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Visualizing Anthocyanins: Colorimertic Analysis of Blue Maize

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ABSTRACT

Anthocyanin, vibrant pigments found in a wide range of plants, including maize, contribute to the red, blue, and purple hues observed in fruits, vegetables, and grains. The inherent color variations in maize, including natural shades of purple, red, blue, and even rainbow colors, pose a significant challenge in accurately assessing maize maturity. This study recognizes the importance of visualizing the distinct blue purplish anthocyanin coloration to determine the optimal harvest time for blue maize, particularly among small-scale producers. To address this crucial need, this research project presents the development of the MaizeMeter, an advanced colorimeter specifically designed to analyze maize color based on anthocyanin pigmentation. Leveraging the power of Internet of Things (IoT) implementation, the MaizeMeter provides real-time monitoring and interpretation of anthocyanin color values. The proposed methodology encompasses the calibration of the color sensor and the prototyping of the MaizeMeter, culminating in the establishment of a comprehensive database of anthocyanin color profiles in blue maize. The generated anthocyanin color database by the MaizeMeter will serve as a vital tool for small-scale farmers and researchers, enabling more efficient and accurate assessment of maize maturity in the future.

1. Introduction

Corn, commonly known as maize, holds immense significance worldwide due to its versatility as a human food source, livestock feed, and raw material for various industries [1]. Maize exhibits a wide range of colors, including purple, red, blue, and even rainbow hues, owing to the presence of anthocyanin pigmentation. Anthocyanin are water-soluble polyphenol pigments responsible for the vibrant colors observed in plants. Blue maize, specifically, refers to maize grains with shades of blue or purple pigmentation. In purple and blue maize, the coloration arises from anthocyanin, which are low molecular weight polyphenolic compounds belonging to the flavonoid family, derived from the

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cation 2-phenyl benzopyrylium. These compounds naturally occur in glycosylated or acylated forms [2]. The presence of anthocyanin imparts the blue color to maize. Precise and accurate assessment methods for identifying the blue and purple anthocyanin in blue maize are crucial, particularly for small-scale growers, as they enable informed decisions regarding the optimal time to harvest the maize crop. Colorimetric measurement of anthocyanin levels provides useful insights regarding maize maturity and optimal harvest timing.

The visual assessment of crop quality plays a critical role in various stages of agricultural production, including determining the optimal time for harvesting, storage, and processing [3]. Among the numerous parameters used to evaluate crop quality, color is a significant characteristic that is often associated with factors such as ripeness, maturity, and nutritional content. However, relying simply on color as a maturity indicator has limits because other physicochemical parameters also correlate with ripening [4]. Texture (hardness, crispness) reflecting cell wall alterations and decreased moisture content as crops dry out are important maturity criteria [5,6]. Thus, combining color measures with moisture and texture studies might allow for more accurate maize maturity assessment [7].

The analysis of color in crops has gained increasing attention, with a particular focus on colorimetric analysis of anthocyanin, which are water-soluble pigments responsible for the blue, purple, and red hues observed in many fruits and vegetables. However, accurately visualizing and interpreting color in certain crops, such as blue maize, can be challenging due to subjective variations in color perception among individuals. This difficulty in accurately assessing the coloration of crops poses significant obstacles to efficient crop management and can result in reduced productivity. To address these challenges, the integration of IoT technologies, in conjunction with in situ sensors, has emerged as a potential solution for digitizing agricultural operations and enhancing productivity [8]. Furthermore, lighting conditions and individual variations, such as color blindness, can further complicate color assessment in agricultural settings [9]. The next paragraph will investigate into the current advancements in this field and shed light on potential solutions to overcome these complexities.

1.1 State of the Art

In this state-of-the-art literature review, the examined recent studies related to color analysis, IoT-based automation, and sensor technologies in the agricultural domain are explored. The objective is to highlight their potential applications and contributions to efficient crop management and quality assessment. By analyzing these state-of-the-art studies, valuable insights and findings emerge, providing a deeper understanding of the significance of these technologies in improving agricultural practices and optimizing crop production.

One study by Liu *et al.,* [10] focused on the application of color featuring and deep learning techniques for maize plant detection. The researchers employed color indices, such as excess green (ExG) and excess red (ExR), along with deep learning models (YOLOv3 and YOLOv3_tiny). The results demonstrated that deep learning methods outperformed color index-based approaches in terms of detection accuracy and robustness to complex field conditions. However, the color feature-based methods exhibited superior detection speed. This research highlights the potential of deep learning technology for accurate and robust maize plant detection, with scope for further improvement in detection speed.

In the realm of plant seedling detection, Kamal *et al.,* [11] presented a study on IoT automation with segmentation techniques for plant seedling detection in the agricultural domain. The researchers aimed to identify software alternatives that offer good detection performance and low computational cost. The study revealed that successful plant seedling separation and classification can be challenging, particularly under unstable environmental conditions. Despite these challenges, the experiments showcased promising solutions for seedling separation, even in situations with noise and limited visibility. The findings emphasize the feasibility of utilizing low-cost and accessible hardware in real-time embedded systems for efficient plant seedling detection.

