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"FermentCheck": Prototype of Smartphone App for pH Monitoring from Extract Hibiscus Flower

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Abstract*—Monitoring pH is a critical process in various fields, including food science, agriculture, and home fermentation. While electronic pH meters are standard, natural indicators like hibiscus flower extract, which changes color across pH levels due to its anthocyanin content, offer an accessible and eco-friendly alternative. However, traditional visual color matching is highly subjective and prone to human error due to lighting and perception variations. This research presents the design and prototyping of "FermentCheck," a smartphone application developed to digitize and objectify pH monitoring using hibiscus extract. The system architecture, mapped via Use Case diagrams, establishes distinct functional workflows for Users to do simple measurement and Administrators to made calibration and model updates. The developed User Interface (UI) guides users through a streamlined process to capture a sample image and utilizing a back-end regression model to translate extracted color data into a precise pH value. The prototype demonstrates that smartphones can successfully bridge biochemical colorimetric reactions with mobile computing. By converting subjective visual assessments into quantifiable, trackable digital data, FermentCheck offers low-cost and portable analytical tool for fermentation monitoring.
Keywords—Monitoring pH; hibiscus flower extract; prototype; smartphone.

I. Introduction

Hibiscus flower extracts are known for their high levels of antioxidants, primarily attributed to phenolic compounds such as anthocyanins. Studies show that these components exhibit significant antioxidant and antimicrobial properties, thus contributing to improved health and prevention of various diseases [1, 2, 3]. Hibiscus extracts are increasingly being utilized for their antihypertensive effects. Research has indicated that regular consumption of hibiscus tea may lower systolic and diastolic blood pressure in individuals with hypertension [4, 5]. The active compounds within the extracts are believed to relax blood vessels and improve circulation, which further supports cardiovascular health. Hibiscus sabdariffa is rich in vitamins and minerals, including vitamin C, calcium, iron, and dietary fiber. Additionally, it contains a substantial amount of dietary fiber and is recognized for aiding in digestive health. The consumption of hibiscus-based products can help enhance the nutritional value of diets, particularly in regions where fruit and vegetable intake is low [6, 7].

pH is a critical parameter during fermentation since it influences microbial activity, flavor, texture, and safety of the final fermented product [8,9]. Monitoring pH allows to manage fermentation precisely, especially in complex environments where multiple microorganisms are involved. Emerging technologies have developed innovative pH sensors such as dual optical sensors that integrate pH measurement with other parameters, enhancing the ability to monitor fermentation processes dynamically [8]. The ability to assess pH in real-time helps in maintaining optimal conditions for fermentation, thus improving product quality and safety while minimizing risks of spoilage or pathogenic contamination [9, 10].

Smartphone apps have become crucial tools for enhancing daily activities, offering a wide array of functionalities from health monitoring to user engagement. Studies have documented a significant increase in health-focused applications designed to aid users in managing various health conditions, such as hypertension, which have been associated with hibiscus flower consumption [1].

Hibiscus flower (Hibiscus sabdariffa) extracts are well-established as natural pH indicators due to their anthocyanin content, which exhibits distinct color changes across different pH levels, making them valuable for applications such as smart packaging films for food spoilage detection. Simultaneously, smartphone-based color analysis has emerged as a powerful tool for quantifying these color changes, offering a low-cost, portable alternative to traditional analytical instruments. However, current research presents two critical gaps: first, the application of smartphone-integrated pH sensing with natural pigments has predominantly focused on solid-phase indicators (e.g., films and labels for packaging), leaving the potential for liquid-phase monitoring of fermentation processes largely unexplored; second, significant technical challenges remain regarding the standardization of image capture under varying lighting conditions and the long-term stability of natural pigment extracts, which hinder practical, end-user applications. Addressing these gaps by developing "FermentCheck"—a dedicated smartphone application for monitoring pH in home fermentation using hibiscus extract—is significant because it would democratize access to quality control for home-scale producers, providing a simple, affordable, and real-time method to ensure product safety and consistency while also bridging the gap between sophisticated smart packaging research and practical, liquid-based household applications.

II. Literature Review

A. Hibiscus flower extracts

Hibiscus sabdariffa, commonly known as Roselle, is a versatile plant widely recognized for its nutritional and medicinal properties. The extract derived from its calyxes is rich in bioactive compounds, including anthocyanins, phenolic acids, and flavonoids, which contribute to various health benefits and extensive applications in food and medicine [11, 12].

