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Development of an Internet of Things (IoT)-Based Solar Chilli Pepper Dryer

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Abstract
Potassium found in chilli pepper works in conjunction with folate to lower the risk of developing heart disease in human. Because of this, its storage and consumption are inevitable. There are a lot of disadvantages to drying it in the sunlight. These include animal interference, pest infestation and dust accumulation. Therefore, this study describes the development of a solar dryer that combines solar energy with Internet of Things (IoT) for effective preservation of chilli pepper. The developed semi-automated solar dryer has sensors and a networked architecture that allows it to monitor humidity and temperature in real time. It includes dual-step DC fan motors and incandescent light bulbs that react dynamically to environmental changes. It is enhanced by an intelligent control system that makes use of a microcontroller. Through precise fan speed adjustments based on temperature and humidity criteria, the system's programming maximizes airflow and speeds up the drying process without sacrificing quality. The dryer effectively removed moisture from chilli pepper either with or without temperature enhancement. For 200g, 400g, 600g, 800g and 1000g specimens of chilli pepper, the average drying time when the dryer was operated with and without additional heat source are 55.2 hours and 62.8 hours respectively. This implies that the moisture removal process was faster when the dryer was operated with additional heat source than when it was operated without the additional heat source. The developed dryer successfully provides clean and speedy drying thereby enhancing the preservation of chilli pepper.

Keywords: Internet of Things, Solar dryer, Chilli Pepper, Microcontroller, Real-time monitoring.

INTRODUCTION
The primary source of income for those residing in rural areas of developing nations is agriculture. When crops and vegetables are abundantly harvested, post-harvest losses occur due to inadequate and ineffective preservation (Hussain *et al.*, 2021). One of the preservation methods is drying. Most farmers consider drying to be an affordable way to extend the shelf life of harvested goods as it is also utilized to ripen agricultural goods like coffee and pepper (Sharma *et al.*, 2022; Hananda *et al.*, 2023). By removing the majority of the moisture content, drying enhances the quality of agricultural products, enables farmers to keep relatively steady pricing for their crops and saves post-harvest losses and transportation expenses (Zambrano *et al.*, 2019). For agricultural products meant for storage, drying is a must in order to stop the growth of fungi and insects which thrive in moist environments (Likhayo, 2018). Meanwhile,

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one of the difficulties has been finding appropriate and reasonably priced drying equipment (Bradford *et al.*, 2018). According to Phitakwinai (2019), conventional drying methods, such as open-air drying, have limits when it comes to controlling insect infestation and lessening the consequences of erratic weather. Researchers have investigated a variety of drying technologies, such as forced and natural convection solar dryers to get over these obstacles and improve drying efficiency. While forced convection dryers use extra tools, including heat collectors and forced air circulation to improve drying rates and product quality, natural convection solar dryers use the air's natural flow (Nabnean and Nimnuan, 2020; Jiskani *et al.*, 2020; Bhavsar and Chetankumar, 2021). Solar drying, an act of using incident sun radiation to create heat for drying and natural airflow to remove moisture from the products has become a promising alternative (Situmorang, 2022). Solar dryers provide benefits such as increased temperatures, better drying rates, shorter drying times, and consistent drying of the finished product when compared to open sun drying (Sanorchit, 2021). Meanwhile, environmental concerns, the predicted depletion of conventional energy sources and the volatility of fossil fuel costs have all contributed to the increased interest in the use of solar energy in the agricultural sector. This has made the solar-assisted drying devices to become very attractive in tropical nations (Majeed *et al.*, 2023) Commercial solar dryers that satisfy technological, financial, and socioeconomic criteria have been developed as a result of earlier research efforts (Chauhan and Rathod, 2020). In the meantime, current research has concentrated on improving the drying process by creating automated drying systems that use cutting-edge control mechanisms like microcontrollers, to adjust the drying chamber's temperature and humidity (Missana *et al.*, 2020).

