieve the Sustainable Development Goals (SDGs). This aligns with goal with SDGs 7, which emphasizes the importance of clean and affordable energy, as well as goal number 12, which encourages responsible production and consumption patterns toward the environment.

One of the innovative solutions that has the potential to be developed is the application of renewable energy as the main resource in the operation of technology-based insect pest control devices. Photovoltaic have become one of the most relevant options because they utilize sunlight to generate electrical energy. The energy generated can be supply various electronic devices, including pest control tools such as ultraviolet lamps and insect suction fans, which are specifically designed to attract and capture pests efficiently. Several studies using PV system for algaculture such as [16-18]. The study examined the design of an autonomous PV used as an energy source for insect pest traps. This system involves several main components, such as solar panels that play a role in converting solar energy into electricity, an SCC that manages the flow of charging and discharging power between the panels, batteries, and loads, and batteries as the medium for energy storage. This stored energy is then used to operate a microcontroller-based system, with Arduino as the control center, RTC DS3231 as the time input, and an OLED LCD and relay as the system outputs.

Based on the background description and referring to various previously developed planthopper traps, including similar research, the researcher designed an innovative new tool in the form of an electric shock system. This innovation utilizes a conductor wire as a current carrier and is equipped with a PIR sensor that functions to detect the presence of insects when they approach the device.

2. Methods

This study adopts a Research and Development (R&D) approach involving system design, implementation, and experimental validation [19-20]. The developed system consists of a photovoltaic (PV) module, a solar charge controller (SCC), a battery storage unit, and a microcontroller-based control system.

As shown in **Figure 1**, the system integrates input components, including a PIR sensor and a Real-Time Clock (RTC) module, which are processed by an Arduino Nano microcontroller. The output components include a high-power LED (HPL) lamp and an electric grid (mosquito racket module), both powered by the battery. The PV module converts solar energy into electrical energy, which is regulated by the SCC to ensure safe charging of the battery. The stored energy is then used to operate the system during nighttime conditions. The RTC module controls the operating schedule, while the PIR sensor detects insect movement and triggers the electric grid for pest elimination.

2.1 Application Design

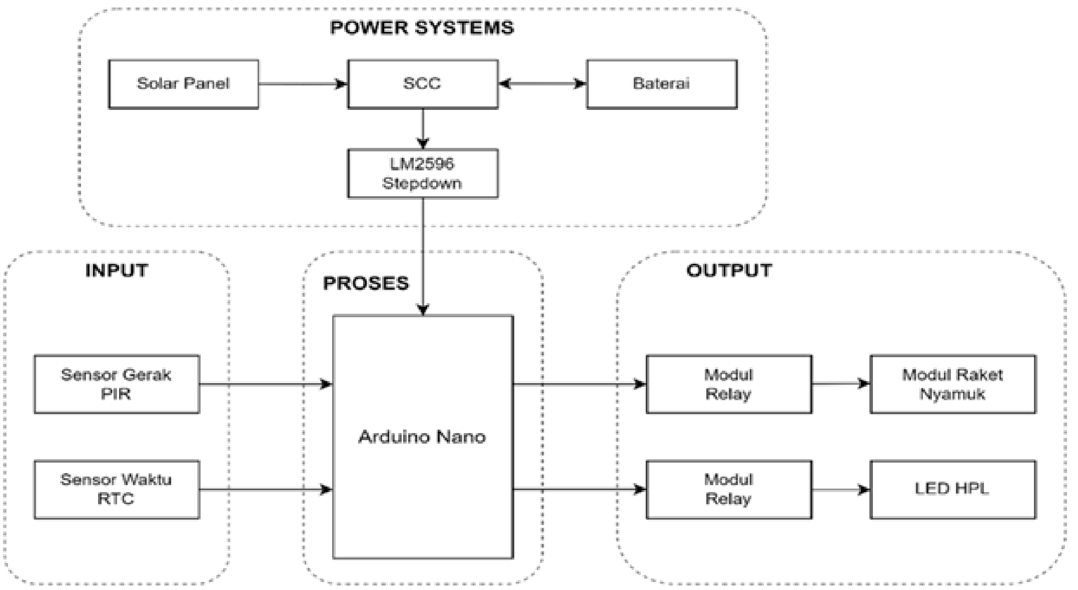

Figure 1. Block Diagram.

