

¹ Hema Kale² Nitin Dhote³ Swapna
Choudhary⁴ Kirti Vaidya

Development of an Electronic Photo Sensor for Chlorophyll Detection



Abstract: The amount of chlorophyll in plant leaves can be measured using time-consuming and challenging traditional chemical procedures; alternatively, highly expensive sensor-based meters are available in the market. In this paper, the design of an inexpensive, less complex, optimum-sized ESP-32-based electronic chlorophyll reader is presented. For the suggested electronic reader the design of the photosensor circuit is the primary focus of the study. It includes designing current amplifier circuits for photodetectors and LED driver circuits for red and infrared LEDs. Spectral absorption by leaf chlorophyll is the parameter used for measuring chlorophyll. Regarding leaf chlorophyll spectral absorption, red LEDs are the most absorbing. Utilizing this function, red LED spectrum absorption measurements are made for various plant leaves. The chlorophyll content of the same leaves is then determined in the botany lab using Arnon's method. To confirm the photosensor design, the red LED spectrum absorbance and the chlorophyll identified using Arnon's technique are analyzed for different leaves. The photosensor is verified to be operating correctly. Additionally, a linear regression model for performance analysis is provided.

Keywords: LED Driver circuit, Current Amplifier Circuit, Spectrum Absorption, Linear Regression, Chlorophyll Content Index, Botanical Method

I. INTRODUCTION

Measurements of the amount of chlorophyll in plant leaves can be used to assess nutritional status, fertilizer requirements, stress tolerance, and best harvest time. Conventional techniques for chlorophyll detection are hazardous and time-consuming. [1]

Leaf chlorophyll contains absorption peaks in two different regions of the light spectrum: the red area (600–700 nm) and the blue region (400–500 nm), with zero infrared (NIR) region transmission [3]. Sensors that generate light in the red and near-infrared regions by utilizing this fact are created. There are two commonly used commercially available electronic readers are there [3]. Most Indian farmers cannot afford these readers. Although the design details of the photosensor are not provided, a cost-affordable chlorophyll meter approach is presented [4]. In a similar vein, numerous other studies have covered methods for measuring chlorophyll and the corresponding performance analysis that takes into account various leaves; however, the specifics of the photosensor's design have not been covered. Additional techniques based on image processing have been proposed for measuring chlorophyll [5,6,7], and predictions using advanced technology are discussed [8].

The project is designed to create the best possible electronic gadget at a price that small-scale farmers can afford. With the aid of this reader, farmers will be able to make wise harvesting selections that will improve yield and lower production costs.

A previous study [9] on this project provides the analysis of performance taking into account a limited number of data. Based on the suggested electronic reader's design concept, a patent [10] was also released in 2021. Additional publications [11–24] provided details on SPAD meter design and operation, standard operating procedures, and several approaches to measuring chlorophyll.

The design methodology for an original photosensor circuit is presented in this article. A performance analysis based on red LED chlorophyll spectrum absorption is provided to assess the concentration of chlorophyll in plants. First, calculate the transmission through the infrared LED. If it is nearly 100% then proceed to find the chlorophyll spectrum absorption for red LED. The Chlorophyll Content Index (CCI) calculation also requires the transmittance of infrared and red LEDs. Spectral absorbance for red LEDs is the difference between the two

¹ *Corresponding author: Author 1 Affiliation

² Author 2 Affiliation

outputs from the photodetector, that is to say, it is the difference between the Photodetector outputs Without inserting a leaf and with inserting a leaf.

% Transmission Through LED is to be found out by taking the ratio of Photodetector outputs Without inserting a leaf and with inserting a leaf.

The paper's first section provides the circuit diagram for an Electronic Chlorophyll reader using ESP 32. Then detailed description of the photosensor design is given, which includes circuit designs for LED drivers and current amplifiers for photodetectors. Following that, a process flow for measuring red LED spectral absorption is provided. The suggested spectral absorbance measurements for red LEDs from an electronic photosensor and the traditional Arnon's method's readings for chlorophyll measurement are compared. Given the strong correlation between the quantity of chlorophyll in leaves and the spectral absorbance of red LEDs, this paper investigates the spectral absorbance parameter, to confirm the design of the photosensor. Furthermore, regression analysis is also presented to analyze the performance. The manuscript is concluded in Section 4, which also provides a future vision.

II. MATERIALS AND METHODS

A. Experimental design

The ESP 32 microcontroller chip was used to develop an electronic reader to measure chlorophyll. For the hardware implementation, the Interfacing elements to ESP 32 were a Photosensor circuit using Infrared LED of 940 nm wavelength, red LED of 650 nm wavelength, Photodetectors using photodiodes and current amplifiers IC TL072, OLED Display (128x64), GPS Module (NE06M) and Keypad (4x4). The IDE software is employed to implement the program.

The functional block representation of the many input/output devices that interfaced with the microcontroller can be seen in Figure 1.