Regarding farm management, Kothari and Joshi [12] explored the implementation of an IoT-based sensor module for real-time monitoring of fruit maturity in crop fields and storage. The authors emphasized the role of IoT in collecting vast amounts of data from sensors and controlling internal processors for efficient farm management. By interconnecting physical devices embedded with sensors, IoT technology enables farmers to make informed decisions based on real-time data. This study highlights the potential of IoT in revolutionizing smart farming practices by improving farm management efficiency and optimizing crop yield.

In the context of maize plant phenotyping, Liu *et al.,* [13] developed PocketMaize, an Android-based smartphone application for maize plant phenotyping. This portable phenotyping platform enables breeders to obtain detailed phenotypic characterization of maize plants in the field. The application utilizes computer vision techniques, including a DeepLabV3+ model for image segmentation and an angle calibration algorithm to reduce imaging angle errors. The results demonstrated that the application effectively measured various plant, leaf, and stem traits. This development provides a cost-effective and portable solution for fast phenotyping, facilitating efficient maize phenotyping in the field and benefiting crop breeding endeavors.

In the context establishing a comprehensive database of color values, recent publication by Azmi *et al.,* [14] conducted a theoretical and quantitative analysis of cyanosis coloration in newborn babies. They aimed to quantify the correct CIE L*a*b* color values of cyanosis and implement them in a cyanosis baby manikin. This research highlights the importance of establishing a database of color values for future implementation. Such a database can serve as a valuable resource for accurately representing cyanosis in medical training manikins or simulators, as well as for further research and analysis in the field of newborn healthcare.

Overall, these studies underscore the potential of color analysis, IoT-based automation, and sensor technologies in revolutionizing agricultural practices, enhancing efficiency, and optimizing crop production. The insights gained from these state-of-the-art studies contribute to a deeper understanding of the significance of these technologies in advancing the field of agriculture. While low-cost colorimeters have been explored for agricultural applications, limitations persist regarding their suitability for analyzing the distinct purple-blue anthocyanin pigments in blue maize. Many affordable colorimeters are designed for generalized RGB color measurement, without optimization for the specific optical properties and sample preparation needs of blue maize [15]. Factors like the sample viewing area, pressure applied, device form factor, and calibration methodology can impact measurement accuracy and reproducibility when quantifying blue maize color. Additionally, the harsh field conditions under which measurements must be taken can degrade performance if devices lack sufficient robustness and customization. Thus, there is a technology gap for a dedicated low-cost colorimeter tailored to facilitate the colorimetric analysis of blue maize grains based on the characteristic anthocyanin cues that determine maturity levels.

1.2 Bridging the Gap: Low-Cost Colorimeter for Anthocyanin Analysis in Blue Maize

The focus is on the existing research gap regarding the measurement device for accurately quantifying the color of blue maize, specifically the anthocyanin content. While colorimetric analysis of anthocyanin has been extensively studied in other crops like grapes and berries, there is a need for a measurement device suitable for blue maize due to variations in sample preparation and color characteristics [16-18]. This study aims to bridge this research gap by designing a low-cost colorimeter for measuring the anthocyanin color value in blue maize and exploring the colorimetric analysis of blue maize using an IoT implementation. The outcomes of this study are expected to contribute significantly to the understanding of colorimetric analysis of anthocyanin and develop a reliable method for assessing the quality and readiness to harvest of blue maize. Such advancements have significant implications for the maize industry and the broader agricultural sector. The results obtained from this study will provide valuable insights into the colorimetric analysis of anthocyanin, offering a promising approach for improving quality assessment techniques in blue maize cultivation.

2. Methodology

This section offers a comprehensive insight into the methodology adopted for the research project. The methodology has been structured into two primary domains: hardware development and software implementation. These domains interconnect to facilitate the accurate colorimetric analysis of blue maize. The subsequent sections delve into the specifics of each domain, outlining the systematic procedures employed to achieve the project's objectives.

2.1 Hardware Development

The hardware development phase encapsulates the design, assembly, and integration of physical components necessary for the realization of the MaizeMeter. This includes the creation of the prototype, circuit connections, calibration procedures, and the incorporation of various electronic parts.

2.1.1 Block diagram

The hardware development, as depicted in Figure 1, commences with the user's interaction through the on/off switch, a conscious choice to manage power consumption during periods of device inactivity. This intuitive step is then followed by the establishment of a connection facilitated by the push button, which serves as the sole input sensor to trigger the color sensor's activation. The TCS3200 color sensor is the most advanced electrical component for detecting and analyzing the RGB value of any color [16]. It will connect from the TCS3200 to the microcontroller Node MCU. The single-board microcontroller controls other components such as the on/off switch, the push button, the TCS3200 color sensor, and the OLED display. Node MCU is inexpensive for an IoT platform and includes the ESP8266 Wi-Fi SoC that must be assembled. Node MCU's size and dimensions are more ideal for colorimeters than those of Arduino UNO or Raspberry Pi. After the TCS 3200 color sensor determines that blue maize is present, the data will be analyzed and transmitted to the microcontroller. The source code includes developing the code using the Arduino IDE to create instructions for the microcontroller to determine if the blue maize is harvestable or not. The OLED display is connected to the microcontroller as an output sensor. If the blue maize is able to gather, "Mature" will appear on the OLED display. If the blue maize is not ready for harvest, the OLED display will indicate "Immature." The implementation of the IoT system follows. The data will be transmitted to Blynk. The Blynk programmer can assist users in analyzing the 0-255 RGB color values. The Red, Green, Blue (RGB) color model is widely utilized in computer systems, cameras, and file formats like JPEG (.jpg) and bitmap (.bmp). It consists of a triple representation of red (R), green (G), and blue (B) channels. In the RGB space, each channel's values range from 0 to 255 [19].