The quality of agricultural products can be preserved and energy consumption reduced by automating the drying process to maintain constant and controlled drying conditions. In order to enable real-time data collection, processing and user notifications regarding agricultural goods drying state, an Internet of Things (IoT) based remote monitoring and alert system for solar dryers is required (Enyoghasi *et al.*, 2021). The Internet of Things is a continuous internet development in which things are able to send and receive data due to their communication capabilities. The server and client comprise the entirety of the Internet of Things-based system. Upon receiving electricity, sensors begin to sense the associated parameters. The information gathered from sensors is processed and enhanced in order to connect it to a microcontroller system. The sensed data are simultaneously uploaded to a webpage or sent via a sim module that is linked to a microcontroller to transmit a message. The authorized individual can successfully manage the drying process, check the parameters and access the data at any time and from any location. Basically, the IoT device is incorporated with the solar dryer so that the farmer can have first-hand information about the product being dried and take proper action as and when due (Nikita *et al.*, 2023; Viviane *et al.*, 2023).
Inefficiency associated with some of the existing solar dryers is as a result of seasonal change and unavailability of sunshine at night and its intermittent nature during the day. Therefore, this study describes the successful development of a semi-automated solar dryer with 2-60 W bulbs as an alternative heat source when the sun sets or not available, using locally-sourced materials, with proper assessment of its effectiveness in drying chilli pepper.

Significant progress has been made recently in the areas of food preservation and solar drying. Many investigations on drying various items have been conducted. To support small-scale farmers in the nut market, Alvinika, *et al.*, (2021), Ngo *et al.* (2021) and Patil *et al.*, (2022) designed and implemented an autonomous and economical control system for an indirect solar dryer. These systems used DS3225 servo motors to regulate valves in response to sensor data, Arduino programming for air velocity computations, DHT22 and BMP280 sensors to monitor the drying parameters. Using the ThingSpeak IoT platform, the Blynk application and GSM/GRPS and Arduino UNO, real-time data visualisation and notifications were made possible. Although Proteus simulations indicated a good system design, it was emphasized that additional validation through pilot studies or real-world tests was necessary to guarantee the system's efficacy and dependability in actual agricultural situations. Since the system design were based on Proteus simulation and the results shown through the Blynk application and the ThingSpeak IoT platform, the simulation results might not accurately reflect the complexities and variables that exist in the actual world and could have an impact on the control system's performance.

From the literature, the drawback of the majority of the existing solar dryers is inefficiency occasioned by seasonal changes and unavailability of sunshine at night. In order to overcome this challenge, this study describes the successful development of a solar dryer with 2-60 W bulbs as an alternative heat source when the sun sets or not available. This was done with proper assessment of its effectiveness in drying chilli pepper, thereby offering a practical and efficient solution to drying process inadequacy brought about by time and seasonal change, by harnessing solar energy, automation and real-time communication.

MATERIALS AND METHOD

In order to improve drying efficiency, the chilli pepper drying system was developed using a combination of solar energy, temperature control, airflow control and Internet of Things connection.

System Description

The system layout of this work is shown in Figure 1.