The PV array serves as the main power source for the insect trap device, where the generated energy is used to meet the needs of the solar power generation system as soon in **Figure 2**. PV convert solar energy into electrical energy that controlled by a Solar Charge Controller (SCC) for battery charging and protection against overcharging. The battery serves as a power source when the PVs are inactive, with the voltage adjusted using the LM2596 step-down module. The PIR sensor is used to detect the presence of insects, while the RTC regulates the operating time of the device. Arduino Nano acts as the control center that processes sensor data and activates two relays, namely the relay to operate the mosquito racket as an electric shock system and the relay to turn on the HPL-LED as an insect attractor. Both output components receive direct power supply from the battery.

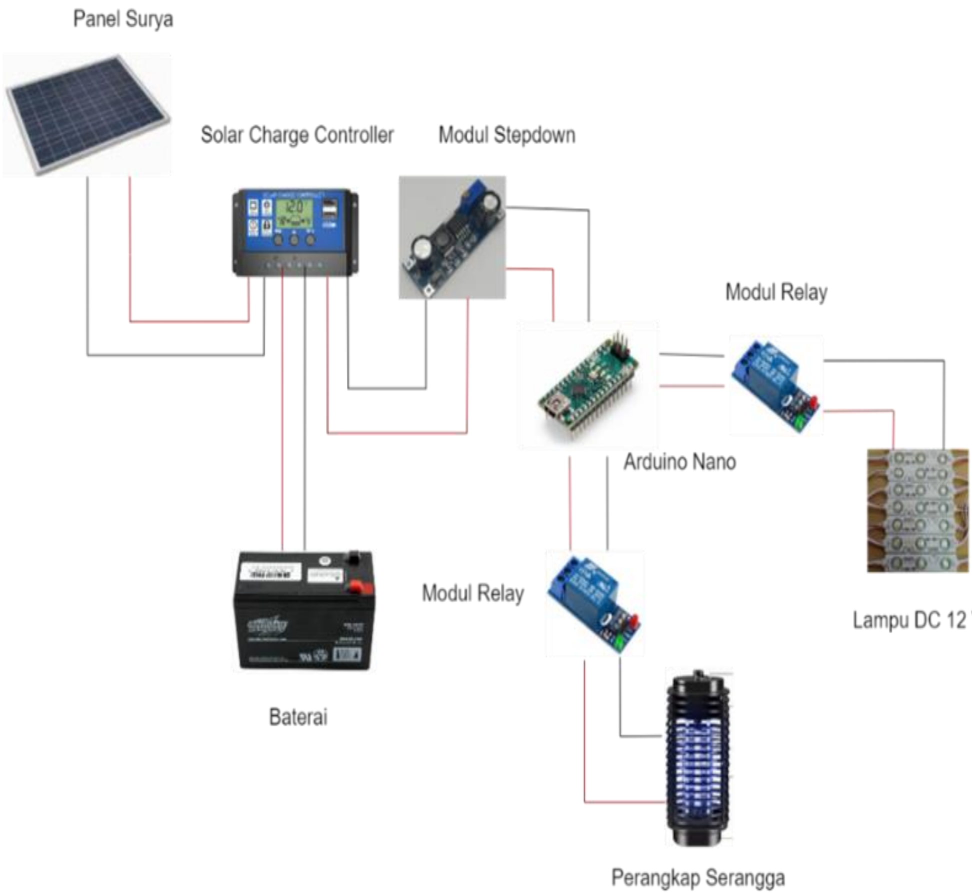

Figure 2. Solar Power System Circuit.

2.2 Operation System

The working system of the PV as a power source for the insect trap device can be seen in the flowchart diagram as shown in **Figure 3**. Based on the displayed flowchart, the system begins with the initialization process of all input and output components, including the RTC sensor, PIR sensor, HPL LED lamp, and insect racket module. After the initialization stage is complete, the system reads the actual time data from the Real Time Clock (RTC) module. Next, the time is compared with the predetermined operational schedule, such as the nighttime period when the planthopper pests are active. If the time does not match the settings, the light remains off, and the system re-reads the time from the RTC. Conversely, when the time meets the criteria, the HPL LED light will be turned on to attract planthopper insects that exhibit positive phototaxis. When the light is activated, the PIR sensor starts working to detect the movement of insects approaching the light source. The system then checks for the presence of movement detected by the sensor. If no movement is detected, the insect racket module remains inactive. However, if the PIR sensor detects movement, the system will activate the insect racket to deliver an electric shock as a extermination mechanism.