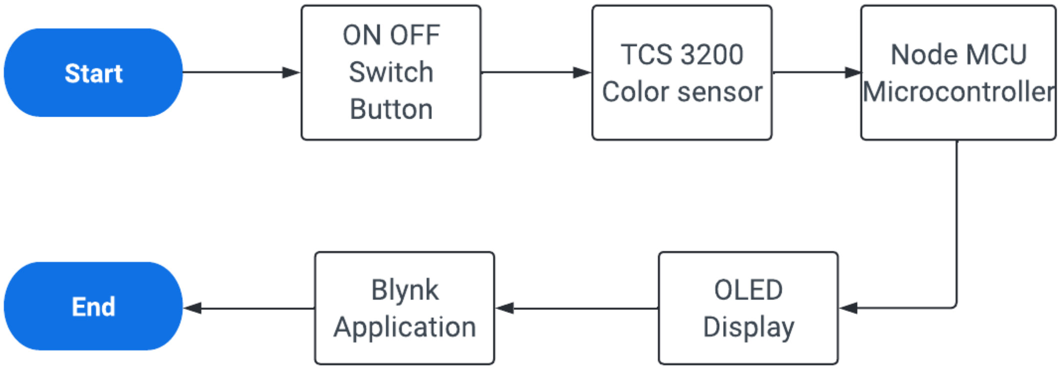

Fig. 1. Block diagram of MaizeMeter

2.1.2 Circuit diagram

The circuit diagram, depicted in Figure 2, serves as a fundamental blueprint for the successful integration of components within the MaizeMeter system. As an indispensable guide, it not only ensures the proper interconnection of elements but also acts as an invaluable resource for those aiming to adapt the device for agricultural applications.

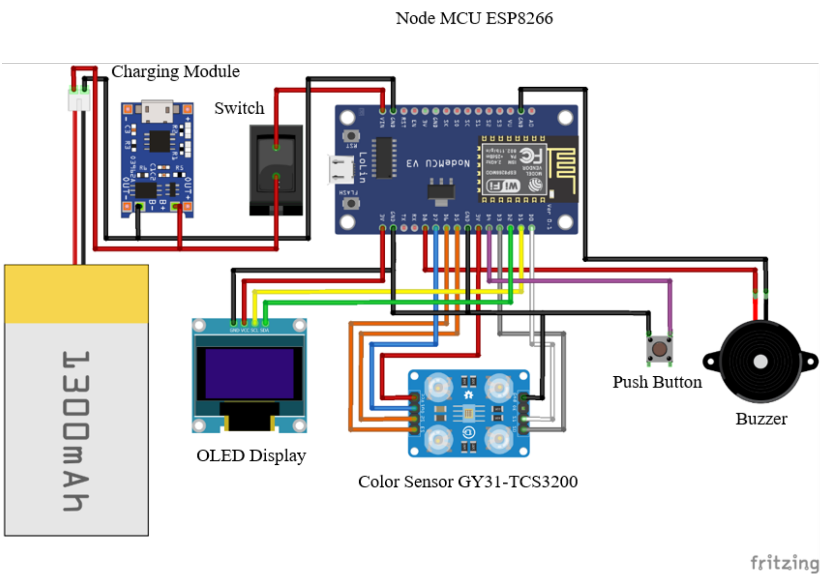

Fig. 2. Designed circuit diagram using Fritzing App, showcasing precise component interconnections for the MaizeMeter system

In the development of MaizeMeter, a series of key components have been seamlessly integrated to create a functional system. First, the on/ off button acts as an input sensor, controlling the power supply by toggling between voltage flow and voltage stop. Next, the push button enables pausing or resuming device operations, particularly during the detection of blue maize color using the TCS3200 color sensor. This sensor accurately detects RGB values, facilitating the identification of various color hue. Then, NodeMCU, an open-source platform based on ESP8266, establishes Wi-Fi connectivity and data transfer, collecting and transmitting hardware data to the Internet of Things (IoT)- based application, named Blynk, on the user's smartphone [20]. Additionally, the MaizeMeter occupied with an OLED display provides clear visual feedback, to indicate whether blue maize is "Mature" or "Immature" based on the analysis. The device is powered by a 7.4V battery, selected for its extended longevity compared to lower voltage alternatives. Finally, a buzzer serves as a signaling device for alerts and notifications, enhancing user interaction and awareness. Through this meticulous integration of components, MaizeMeter gains the ability to accurately assess and classify blue maize for agricultural purposes.