The LED driver circuits and the current amplifiers with photodetectors are the main design aspects in the block diagram of Figure 1. Red and infrared LEDs will turn on when ESP 32 output pins send a logic 1 signal to the transistor base terminals of LED driver circuits. In front of the LEDs are photodetectors. A leaf will be placed between the LEDs and the photodetector output, for a second set of measurements to be obtained after the initial reading is taken without the leaf. A built-in A/D converter of ESP 32 will be connected to the photodetector output. After that, the digital output generated by the A/D converter (photodetector) is noted. The red LED's spectral absorbance shall be computed and shown on the OLED display. The place of the measurements will be indicated by the Global Positioning System (GPS) module. The ESP 32 input pin is wired to the GPS output. All the data regarding the place of measurement and actual chlorophyll measurements will be stored in the cloud. For the user interface, the keypad is used.

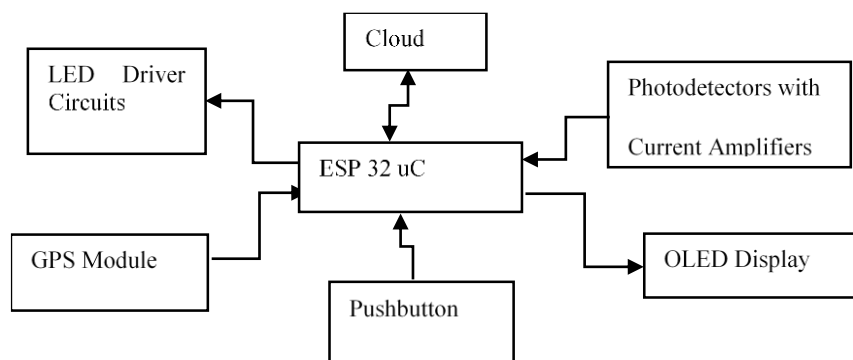


Figure 1. Block diagram

The circuit diagram for the hardware implementation of the proposed electronic is depicted in Fig. 2. Two of the ESP 32 output pins are connected to the Transistor bases of the transmitter circuit. The two outputs from the

current amplifiers of the receiver circuits are connected to the analog inputs of ESP 32. The schematic displays the pin connections for the keypad, GPS module, and Wi-Fi module. Later on, a keypad is not utilized; only a pushbutton is.

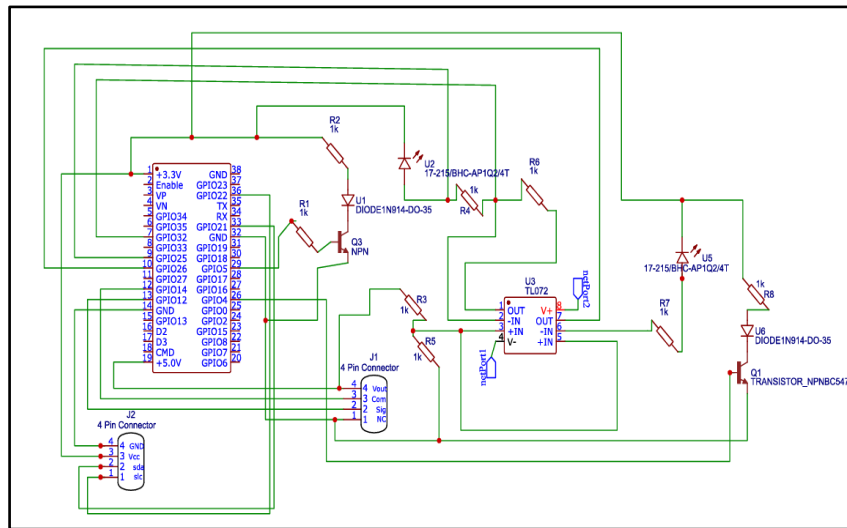


Figure 2. Circuit Diagram using ESP 32

1) Photo Sensor Design

There are two components to the Photo Sensor device's architecture for the detection of chlorophyll, Transmitter Circuits made up of LEDs as the main part and Receiver Circuits made up of Photodiodes as the main part. Here, chlorophyll estimation is done by finding the spectral absorbance of leaf chlorophyll. Since red LEDs have the highest absorbance of leaf chlorophyll and infrared LEDs have the smallest absorbance, photosensor circuits have been constructed to take benefit of this unique property of chlorophyll. The main consideration taken into account in this chlorophyll detection is the red LED spectral absorption. Here, the spectral absorbance of Infrared LEDs was used as a point of reference.

a) Transmitter Circuits

Transistors are utilized in the design of the transmitter circuits. The rays are transmitted via IR LEDs of 940 nm and Red LEDs of 650 nm, using driver circuits constructed from transistors. The transistor BC547B is a frequently employed component in this particular case. The Arduino is connected to the circuitry for the IR and RED LED drivers. To turn on and off the IR and RED LEDs, two LED driver circuits' inputs, or the transistors' base terminals, are connected to ESP 32 output pins.