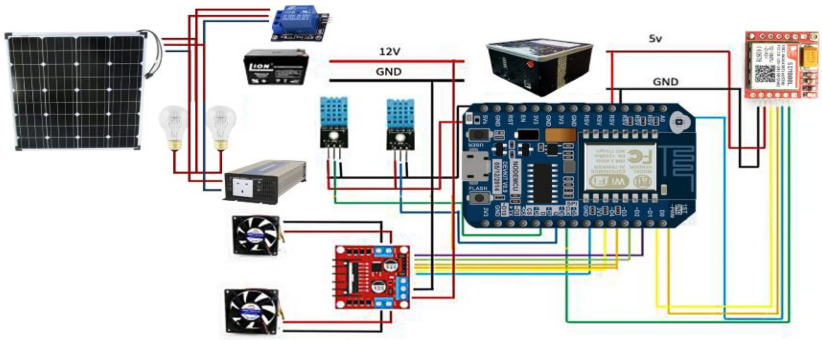

Figure 1: System layout of solar dryer

The system's hardware components, which include sensors, actuators, power supplies, microcontroller, DC fans, incandescent lights, H-Bridge motor drivers, 12V lithium cells, solar panel and solar inverter are shown in Figure 3.1. The arrangement of the parts gives the setup functionality and allows it to function as intended. The automation system improves message transmission ability by means of the sim module integrated with the microcontroller. The ESP32 microcontroller that was chosen for this project possesses the innate capacity to smoothly integrate Internet of Things communication into the system architecture. A stand-alone 3.7V lithium battery powers the microcontroller, which is an essential part of the system. The purpose of the DHT11 (-40 to 100 °C) sensor is to monitor the solar dryer's internal environment while the DHT22 sensor is meant to detect humidity. The Sim800L links the system to the cellular network, allowing monitoring and control. The drying cabinet's two DC motor fans, placed on opposing sides, control air flow. When the sun isn't accessible, the connected incandescent bulbs (60 Watts x 2) produce heat that is used for drying. The system is powered by an integrated solar inverter system, which ensures that power is available to it every day for 24 hours.

Drying Cabinet Design and Fabrication

The direct mode structure of the solar drying cabinet eliminates the need for an additional heat collector. This arrangement guarantees effective management of the airflow within the cabinet. The cabinet's measurements are as follows: its length is 40.6 cm, its width is 60 cm, and its height is 20.8 cm. Iron sheets that are both lightweight and thermally conductive were used for the cabinet's construction. To improve solar radiation absorption, the cabinet's interior is painted black. Two motors, one on each side and driven by a 12 Volt lithium battery linked to a solar inverter mounted on the cabinet, are used to control the airflow inside the cabinet. The cabinet's top is protected by a transparent glass cover that allows light to pass through without obstruction. The constructed cabinet is shown in Figure 2.

Figure 2: Constructed Cabinet

When the chilli pepper is placed in the cabinet and the system is turned on, the drying process begins. Three kilograms of chilli pepper in total were used in the experiment; these were split into five portions, weighing 200 grams, 400 grams, 600 grams, 800 grams and 1 kilogram. The experiment's main goals were to evaluate each category's rate of drying and ascertain the efficacy of the developed dryer. The process of drying was initiated and monitored carefully. Through the solar collector mounted on the cabinet, heat from the sun was transferred inside the cabinet. The two DC fans in the system are controlled by the H-Bridge motor driver, which also serves as an electrical switch. This allows for exact control over the direction and speed of each fan, which in turn regulates the direction of airflow. It also allows the motor's speed to be modulated by changing the input voltage, providing different degrees of air circulation inside the cabinet to guarantee the efficacy and quality of the drying process for chilli pepper. The DHT11 and DHT22 temperature and humidity sensors monitor the solar dryer's interior conditions in order to measure these two parameters. When the temperature and humidity fall below designated thresholds of 45^{o}C and 15% respectively, the microcontroller, through the relay, triggers the connected 60 Watts bulbs, regulate the DC motor fans to maintain lower speed, thereby enhancing the cabinet's internal temperature to optimize airflow and speed up the drying process while preserving the pepper’s quality. The GSM module links the system to the cellular network, enabling the system operator to receive real-time notifications via short message service. The results of the chilli pepper drying carried out using the developed dryer with and without the alternative 2-60 W heat source were documented and analyzed. The completed prototype is shown in Figure 3.