2.1.3 Color calibration

Prior to delving into the analysis of blue maize color values, a pivotal step of paramount importance is color calibration. This crucial process ensures the accuracy and reliability of color measurement, contributing to the precision of the MaizeMeter system. The utilization of ColorChecker X-Rite ensures both accuracy and repeatability in color outcomes [21]. The ColorChecker has 24 colors in the board such as dark skin, light skin, blue sky, foliage, blue flower, bluish green, orange, purple red, moderate red, purple, yellow green, orange yellow, blue, green, red, yellow, magenta, cyan, white, neutral 18, neutral 6.5, neutral 5, neutral 3.5 and black. With dimensions of 20.57 x 28.9 cm, its size is optimally suited for precise black and white balance calibration. This calibration uses black and white as reference color values. This facilitates the calculation of the maximum and lowest color values. The subsequent step involves deriving additional RGB color values by analogously mapping them based on the reference RGB color values of black and white. Specifically, the resulting mappings for white and black RGB color values are (15, 15, 10) and (66, 62, 46) respectively. During the calibration process, the Puluz Photo light box was employed to replace the natural lighting and ensure the consistent iluminant, as shown in Figure 3. It has 20 pieces white LED with a white backdrop.

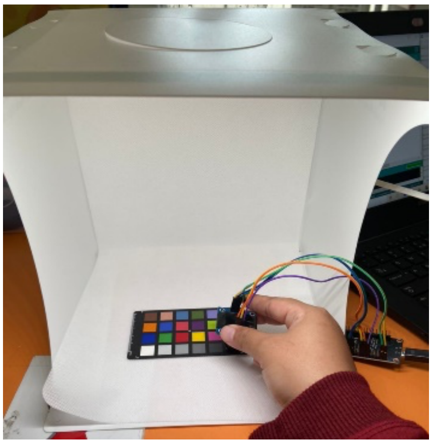

Fig. 3. Color measurement in Puluz photo light box

The assessment of color accuracy necessitates the calculation of a color error percentage, revealing the disparity between theoretical and measured values. In the context of the RGB color space's three dimensions, this color error percentage is derived using the Euclidean distance formula this part, a color error has been calculated to shows the error between the theory and measured value. The color error was then quantified by determining the color difference (ΔE) between the measured RGB ($R_2G_2B_2$) values and the ColorChecker's manufacturer stated values, ($R_1G_1B_1$) using the CIEDE2000 formula [22]. A lower ΔE indicates better color replication and thus superior sensor performance.

Color difference (ΔE) = $\sqrt{(R_{2-}R_1)^2 + (G_{2-}G_1)^2 + (B_{2-}B_1)^2}$ (1)

2.1.4 Conceptualization and design through prototyping

The process of conceptualization and design through prototyping represents a critical phase in the development of the MaizeMeter system. This stage involves transforming theoretical ideas into factual and functional prototypes, ensuring the theoretical concepts with practical implementation. The prototype employs 3D printing process and was designed using AutoCAD software. First, the construction of the colorimeter involved the creation of its body, precisely constructed in 3-dimension using the AutoCAD to encompass precise dimensions and detailed measurements for each side. The final AutoCAD drawing as in Figure 4 can be translated into a physical form through 3D printing.

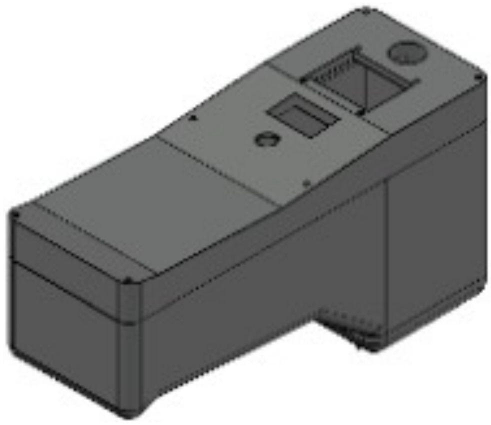

Fig. 4. Complete MaizeMeter CAD design

2.1.5 Finish product of MAIZEMETER

The crucial part in the development of MaizeMeter is to ensure the final prototype is working and functions as expected. To assemble project components using the developed prototype, there are multiple steps and precautions to be observed and considered like utilizing the correct voltage and power. Each connection pin and port in the circuit demands meticulous inspection before assembling process. Before connecting a device to a power source, the approach necessitates that all components be meticulously executed. Figure 5 illustrates this meticulous arrangement within the 3D-printed MaizeMeter structure, following the appropriate configuration. Ultimately, the final prototype was 15 x 5.5 x 10 cm and was 3d-printed by virtual shop named 3DExpress.my.