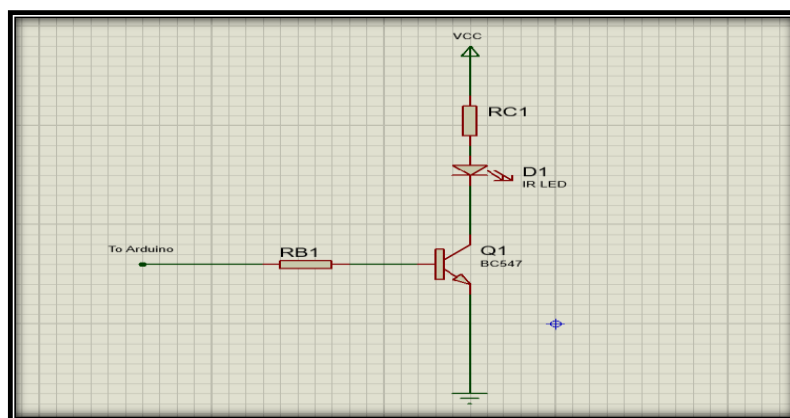


Figure 3. LED driver circuit for IR LED

Fig. 3 illustrates an IR LED driver circuit. IR LED is connected to the collector terminal. The base resistor and collector resistor are selected to match the LED voltage and current specifications. To determine the circuit parameters of an IR LED driver circuit take a look at the IR LED specs. The current specification for IR LED is 25 mA and the voltage specification is 1.6 V

IR LED driver circuit calculations are given below,

$$I_c = 25 \text{ mA}$$

$$\beta = \beta_{\min}$$

$$I_c = 25 \text{ mA}$$

$$I_B = 25 \text{ mA} / 110$$

$$= 227.27 \text{ uA}$$

$$V_{ce(\text{sat})} = 0.25$$

$$V_{be(\text{sat})} = 0.9$$

$$\text{Voltage across } R_c = V_1 = 3.15 \text{ V}$$

$$\text{Voltage Across } R_b = V_2 = 4.1 \text{ V}$$

$$R_B = V_2 / I_B = 4.1 / 227.27 \text{ uA} = 18.04 \text{ K}\Omega$$

$$R_c = V_1 / I_c = 3.15 / 25 \text{ mA} = 126 \text{ }\Omega$$

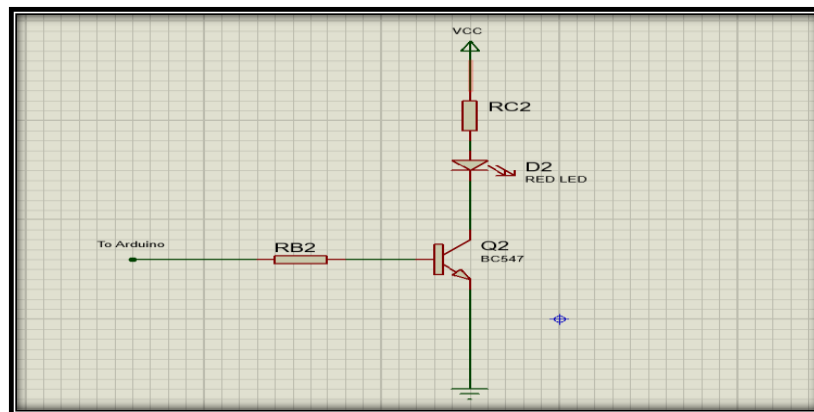


Figure 4. LED driver circuit for red LED

Figure. 4 illustrates a red LED driver circuit. The red LED is connected to the collector terminal. The base resistor and collector resistor are selected to match the LED voltage and current specifications.

To determine the circuit parameters of a red LED driver circuit, take a look at the red LED specs. The current specification for red LED is 25 mA and the voltage specification is 3.6 V.

$$I_c = 25 \text{ mA}$$

$$\beta = \beta_{\min}$$

$$I_B = 25 \text{ mA} / 110 = 227.27 \text{ uA}$$

$$V_{ce(\text{sat})} = 0.25 \text{ V}$$

$$V_{be(\text{sat})} = 0.9 \text{ V}$$

$$\text{Voltage across } R_c = V_1 = 1.15 \text{ V}$$

Voltage Across $R_b = V_2 = 4.1 \text{ V}$

$R_B = V_2 / I_b = 4.1 / 227.27 \mu\text{A} = 18.04 \text{ K } \Omega$

$R_c = V_1 / I_c = 1.15 / 25 \text{ mA} = 46 \text{ } \Omega$

Figure 5 shows the red LED driver circuit implementation on the breadboard using Arduino one can see the photodetector circuit also using IC TL072