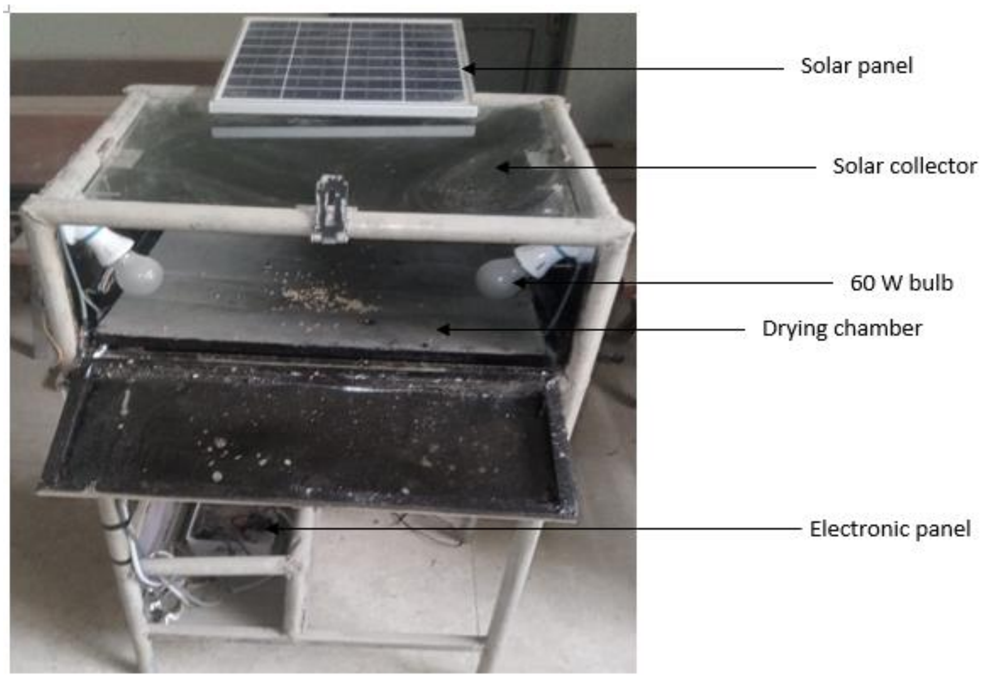

Figure 3: Completed chilli pepper dryer prototype

RESULTS AND DISCUSSION

The solar dryer completes the entire operation of drying of chilli pepper in a number of steps shown in the flow chart of Figure 4.

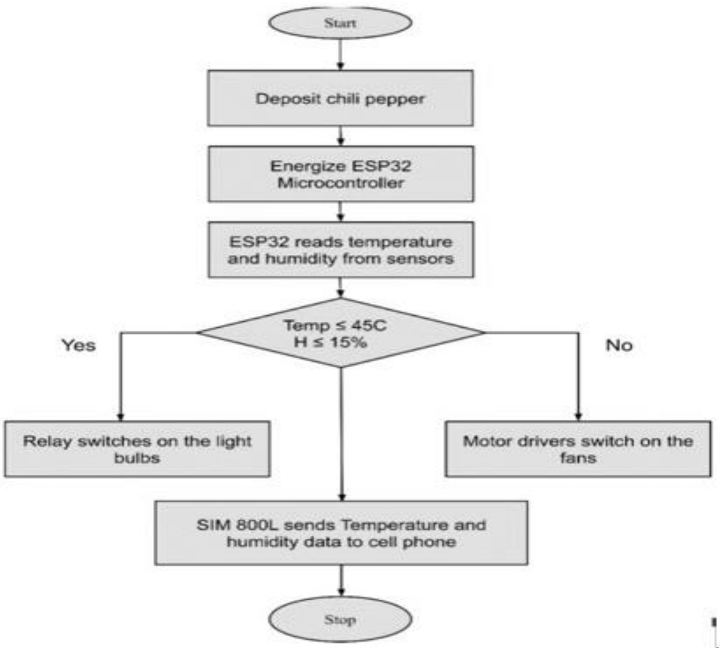

Figure 4: Flow chart of operation of the solar dryer

As shown in Figure 4, when chilli pepper with an initial moisture content of the range 74% to 82.5% (ref) are deposited in the drying chamber, the inverter system is switched on to energize the entire system. The solar collector converges sun rays to heat the drying cabinet. As the drying process continues, the microcontroller, being the brain of the system, reads data from temperature and humidity sensors continuously. Based on the readings, it decides whether to switch on the fans or activate the relay to switch on the light bulbs to increase the heat. During

the drying process, the microcontroller sends the temperature and humidity data to a SIM module and the module sends same as a text message to the operator.
The outcomes of the specimen dried, before and after the drying process with the alternative 2-60 W heat source are shown in Figures 5 - 9.

Figure 5: 200g specimen before, during and after drying

Figure 6: 400g specimen before, during and after drying

Figure 7: 600g specimen before, during and after drying

Figure 8: 800g specimen before, during and after drying

Figure 9: 1000g specimen before, during and after drying

The results show that the total time taken for the first specimen of 200 grams to dry was 47 hours. As shown in figure 5, after drying, the weight reduced to 36 grams. The drying time of the 400-gram specimen was 51 hours and its post-drying weight was 79 grams. The 600-gram chilli pepper took 54 hours to dry while the new weight after drying was 105 grams. It took the fourth portion weighing 800 grams 59 hours to get dried. As shown in Figure 8, the post-drying weight was 135 grams. Finally, the fifth portion weighing 1000 grams (1kg) took the longest time of 65 hours to get dried. It has a post-drying weight was 175 grams.