Fig. 5. Final product prototype of MaizeMeter

2.1.6 Operational mechanism of MAIZEMETER

This section discloses the MaizeMeter system's operational mechanism, bridging theoretical concepts to practical applications. It outlines the systematic steps governing device functionality, clarifying the process of accurate blue maize assessment through colorimetric analysis. The initial step in the operational mechanism of the MaizeMeter as in Figure 6 involves activating the device by pressing the on/off button, which initiates the power supply to the system. This action engages the core components, preparing the MaizeMeter for subsequent operations. Following the device's activation, users are prompted to launch the Blynk application to assess its online/offline status and wait for the OLED screen to display 'Connected,' indicating a successful connection to the Wi-Fi or mobile hotspot. After placing the sensor tip towards the blue maize, the observer can assess its RGB color values. By pressing and holding the button, a dual 'bip' sound is emitted from the buzzer. This action prompts the display of the blue maize's RGB value and condition on the OLED screen and Blynk application either in mobile phones or in desktop application.

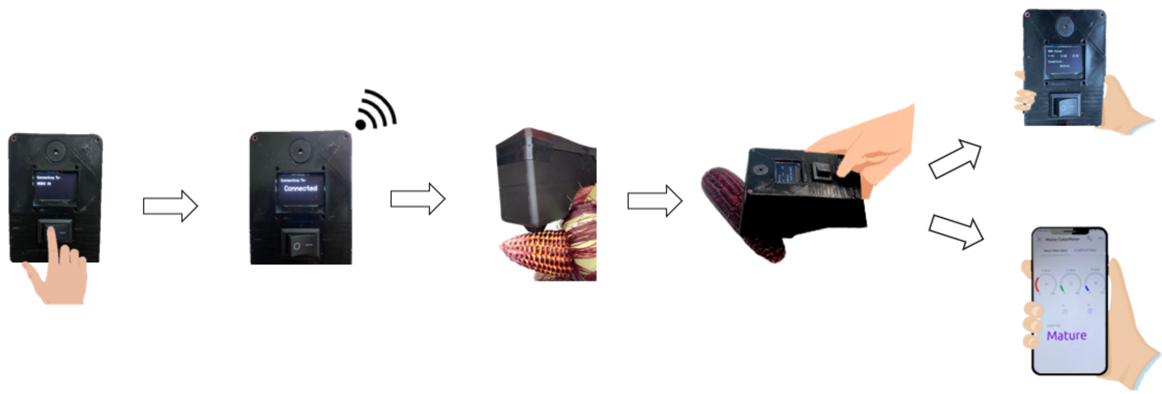

Fig. 6. Operational Mechanism of MaizeMeter

3. Results and Discussion

3.1 Color Measurement using X-Rite ColorChecker

Data collection and observation were conducted using different tip styles, with a focus on enhancing ColorChecker performance, iterating through uncovered tip (Figure 7), cotton tip (Figure 8), and 3D-tip (Figure 9), in evaluating optimal results. By using different configurations of tips, the data have been collected and analyses the value color of RGB according to the X-Rite ColorChecker. Initial measurements were conducted with uncovered tip, followed by assessments with a DIY cotton tip, and ultimately utilizing a 3D-designed tip for the final MaizeMeter prototype.

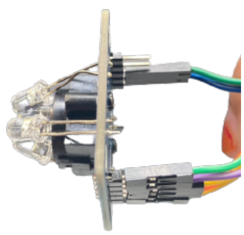

Fig. 7. Uncovered tip

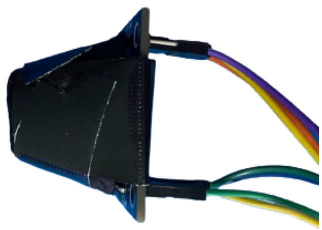

Fig. 8. DIY- cotton tip

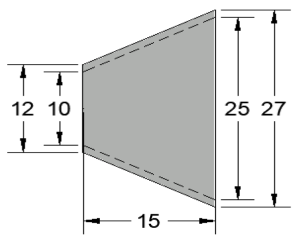

Fig. 9. Top view CAD design of the prototype

3.2 Calculation of Color Error with Different Tip

In the absence of established theoretical RGB values for blue maize, an alternative approach was taken to evaluate measurement accuracy using the 24 color swatches of the standard X-Rite ColorChecker chart with precisely defined sRGB reference values. Multiple readings (n=3) were performed with each sensor tip on the ColorChecker color samples under consistent lighting. The average RGB values were calculated for each color patch based on the 5 repeats.

The color samples referenced in the first column of Table 1 correspond to the 24 different color blocks present on the standard X-Rite ColorChecker chart used for device calibration and accuracy testing. This color chart contains labeled patches with precisely defined RGB values spanning diverse hues like skin tones, primary colors, neutral greys, vegetation colors, and more. Using the manufacturer-defined color coordinates of the industry-standard ColorChecker chart eliminates subjective visual color interpretation and human observation errors. Comparing the MaizeMeter sensor measurements against these established reference values facilitates objective, quantified analysis of accuracy across the different tip conditions tested. This process validates the ability to reliably distinguish subtle color nuances before applying the device to discern blue maize maturity stages based on anthocyanin pigmentation levels.