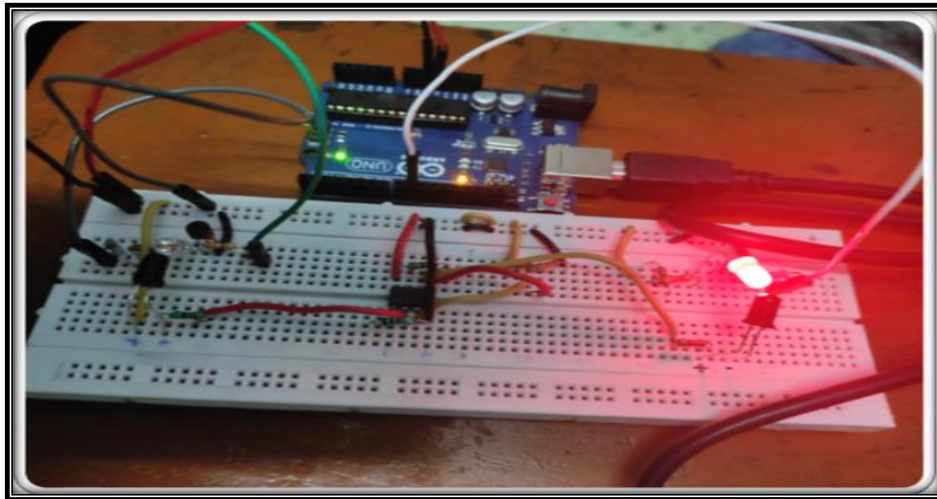


Figure. 5 LED driver & photodetector circuit implementation

b) Receiver Circuits

FET input current amplifiers and photodiodes as detectors are used in the design of the receiver circuits. The circuit for the photodiode current amplifier for infrared LED is shown in Figure 6. Other op-amps, such as LM 324, may also be utilized. Pin 2 of the IC TL072 is linked to the anode (+) of the diode (IR LED), while the VCC is connected to the cathode. The photodetector is thus operated in reverse-biased mode. The output pin of the integrated circuit and the inverting input terminal are connected via resistor R2. The voltage divider circuit is connected to the op-amp integrated circuit's non-inverting input terminal.

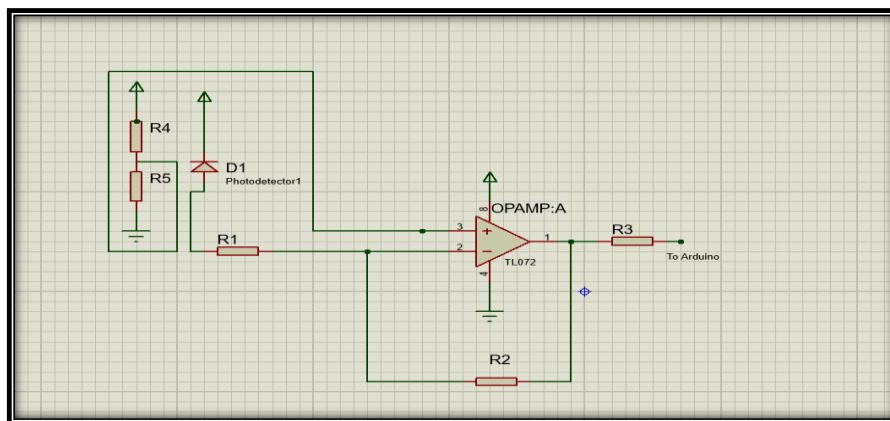


Figure 6. Photodiode detector circuit for IR & red LED

The following resistor values are used in the photodetector circuits to obtain the desired output,

$R_1 = 330 \text{ } \Omega$, $R_2 = 10 \text{ K } \Omega$, $R_3 = 2.2 \text{ K } \Omega$, $R_4 = R_5 = 2.5 \text{ K } \Omega$

A tiny reverse current that flows through the diode as a result of the photodiode receiving LED light is amplified by the current amplifier. The ESP 32 analog input port will receive the output of the current amplifier integrated circuit. It has been confirmed that when the leaf is inserted, the photodetector output for red LED drops . Since

the plant leaf chlorophyll has no absorbance, the output of an IR LED photodetector is constant both in the presence and absence of leaves.

B. Methodology

The microcontroller chip is used in the design of an electronic reader that measures the concentration of chlorophyll in plants. The following describes the experimental process used to determine the red LED's spectrum absorbance using leaf chlorophyll. First, a setup must be done so that the appropriate photodetectors will receive the LED transmission. Initially, a signal will be sent by the microcontroller to turn on the two LEDs in a sequential manner: the red LED (650nm) and the infrared LED (940nm). The two properly positioned photodiodes will receive the light beams from the LED. Two FET input current amplifiers (TL072) will be used to boost the photodiodes' output signal. The microcontroller's analogue input (A/D converter) receives the output of the current amplifiers. Two situations are used to take these readings: in first case readings will be taken with no leaf inserted and the second case will be with the leaf inserted. Upon placing a leaf, there will be three measurements made: top, middle, and bottom of the leaf. On the OLED display, the red LED's spectrum absorption will be shown. The GPS module, NE06M, will provide the location, date, and time of the reading. Procedure steps for the experimental determination of Spectral Absorbance for red LEDs using leaf chlorophyll