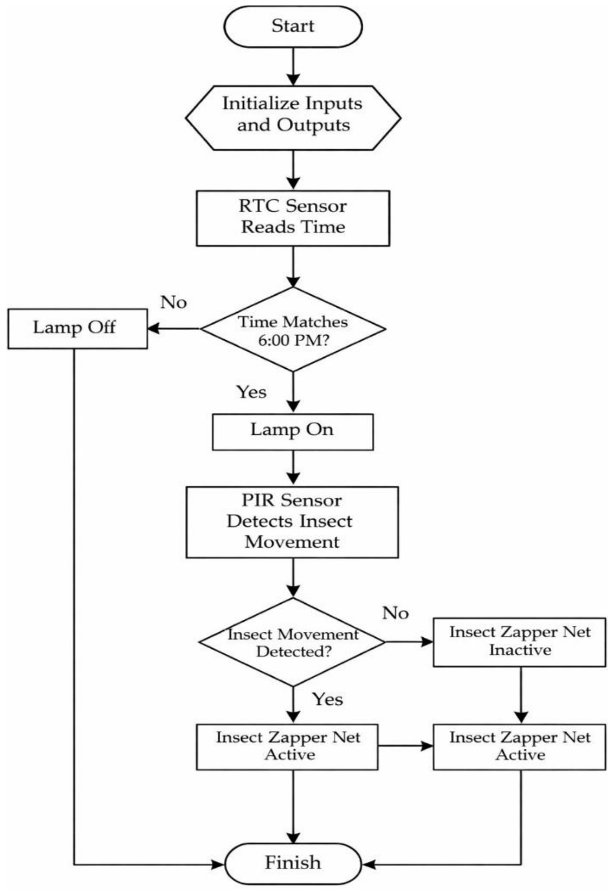

Figure 3. Flowchart System.

The working principle of this system utilizes the positive phototactic behavior of planthoppers, which tend to be attracted to light, especially at nite. The RTC module functions to regulate the operational time so that the lights only turn on at specific intervals when the pests are active, thereby minimizing battery power consumption. The PIR sensor plays a role in detecting insect movement, and when detected, a signal is sent to the relay to activate the racket module.

The energy source of the system comes from PV equipped with a SCC to control the battery charging process. Thus, the device can operate independently in agricultural fields without relying on PLN's electricity supply. This renewable energy-based approach becomes an environmentally friendly and effective solution in controlling rice planthopper pests without the use of chemical pesticides that could potentially pollute the rice field environment.

Figure 4. Physical Form of the Solar Panel System

3.Results and Discussion

3.1 Installation of the Solar Power System and Microcontroller

The developed system is the final result of the design process and consists of two main components, namely the Solar Power Generation Module (PLTS) and a microcontroller circuit as the control center. The stages of the system design are presented in the form of a block diagram in **Figure 4**. This tool is designed as a planthopper pest trap and has been directly implemented in the agricultural fields of Panggungrejo Village, Kepanjen District, Malang Regency. On the other hand, the physical realization of the microcontroller is the tangible form of the schematic design that has been created previously. The schematic was designed using a PCB board as the circuit base, complete with pin headers that serve as both mounting points and connectors between components in the microcontroller system.

Table 1. Technical Testing Results Data

No	Components	Condition	
		Good	Broken
1	Solar Panel	Yes	-
2	Solar Charger Controller	Yes	-
3	Baterai	Yes	-
4	Microcontroller	Yes	-
5	RTC	Yes	-
6	DC-DC Converter	Yes	-
7	Relay	Yes	-
8	Lamp	Yes	-