Table 1
Measurement for color error with different tips

Color	Uncovered Tip	Cotton Tip	3D-printed Tip
Dark skin	66.14	16.16	13.78
Light skin	119.81	31.37	19.21
Blue sky	121.52	22.74	13.93
Foliage	83.59	10.86	13.34
Blue flower	129.12	28.93	26.85
Bluish green	147.64	48.05	55.15
Orange	146.53	55.54	35.48
Purple red	165.18	35.90	52.66
Moderate red	137.33	29.14	9.27
Purple	148.37	39.43	26.02
Yellow green	160.21	58.33	49.34
Orange yellow	137.33	84.35	54.09
Blue	125.56	32.77	36.69
Green	151.65	38.30	34.15
Red	130.05	32.80	13.60
Yellow	160.49	97.66	86.45
Magenta	113.23	41.19	35.68
Cyan	167.07	83.33	78.57
White	21.38	6.63	11.05
Neutral 18	80.50	21.42	24.82
Neutral 6.5	117.22	35.23	19.03
Neutral 5	104.60	12.08	8.31
Neutral 3.5	101.66	7.35	27.66
Black	115.28	3.74	33.30
Average Color Error	122.99	36.39	32.43

The color error metric, quantified using the Euclidean distance formula (Eq. (1)), was then determined between the measured and reference values. This facilitated objective analysis of measurement reproducibility. Lower color errors indicate better accuracy in replicating the true color. The average color errors observed in Table 1 were $\Delta E=32.43$ for the 3D printed tip, $\Delta E=36.39$ for the cotton tip, and $\Delta E=122.99$ for the uncovered tip after 5 repeated measurements per color patch. Based on having the lowest average ΔE, the 3D printed tip designed specifically for anthocyanin sensing exhibited the best color measurement accuracy compared to the generic alternatives.

The maximum value of color is 255,255,255 (white) and the minimum value of color is 0, 0, 0 (black). Therefore, the color value should remain between 0 and 255. Deviating from this range can impact color error observations and complicate the assessment of which tip analysis is suitable for integration into the MaizeMeter. On further examination, the 3D-printed tip yielded superior accuracy across many individual swatches, particularly for colors like purple, blue, red, yellow and neutral tones. This shows its ability to reliably quantify a diverse range of hues. Meanwhile, the cotton tip performed reasonably well but had some variability in errors depending on swatch color. Lastly, the high average error of the uncovered tip indicates its unsuitability for color measurement.

In summary, the 3D-printed tip designed specifically for anthocyanin analysis in blue maize outperformed the generic cotton and uncovered alternatives. The improved accuracy can be attributed to its customized design that optimizes the sensor's viewing area and isolates external light. Thus, incorporating this specialized 3D-printed tip in the MaizeMeter device will ensure reliable quantification of the characteristic blue-purple anthocyanin pigmentation. Overall, these results validate the selection of the 3D tip to enable precise colorimetric modeling of maturity levels in blue maize samples based on RGB measurements.

3.3 RGB Database Development using MaizeMeter

The final MaizeMeter prototype enables the key next step of developing an RGB database cataloguing colorimetric changes during blue maize maturation. Multiple cobs (n=5) underwent color measurements at the immature stage (days 60-65) and mature stage (days 65-70) to quantify this progression. The analysis specifically focused on a single maize variety tracked longitudinally across the 60-70 day period spanning both maturity phases. Measurements at 3 locations per corn sample aimed to capture surface variability in anthocyanin levels. Collaborations with local farmers allowed accessing suitable blue maize fields for measurements using the customized MaizeMeter tool. Figure 15 and Figure 16 showcase example images of the measurement process in the growth duration between days 60-65 and the transition to days 65-70 respectively. The compiled RGB readings will provide a quantitative basis for defining fingerprint color ranges defining immature versus mature classification. Over time, expanding this database across maize strains, farms and seasons can generate robust field validated benchmarks. In the future, this early-stage foundation measuring anthocyanin color differences could transform into standardized colorimetric models for precise harvest guidance.

Fig. 15. Measurement for Maize day 60 – 65

Fig. 16. Measurement for Maize day 65 - 70

The process of generating a color swatch using Wolfram Mathematica involves utilizing the RGB values obtained from the measurements [23]. Mathematica employs these RGB values to create a graphical representation of the color, where each value corresponds to the intensity of red, green, and blue components. By combining these intensities, Mathematica generates a color that accurately represents the maize's hue. This color swatch provides users with a clear and visually informative comparison, enabling them to distinguish between immature and mature maize with greater precision. Table 2 presents the RGB values both for immature and mature days, and corresponding color swatches for five different cobs of maize. Each measurement was performed three times to ensure accuracy.

Table 2
RGB values and color swatch for 5 different maize

Maize	RGB Values (Immature, Day 60-65)			Color Swatch	RGB Values (Mature, Day 65-70)			Color Swatch
Maize 1	106	61	51		76	23	22	
	106	77	58		81	28	15	
	106	66	51		81	23	15	
Maize 2	141	55	43		86	50	51	
	141	55	43		81	50	36	
	171	66	51		86	55	43	
Maize 3	126	66	58		96	55	43	
	126	77	58		96	55	51	
	106	66	58		91	55	51	
Maize 4	126	88	72		86	44	36	
	121	88	65		81	34	36	
	116	77	56		86	44	36	
Maize 5	126	88	72		81	44	36	
	126	82	72		86	44	36	
	126	88	72		81	44	36	

3.4 IoT Implementation for MaizeMeter

MaizeMeter is a low-cost colorimeter that measures the RGB values of bluish color of anthocyanin in blue maze. It incorporates IoT technology to establish a seamless connection between software and hardware. This application has a customizable user interface design, allows for easy configuration. The RGB color values are then analyzed using an IoT implementation. Presented in Figure 17 is an illustration depicting the maturity conditions of maize. The coding incorporates a range setting derived from the database gathered during previous measurements. This range-setting process categorizes conditions as either Mature, Immature, or Not in Range.