Step 1: To Switch ON the circuit

Step 2: First Turn ON the red LED

Step 3: Take Photodetector reading for red LED without leaf

Step 4: Turn off the red LED and Turn ON IR LED

Step 5: To Turn ON IR LED

Step 6: Take Photodetector reading without leaf for IR LED

Step 7: Repeat the Steps from 1 to 6 after Inserting the Leaf

Step 8: Calculate Spectral Absorbance for red LED

ESP 32 has a feature of integrated Wi-Fi connectivity that will be used to store the location data from the GPS unit and the chlorophyll measurements in the cloud. These readings are available on mobile devices and can be downloaded from the cloud into an Excel file.

Figure 7 shows the circuit's breadboard implementation. Following PCB installation, a 3D-printed model of the circuit enclosure is created. The dimensions of the 3D-printed model (figure 8) are, a length is 15cm, a breadth of 12 cm, height of 4.5 cm. The Front Nosal part dimensions are a length of 3cm and, a width of 4 cm.

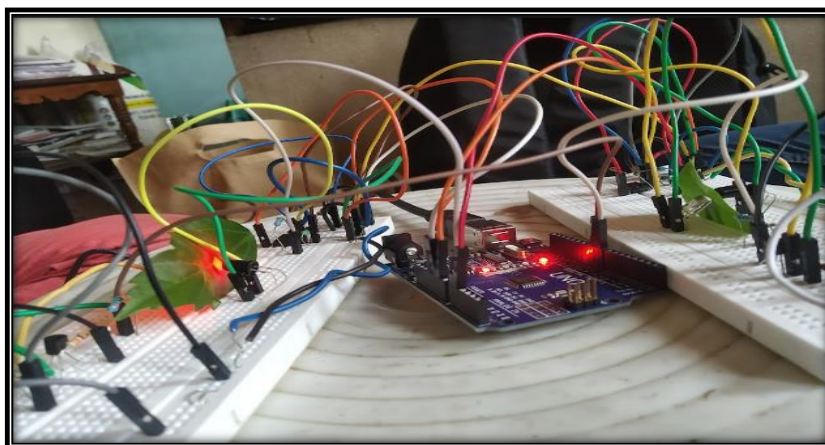


Figure 7. Breadboard Implementation

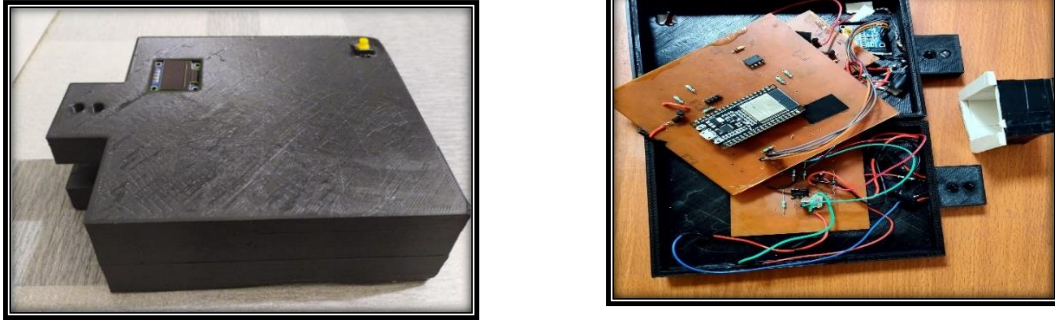


Figure 8. 3D Printed model

For the proposed model, initially, microcontrollers Arduino uno and ESP 8266 are used. Next, the model is modified by replacing Arduino uno and ESP 8266 by ESP 32 microcontroller only, which can give Wi-Fi connectivity, and Bluetooth feature and has multiple analog inputs. Three PCBs are there inside the 3D printed model, the first PCB for LED driver circuits for red & IR LED, the second PCB for Photodetector circuits & third PCB for microcontroller ESP 32 and interfacing.

The suggested electronic reader's readings are contrasted with those obtained using Arnon's method (the conventional botanical process), which is described below.

To calibrate the electronic reader, experiments are carried out in the botany lab of RTMNU Nagpur University. The leaves must be crushed for chlorophyll detection. To do this, the spectrum absorbance data is first obtained using the photosensor, and the standard Arnon approach is then employed. There is then a correlation discovered between the measurements of spectral absorbance and chlorophyll.

The following are needed for the botanical method: a centrifuging machine, a UV-visible double spectrometer, and 20 milliliters of acetone acid.

The Arnon method of measuring chlorophyll is described below [9].

- a) Take the plant's leaves and smash them with acetone acid added.
- b) The liquid passes into a centrifuging machine for mixing after the leaves have been crushed.
- c) Subsequently, the spectrometer's solution is fixed, and the wavelength is modified to determine the leaves' absorption.