The results of the specimen dried, before and after the drying process without the alternative 2-60 W heat source are shown in Figures 10 - 14.

Figure 10: 200g specimen before, during and after drying without additional heat source

Figure 11: 400g specimen before, during and after drying without additional heat source

Figure 12: 600g specimen before, during and after drying without additional heat source

Figure 13: 800g specimen before, during and after drying without additional heat source

Figure 14: 1000g specimen before, during and after drying without additional heat source

Figure 10 shows that the 200 grams specimen got dried in 53 hours with the post-drying weight of 37 grams. The time taken to dry the 400-gram specimen was 58 hours and its post-drying weight was 78 grams. The 600-gram specimen took 62 hours to dry while the new weight after drying was 105 grams. The fourth portion weighing 800 grams dried in 68 hours having the post-drying weight of 136 grams. The fifth portion weighing 1000 grams was dried in the longest time of 73 hours. Its post-drying weight was 176 grams.

Tables 1 and 2 show the post-drying weight and the total weight lost by the chilli pepper during the drying process using the dryer with and without additional heat source respectively.

Table 1: Drying outcome with additional heat source

Time (hrs)	47	51	54	59	65
Pre-drying weight (g)	200	400	600	800	1000
Post-drying weight (g)	36	79	105	135	175
Lost weight (g)	164	321	495	665	825

Table 2: Drying outcome without additional heat source

Time (hrs)	53	58	62	68	73
Pre-drying weight (g)	200	400	600	800	1000
Post-drying weight (g)	37	78	105	136	176
Lost weight (g)	163	322	495	664	824

From Tables 1 and 2, the average weight loss when the dryer was used with and without additional heat source is 494 grams. This is an indication that the dryer effectively removed moisture from the chilli pepper either with or without temperature enhancement. The average drying time when the dryer was operated with and without additional heat source are 55.2 hours and 62.8 hours respectively. This implies that the moisture removal process was faster when the dryer was operated with additional heat source than when it was operated without the additional heat source. In comparison with the earlier research by Gülşah and Cengiz (2009) and Aduewa *et al.*, (2019) where the drying time difference between drying with solar dryers operated with and without additional heat source are 5 hours and 120 hours respectively, this work, with the time difference of 7.6 hours has reduced the inability to stabilize and regulate temperature level of the solar drying system, especially during the off-peak insolation period. As the pre-drying weight of the chilli pepper increased in every instance, the post-drying weight was noticeably higher and the drying time rose proportionately with the pre-drying weight. This inference is in consonance with research outputs; Janjai *et al.*, (2009) and Saravanan *et al.*, (2014) because consistent drying condition that increased drying efficiency was maintained throughout by utilizing both natural solar heat during the day and an artificial heating element during the night. This was accomplished by using two 60W incandescent light bulbs as temperature assistance in conjunction with the dynamic fan control mechanism.

CONCLUSION

This study describes the development of a solar dryer that combines solar energy with Internet of Things (IoT) for effective preservation of chilli pepper. The developed semi-automated solar dryer has sensors and a networked architecture that allows it to monitor humidity and temperature in real time. It includes dual-step DC fan motors and incandescent light bulbs that react dynamically to environmental changes. It is enhanced by an intelligent control system that makes use of a microcontroller. Through precise fan speed adjustments based on temperature and humidity criteria, the system's programming maximizes airflow and speeds up the drying process without sacrificing quality. The dryer effectively removed moisture from chilli pepper either with or without temperature enhancement. For 200g, 400g, 600g, 800g and 1000g specimens of chilli pepper, the average drying time when the dryer was operated with and without additional heat source are 55.2 hours and 62.8 hours respectively. This implies that the moisture removal process was faster when the dryer was operated with additional heat source than when it was operated without the additional heat source. The developed dryer successfully provides clean and speedy drying thereby enhancing the preservation of chilli pepper.

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