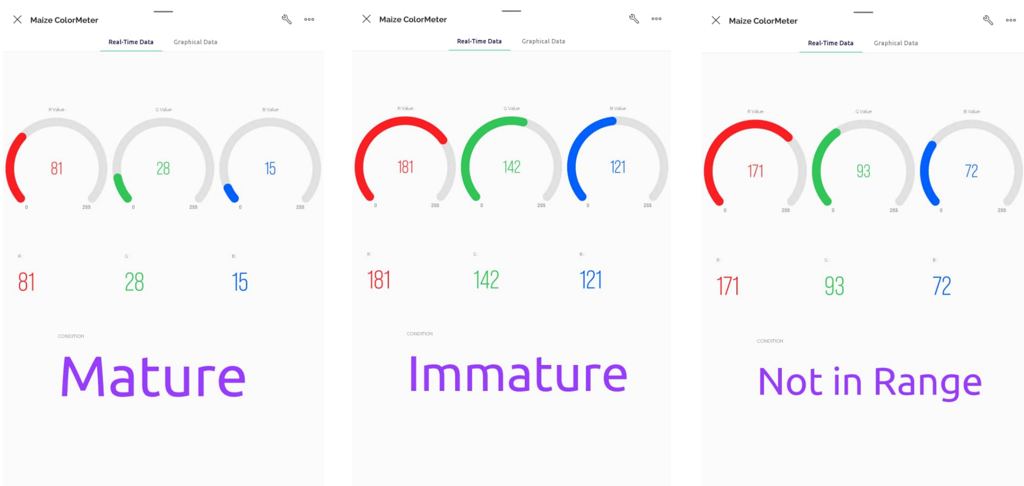

Fig. 17. Interface in Blynk application from the smart phone

Through an IoT integration, the RGB color values undergo analysis, and the results are displayed on the OLED screen as in Figure 18, upon data transmission from the color sensor to the microcontroller. This application functions as a real-time monitoring tool, enabling continuous assessment of blue maize ripeness. Through this functionality, real-time notifications can be promptly transmitted to the owner, enhancing timely decision-making.

Fig. 18. Real-time notification of the maize maturity in the OLED

3.5 Validation through On-Site Measurement

On-site measurement serves as a crucial validation test for the MaizeMeter system. This validation process involves conducting measurements under outdoor sunlight to assess its accuracy and reliability as in Figure 19. Through these evaluations, the effectiveness of the MaizeMeter's performance can be thoroughly examined and validated.