We propose to display the CCI Index, time and date, GPS position of each plant, and other information on the website that is built. The website is intended to give farmers and government organizations information on the crops. For the time being, we are storing information on plants' CCI Index using XAMPP Server, or PHP MyAdmin. The website development is under process.

III RESULTS

The primary focus of the investigation was the photosensor circuit, which uses two LEDs, a red LED at 650 nm and infrared LED at 940 nm as a photo transmitter and two photodetectors for each LED, respectively. Red LEDs have the highest leaf chlorophyll absorbance, while infrared LEDs have the lowest. The red LED spectrum absorbance by leaf chlorophyll serves as the main parameter for evaluating the effectiveness of the recommended electronic reader. Changes in leaf chlorophyll do not impact IR transmittance values since they have no effect on infrared LEDs. Thus, the main emphasis was on how differences in leaf chlorophyll affected the spectrum absorption of the red LED.

Spectral absorbance for red LEDs is the difference between the two outputs from the photodetector, it is the difference between the Photodetector output Without a leaf & Photodetector output with a leaf.

Initially, we selected two commonly available veggies with elevated chlorophyll levels, Jasminum sambac (Doodhi Mogara) and spinach (Palak) to evaluate the proposed electronic reader [9]. The high values of the spectral absorbance indicate that spinach leaves have a higher chlorophyll concentration [9].

Brahmi (*Bacopa Monnier*) is a promising therapeutic plant for the pharmaceutical and herbal sectors because of its comprehensive effect on the central nervous system function as a memory enhancer. It is an essential raw material used in the process of isolating the active components of many major pharmaceutical products. When the chlorophyll concentration of the *Bacopa Monnier* plant's leaves drops for various reasons, both the plant's commercial value and therapeutic qualities are affected. Because of these factors, proper harvesting is essential, and this can be done by determining the leaf's chlorophyll content. Furthermore, the short development cycle of this plant—roughly three months—made it simple to obtain precise readings.

Using the suggested Electronic Reader, spectral absorbance measurements at 650 nm (Red LED) were obtained for the *Bacopa Monnier* plant (Brahmi)'s several leaves. To experiment, various *Bacopa Monnier* plants (Brahmi) were provided by Shree Shail Herbs Pvt. Ltd., Nagpur. These measurements of spectral absorbance were made on various *Bacopa Monnier* (Brahmi) leaves during two months.

The leaf chlorophyll concentration is determined using the Botanical Method (Arnon's Method) to calibrate the proposed Electronic Reader. We received assistance from Rashtrasant Tukdoji Maharaj Nagpur University's Botany and Pharmacy departments, who let us use their lab for experiments.

The Botanical procedure was carried out in the Botany lab to find the leaf chlorophyll content for three different leaves of the *Bacopa Monnier* plant (Brahmi).

The correlation between the readings by two methods i.e. by the Electronic Reader and by the traditional Arnon's Method is displayed in Table 1. The absorbance of red LED (650 nm wavelength) rays by the leaf will be higher if the leaf has a higher chlorophyll content. As a result, the photodetector receives fewer transmitted rays and produces less output, which is visible on the IDE's serial monitor in digital form. Conversely, if there is less chlorophyll in the leaf, less of the red LED's rays will be absorbed by the leaf and more of the transmitted rays will reach the photodetector. Consequently, a serial monitor's digital output provides a higher reading.

Table 1. Spectral absorbance and leaf chlorophyll correlation - *Bacopa Monnier*

Leaf	Plant Name	Electronic Reader (Photodetector O/P)		RED LED (Spectral Absorbance)	Arnon's Method (Chlorophyll mg/g fresh weight)
		IR LED	RED LED		
	Brahmi			(No Leaf- Leaf)	
Leaf 1	No leaf	1017	951	20	7.86
	leaf	1017	931		
Leaf 2	No leaf	1017	951	09	7.32
	leaf	1017	942		
Leaf 3	No leaf	1017	948	05	4.5
	leaf	1017	943		

It is observed that as the Spectral absorbance reading by the Electronic reader decreases, the Chlorophyll content measured by Arnon's method also decreases, hence spectral absorbance varies in proportion with the leaf chlorophyll ensuring the proper working of the photosensor.

Regression Analysis for the *Bacopa Monnier* leaves is done and different parameters obtained are shown in Table 2. Figure 9 depicts the regression analysis for the same.