Hibiscus (Hibiscus sabdariffa L.), a tropical plant belonging to the Malvaceae family, has garnered significant research attention due to its potential nutritional and medicinal values [13]. The plant is cultivated in tropical and subtropical regions globally, with its calyces (the fleshy red structures protecting the flower) being the primary source of bioactive compounds. Fresh calyces contain approximately 80-90% water, along with proteins, fibers, carbohydrates, and mineral elements including potassium, calcium, magnesium, and iron [14]. The vibrant red pigmentation that characterizes hibiscus calyces is attributed to the presence of anthocyanins, making this plant particularly valuable for both food applications and health-related research.

The stability of hibiscus anthocyanins is strongly pH-dependent. Research indicates that optimal pigment stability occurs under acidic conditions at pH values ranging from 1.0 to 3.0. A comprehensive stability study examining pH 1-9 revealed that crude anthocyanins degraded more slowly at acidic pH when incubated over a 7-day period. At different pH values, two visible absorption points are observed at 519.6 nm and 320.4 nm, corresponding to the two characteristic bands of anthocyanins. This pH-dependent behavior forms the basis for the halochromic properties of hibiscus extracts—the capability to change color at different pH levels . The extract exhibits distinct color changes from red to yellow-green across the pH range of 3-10 [15].

B. pH Monitoring

pH monitoring is an essential process that plays a critical role across various scientific fields, particularly in chemistry, biology, food processing, and environmental studies. In the context of hibiscus extract, pH can significantly influence its extraction efficiency and the stability of its bioactive compounds. Kombucha Production is the application to monitoring of pH during Kombucha fermentation is essential to control the growth of beneficial bacteria and yeast. Studies have shown that variations in pH during fermentation can lead to significant differences in antioxidant properties and microbial stability [16]. Carrot Juice Fermentation is application in spontaneous carrot juice fermentations, pH plays a vital role in determining microbial dynamics. Research indicates that lactic acid bacteria can dominate the fermentation process through successive pH changes, which directly affects flavor and safety of the juice [17, 18].

C. Smartphone App

The integration of hibiscus extract with smartphone-based detection follows an established principle: the smartphone camera captures images of colorimetric reactions, and specialized applications convert these images into quantitative data by analyzing color spaces such as RGB (red, green, blue). [19] Demonstrated a foundational approach by developing a milk freshness indicator (H-Paper) prepared through direct rub-coating of hibiscus flowers onto paper substrates. This represented the first example of a food quality indicator prepared without anthocyanin extraction, using the "red chromatic shift" as a quantitative parameter analyzed through a free smartphone application. The H-Paper underwent quantifiable color changes from green to purple to pink corresponding to fresh, spoiling, and spoiled milk samples, demonstrating the feasibility of instrument-free operation in resource-limited settings.

III. Materials and Methods

This research applies a Research and Development (R&D) approach to design and evaluate a prototype smartphone application called FermentCheck for monitoring pH levels using hibiscus flower extract as a natural indicator. The study focuses on developing a functional system that integrates natural colorimetric sensing with digital image processing. The overall process includes preparation of the hibiscus extract, development of the smartphone application, calibration of the system, experimental testing, and data analysis to evaluate accuracy and usability.

The first stage involves the preparation of hibiscus extract obtained from fresh petals of Hibiscus rosa-sinensis. The petals are washed thoroughly to remove impurities and then crushed and mixed with distilled water. The mixture is filtered to obtain a clear extract solution. This extract contains anthocyanin compounds that naturally change color in response to different pH levels. The extract is stored in a dark container at room temperature to maintain its stability and prevent degradation before use in experiments.

The second stage consists of developing the FermentCheck smartphone application. The application is built using a mobile development platform and integrates the smartphone camera as a color detection sensor. The system captures images of hibiscus extract after it reacts with test solutions. The application processes the captured images by extracting

RGB (Red, Green, Blue) color values from the region of interest. These RGB values are then used as input variables for predicting pH levels. The application interface is designed to be simple and user-friendly, allowing users to capture images, view predicted pH results, and store measurement data.