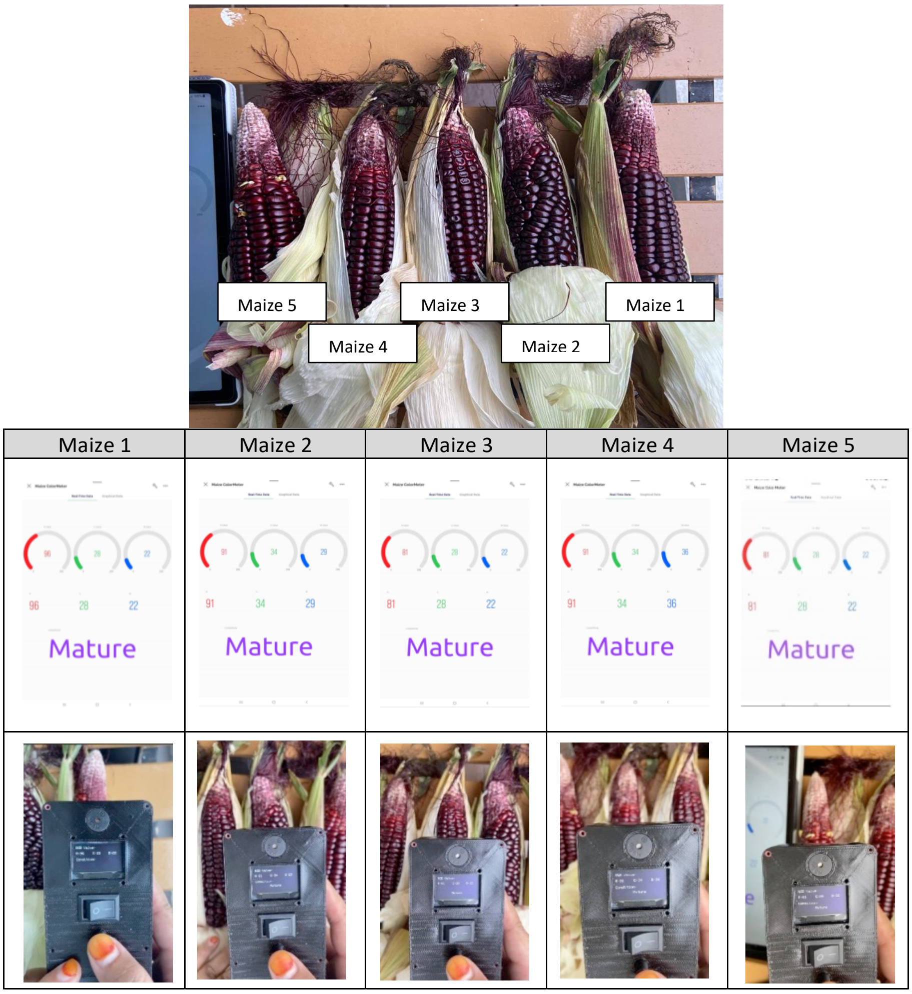

Fig. 19. Measurement of five different cobs of blue maize under direct sunlight using MaizeMeter

Table 3 shows the result for maize maturity using the 5 different maize tested under direct sunlight. The measurement was taken 3 time and notably, all maize samples were determined to be matured based on the measurement results.

Table 3
RGB values, color swatch, and maturity for 5 different maize under direct sunlight

Maize	RGB Values			Color Swatch	Condition
Maize 1	96	28	22		Mature
	91	34	22		
	91	28	22		
Maize 2	91	34	29		Mature
	91	44	22		
	81	34	22		
Maize 3	91	34	22		Mature
	81	28	22		
	81	34	15		
Maize 4	96	34	22		Mature
	91	34	36		
	91	23	22		
Maize 5	81	28	22		Mature
	81	28	22		
	81	34	22		

4. Novelty and Discussion

A novel aspect of this work is establishing an RGB color range to categorize blue maize maturity stages. This involved compiling extensive colorimetric measurements during maize growth from immature (days 60-65) to mature phases (days 65-70). However, several limitations must be noted.

Firstly, the curved shape of the maize kernel may introduce inconsistencies in sensor contact point and pressure. Secondly, the exact viewing angle and orientation is hard to standardize. Moreover, environmental illumination under field conditions can impact perceived color. These aspects can lead to significant measurement variations. To account for these effects, future iterations should incorporate a fixed, standardized viewing window with pressure controls to improve repeatability. Additionally, ambient light sensors could be integrated, along with calibration standards to compensate for lighting changes.

In the current prototype, strategically expanded RGB maturity ranges help accommodate expected variations. However, analytical validation is still essential by testing device performance across maturity stages under diverse scenarios of sample shape, size, moisture and illumination. Statistical quantification of measurement errors would indicate reliability for real-world usage. In summary, while showing initial promise, the measurement reproducibility, accuracy and robustness to external variables need to be rigorously evaluated for the introduced MaizeMeter. Further optimization in the sensor interface and electronics design is necessary before promoting adoption as a practical decision-support tool for farmers.

5. Conclusions

In conclusion, this project has been meticulously executed, following to a clear plan that started with software development and finished in hardware realization. The project's primary objectives, which encompassed the creation of an affordable and efficient device for measuring the RGB color values of blue maize, have been successfully met. This endeavour holds significance in the context of small-scale farming, where the need for an accessible colorimeter solution is paramount. Traditional colorimeters often prove cost-prohibitive and are in high demand across industries requiring precise color analysis.

With a focus on addressing these challenges, the project introduced the MaizeMeter, a low-cost colorimeter specifically designed for assessing bluish color of anthocyanin RGB color values. By offering a more affordable alternative, this innovation has the potential to streamline the agricultural routine for farmers, allowing for more efficient harvest decision-making. The device's OLED display further enhances its usability, providing a visual representation of the color values that indicate the maize's maturity state.

Furthermore, the incorporation of Internet of Things (IoT) technology marks a pivotal advancement in this project, aligning with the principles of Industry 4.0. The integration of an application that interfaces with the hardware embodies the IoT concept within the MaizeMeter framework. This interaction empowers users to gather more valuable insights from the recorded and collected RGB data. The Blynk application, a versatile platform for graphical data representation, showcases the RGB color values through user-friendly widgets. The MaizeMeter's IoT functionality leverages the sensor's RGB color data, relaying it to the microcontroller for subsequent transmission to the Blynk application. This collaborative network provides real-time color analysis and data collection, while also enabling the determination of maize condition based on color.

The MaizeMeter is specifically designed for assessing the bluish color of anthocyanin RGB values in blue maize. Its primary objective is to provide an affordable and efficient device for measuring the RGB color values of blue maize. While the focus of this study is on blue maize, it is important to note that the MaizeMeter can potentially be used for other crops with similar color characteristics and sample preparation needs. However, further research and validation would be required to determine its suitability for other crops. Undoubtedly, MaizeMeter technology stands to revolutionize agricultural practices by equipping farmers with powerful tools for informed decision-making during the harvest cycle. Through the successful implementation of IoT and meticulous color analysis, this project contributes to the evolution of agricultural technology, addressing the needs of small-scale farmers and paving the way for enhanced efficiency and productivity in the field.

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