Table 2. Regression Analysis for Bacopa Monnier

	Coefficient	Standard Error	t start	P- value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	4.517237569	.73865894	2.598116	0.233904783	-17.57451889	26.60899	17.57452	26.60899
Red LED Spectral Absorbance	0.182596685	0.133875087	1.363933	0.402754328	-1.518447583	1.883641	-1.518448	1.883641

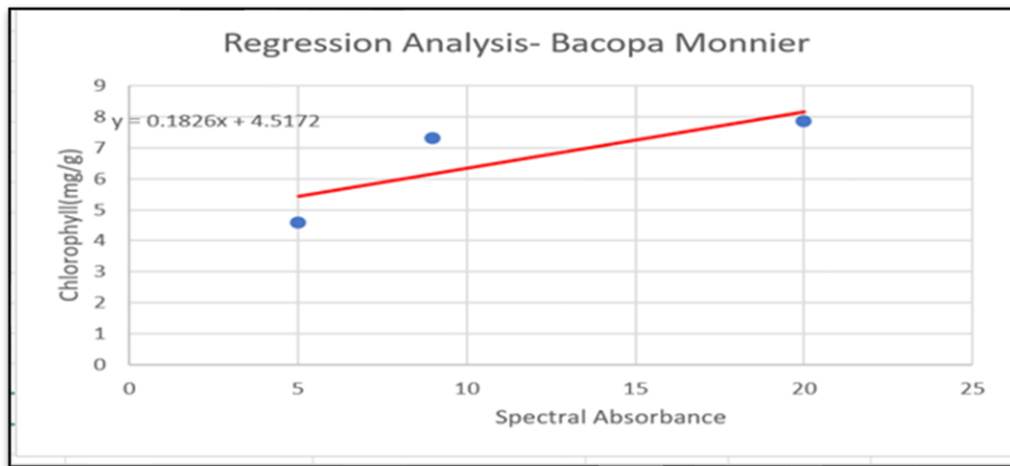


Figure 9. Regression Analysis for Bacopa Monnier

$$y = 0.1826x + 4.5172$$

The weight of the leaf is 0.1g, from the above figure the correlation between the spectral absorbance and leaf chlorophyll can be directly interpreted.

Chlorophyll content measurement by Arnon’s Method for 3 leaves of Papaya is given in Table 3 [23]. Table 3 [9] is again reproduced here for regression analysis

Table 3. Spectral absorbance and leaf chlorophyll correlation - Papaya[9]

Leaf	Plant Papaya	Electronic Reader (Spectral Absorbance)		RED LED (Spectral Absorbance) (No Leaf- Leaf)	Arnon’s Method (Chlorophyll mg/g fresh weight)
		IR LED	RED LED		
Leaf 1	No leaf	1017	954	08	29.626
	leaf	1017	946		
Leaf 2	No leaf	1017	951	09	31.10
	leaf	1017	942		
Leaf 3	No leaf	1017	950	11	31.217
	leaf	1017	939		

Regression analysis for the same is presented below. Regression Analysis for the Papaya leaves is done and different parameters obtained are shown in Table 4. Figure 11 depicts the regression analysis.

Table 4. Regression Analysis for Papaya

	Coefficient	Standard Error	t start	P- value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
intercept	6.327	3.298015193	7.98268002	0.079337	-15.57825627	68.23226	-15.5782562	68.23225627
Red LED Spectral Absorbance	0.462928571	0.350245417	1.32172627	0.412341	-3.987361403	4.913219	-3.98736140	4.913218546

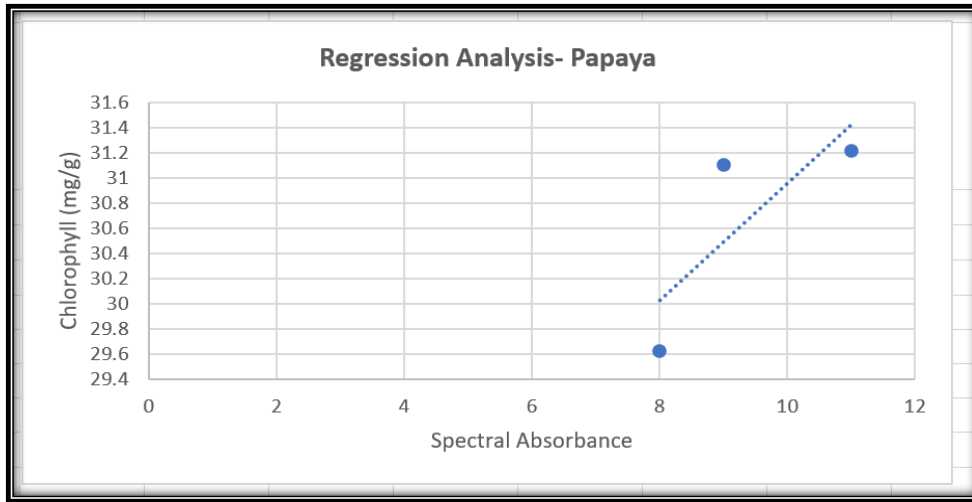


Figure 10. Regression Analysis for Papaya

$$y = .462929 x + 26.327$$

Figure 10 shows that the spectral absorbance variation with leaf chlorophyll is more prominent for Papaya as compared with Bacopa Monnier

The digital measurements of the red LED photodetector output are displayed on the serial monitor of the IDE software in Figure 11.