3.2 Technical Test

Table 2. 48-Hour System Performance Measurement

Time	Solar Panel		Battery		Load		Condition
	V	I(A)	V	I(A)	V	I(A)	
06.00	12	0,30	12	0,30	-	-	*Charging*
07.00	12,7	0,51	12,6	0,51	-	-	*Charging*
08.00	12,9	0,72	12,8	0,72	-	-	*Charging*
09.00	12,9	1,57	12,8	1,57	-	-	*Charging*
10.00	13	2,17	12,8	2,17	-	-	*Charging*
11.00	13,2	2,52	12,9	2,52	-	-	*Charging*
12.00	13,3	2,69	13	2,69	-	-	*Charging*
13.00	13,2	2,59	13	2,59	-	-	*Charging*
14.00	12,9	2,16	12,8	2,16	-	-	*Charging*
15.00	12,9	1,56	12,8	1,56	-	-	*Charging*
16.00	12,8	0,84	12,7	0,84	-	-	*Charging*
17.00	12,8	0,30	12,7	0,30	-	-	*Charging*
18.00	-	-	12,6	0,32	12,6	0,32	*Discharging*
19.00	-	-	12,5	0,32	12,5	0,32	*Discharging*
20.00	-	-	12,5	0,32	12,5	0,32	*Discharging*
21.00	-	-	12,5	0,32	12,5	0,32	*Discharging*
22.00	-	-	12,5	0,32	12,5	0,32	*Discharging*
23.00	-	-	12,5	0,32	12,5	0,32	*Discharging*
00.00	-	-	12,4	0,32	12,4	0,32	*Discharging*
01.00	-	-	12,4	0,32	12,4	0,32	*Discharging*
02.00	-	-	12,4	0,32	12,4	0,32	*Discharging*
03.00	-	-	12,3	0,32	12,3	0,32	*Discharging*
04.00	-	-	12,3	0,32	12,3	0,32	*Discharging*
05.00	-	-	12,3	0,32	12,3	0,32	*Discharging*
06.00	12,4	0,35	12,4	0,35	-	-	*Charging*
07.00	12,5	0,72	12,5	0,72	-	-	*Charging*
08.00	12,6	1,20	12,6	1,20	-	-	*Charging*
09.00	12,7	1,56	12,7	1,56	-	-	*Charging*
10.00	12,8	2,17	12,8	2,17	-	-	*Charging*
11.00	13,2	2,56	13,2	2,56	-	-	*Charging*
12.00	13,3	2,70	13,3	2,70	-	-	*Charging*
13.00	13,2	2,53	13,2	2,53	-	-	*Charging*
14.00	12,9	2,17	12,9	2,17	-	-	*Charging*
15.00	12,9	1,56	12,9	1,56	-	-	*Charging*
16.00	12,8	0,84	12,8	0,84	-	-	*Charging*
17.00	12,8	0,30	12,8	0,30	-	-	*Charging*
18.00	-	-	12,8	0,32	12,8	0,32	*Discharging*
19.00	-	-	12,8	0,32	12,8	0,32	*Discharging*
20.00	-	-	12,7	0,32	12,7	0,32	*Discharging*
21.00	-	-	12,7	0,32	12,7	0,32	*Discharging*
22.00	-	-	12,7	0,32	12,7	0,32	*Discharging*
23.00	-	-	12,6	0,32	12,6	0,32	*Discharging*
00.00	-	-	12,6	0,32	12,6	0,32	*Discharging*
01.00	-	-	12,6	0,32	12,6	0,32	*Discharging*
02.00	-	-	12,5	0,32	12,5	0,32	*Discharging*
03.00	-	-	12,5	0,32	12,5	0,32	*Discharging*
04.00	-	-	12,5	0,32	12,5	0,32	*Discharging*
05.00	-	-	12,5	0,32	12,5	0,32	*Discharging*

In the solar power system, three main components that were tested include the solar panel, solar charge controller, and battery. The test results, as Table 1, show that these three components are functioning well. The PV successfully captures solar energy and converts it into electricity, the solar charge controller is able to regulate the battery charging process stably, and the battery can store and provide power when needed.

Meanwhile, in the microcontroller system, there are several important modules such as Arduino Nano, RTC (Real Time Clock) module, step-down module, relay, and DC lamp. All these modules operate normally. The Arduino runs the program according to instructions, the RTC provides accurate time for the automation system, the step-down module adjusts the electrical voltage to meet the component needs, and the relay functions as a switch to connect the current. The DC lamp, as the system output, also lights up well when activated.

3.3 Functional Test

The testing of the solar panel and microcontroller system was conducted on three main components: the solar panel, battery, and load, with observations over two days as shown in Tables 2. The test results indicate that the charging process in the solar power system occurs gradually. In the morning, the solar panels start generating electricity with low voltage and current, then significantly increase during the period from 10:00 AM to 1:00 PM as the intensity of sunlight increases, making the battery charging process optimal. During the day, electrical energy is fully used to charge the batteries without supplying any load.

At nite, the solar panels do not operate, and the system switches to using power from the batteries to supply the load steadily until morning, with a gradual decrease in battery voltage. This indicates adequate battery capacity and the efficient performance of the energy management system. Although there are slight differences in voltage and current values between the first and second days, the system overall shows consistent performance and is able to operate reliably without disruptions to the main components.