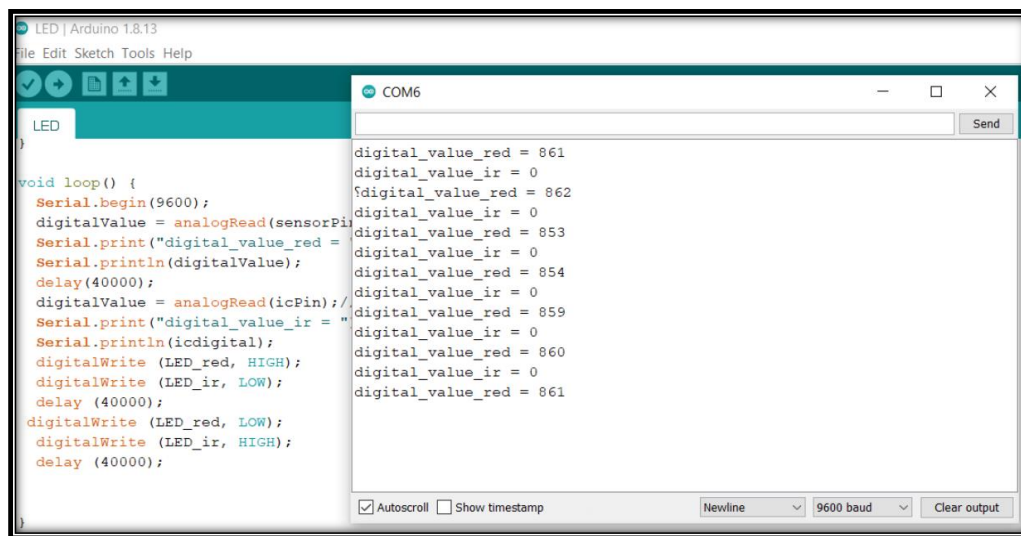


Figure 11. Serial monitor reading for the red LED photodetector

The CCI values for the cotton plant leaves measured by the SPAD meter and the suggested electronic reader are also compared. The comparison demonstrates that even with close CCI values, additional readings should be obtained for calibration. Website design is under process. Figure 12 shows the website screenshot.

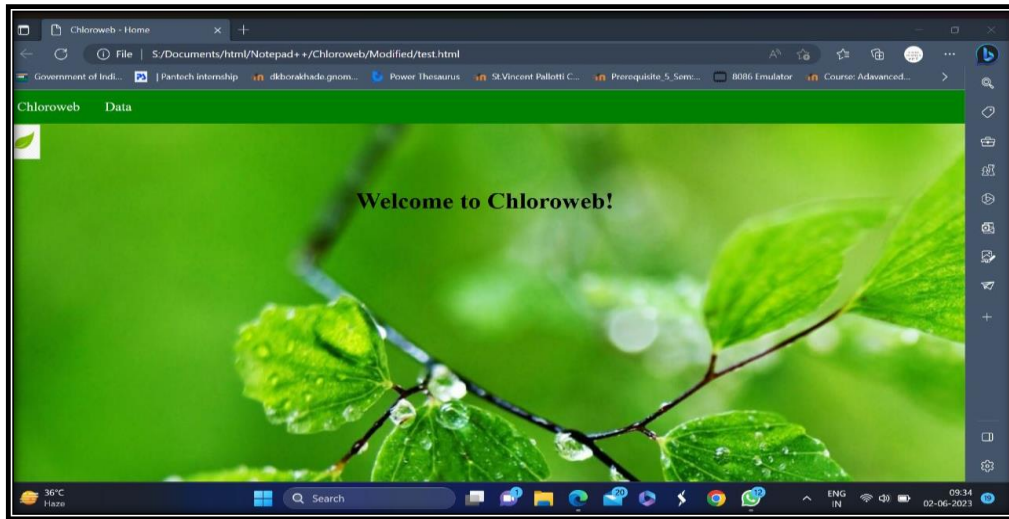


Figure 12. Website Design

IV CONCLUSION AND FUTURE WORK

This experiment design suggests that a device based on an ESP 32 microcontroller could be used to measure the amount of chlorophyll in plants. The photosensor data were calibrated using the conventional Botanical technique for a variety of plant leaves. It was discovered that the photosensor was operating correctly. In this case, the performance investigation was primarily conducted using red LED spectrum absorbance to guarantee the correct operation of the photosensor design. The future plan will be the performance evaluation based on CCI measurements only. The CCI readings calibration will be done with the SPAD meter readings for the full growth period of a single medicinal plant. An expert system can be created for regional farmers by taking into account one local crop during the course of its seasonal growth period. Website data collection for different crops mainly Cotton and Bacopa Monnier is to be done to develop an expert system.

LORAWAN technology can be more effective in developing an expert system, may be at research institute, where all data will be stored regularly over the growth period of the plant, onto the LORAWAN server through LORA Gateway. For that, we have to add the LORA module to our Electronic reader.

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