3.6 Battery Endurance Test

Based on the five-day observation period as seen in **Figure 5**, the battery exhibited a highly consistent discharge pattern. The average peak voltage is 13.04 V at 18:00, the minimum average voltage is 12.59 V by 06:00. The minimal voltage drops, approximately 3.4%, indicates that the energy consumption of the DC lamp and the high-voltage grid is well-balanced with the battery capacity. From the data, the system successfully recovered its charge every day. Despite the nocturnal load, the "Bar" indicator remained at level 4 or 5 throughout the duration of the test. This confirms that the Solar Power System (PLTS) provides an adequate charging current during daylight hours to offset the energy used at night, ensuring long-term operational sustainability. At the end of each cycle (06:00), the voltage remained well above the typical "Low Voltage Disconnect" threshold (usually 11.5 V – 12.0 V). This provides a significant safety margin, suggesting that the device can likely withstand several consecutive cloudy days without total power failure.

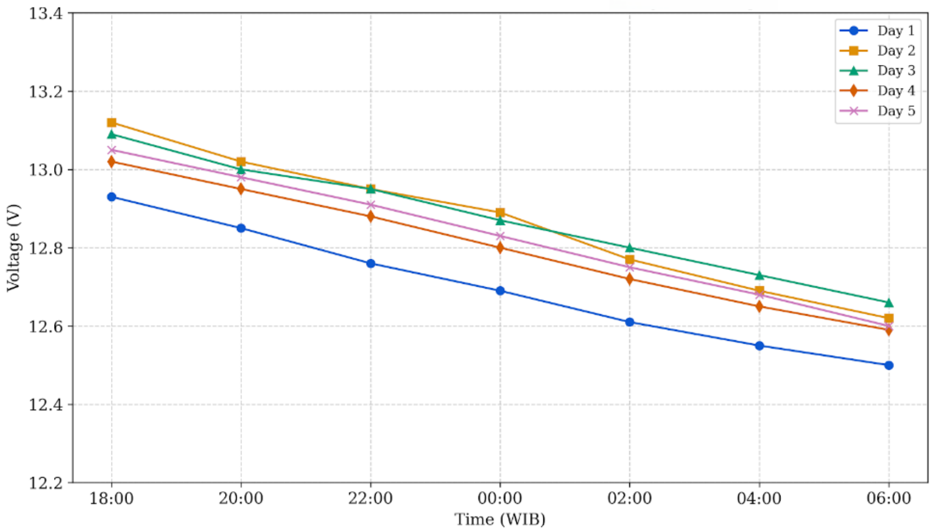

Figure 5. Voltage battery Discharge Curve

3.7 Discussion

Technical evaluations demonstrate the successful integration of the Solar Power System (PLTS) and the Arduino Nano microcontroller unit in the operation of automated pest traps. The Real-Time Clock (RTC) sensor proved crucial for energy conservation, enabling the system to determine the periods of solar charging during daylight hours and operational activity during the night. The consistent performance of the components during technical testing provides a strong basis for the device's autonomous operation in remote areas, including the agricultural regions of Panggungrejo Village. This feature removes the need for manual assistance or additional power from the national electricity grid (PLN).

The experimental results demonstrate that the proposed system operates effectively under real field conditions. The solar power system shows stable performance, with optimal energy generation occurring between 10:00 AM and 1:00 PM, corresponding to peak solar irradiance. During nighttime operation, the system relies on battery storage to power the load components. The battery voltage decreases gradually, indicating efficient energy consumption and adequate storage capacity. The observed voltage drop of approximately 3.4% over the testing period suggests a well-balanced energy management system.

From an application perspective, the system successfully captured 87 insect pests within two days, confirming the effectiveness of the light-based attraction mechanism. The illumination radius of approximately 5 meters provides sufficient coverage for small-scale agricultural implementation. Overall, the integration of the

PV system and microcontroller-based control demonstrates a reliable and sustainable solution for pest management, particularly in remote areas without access to grid electricity.

4. Conclusion

This study successfully developed a solar-powered insect trapping system utilizing a photovoltaic energy source and a microcontroller-based control mechanism. The system integrates a PIR sensor for motion detection, an RTC module for scheduling, and an electric grid for pest eradication. Experimental results confirm that the system operates effectively, achieving a 5-meter illumination range and capturing 87 insect pests within two days. Additionally, the energy management system demonstrates stable performance, ensuring continuous operation through efficient battery charging and discharging cycles. The proposed system offers a sustainable and environmentally friendly alternative to conventional pesticide-based pest control. Future improvements may include optimizing light wavelength, enhancing sensor sensitivity, and expanding system scalability for broader agricultural applications.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials - All data is available from the authors.

Competing interests - The authors declare no competing interest.

Additional information - No additional information from the authors.

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