Calibration is performed to establish the relationship between RGB color values and actual pH levels. Standard buffer solutions with known pH values ranging from acidic to alkaline conditions are prepared. Hibiscus extract is added to each buffer solution, and the resulting color changes are captured using the smartphone camera under controlled lighting conditions. At the same time, a digital pH meter is used as a reference instrument to measure the true pH values. The collected RGB data and corresponding reference pH values are analyzed using regression analysis to develop a mathematical model that converts RGB values into predicted pH values. This calibration model is then embedded into the application.

System testing is conducted to evaluate performance. Accuracy testing compares the pH values predicted by FermentCheck with those measured by the standard pH meter. Error metrics such as mean absolute error (MAE) and percentage error are calculated to determine the reliability of the prototype. In addition, usability testing is carried out by involving several users who test the application and provide feedback through questionnaires. The evaluation focuses on ease of use, clarity of the interface, and overall user satisfaction.

The collected data are analyzed statistically to determine the correlation between RGB values and pH levels and to assess the predictive accuracy of the system. The prototype is considered effective if it demonstrates a strong correlation between predicted and actual pH values, low measurement error, and positive user feedback. The final outcome of this research is a validated prototype of the FermentCheck smartphone application that demonstrates the potential of hibiscus extract as a low-cost, natural pH indicator integrated with mobile technology for fermentation monitoring. This method research, as seen in Figure 1.

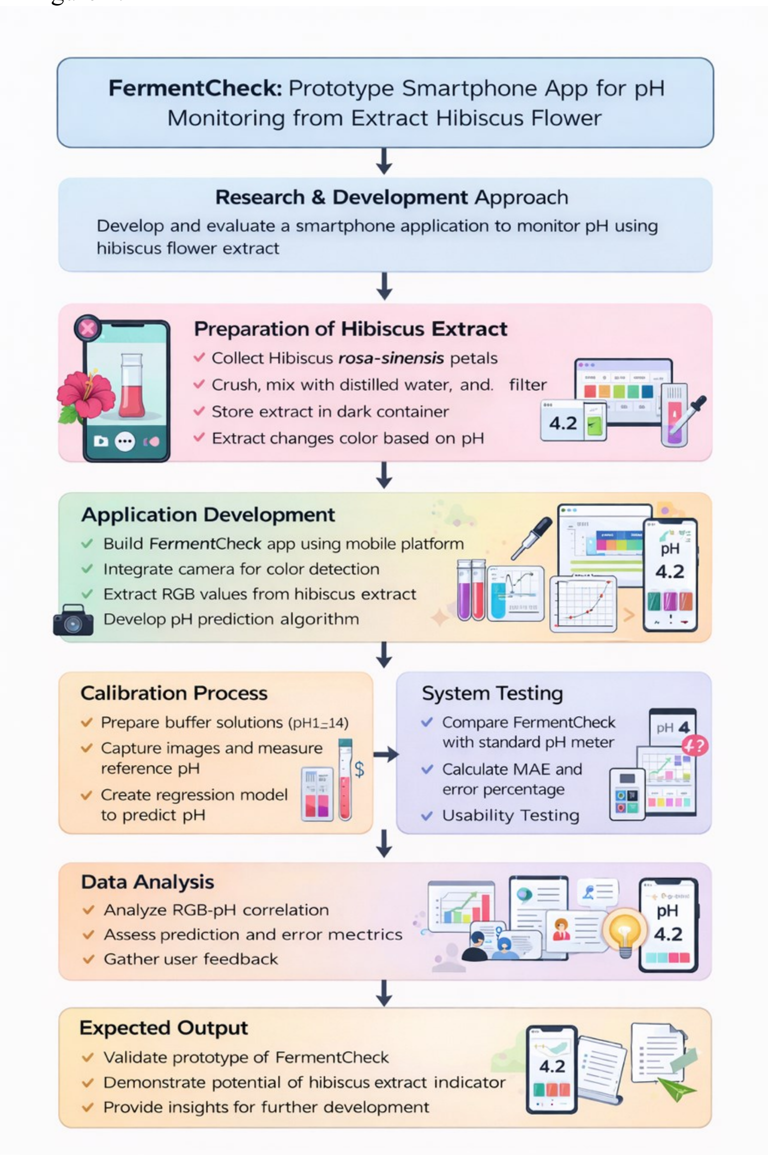

Figure 1. Research Method “FermentCheck”

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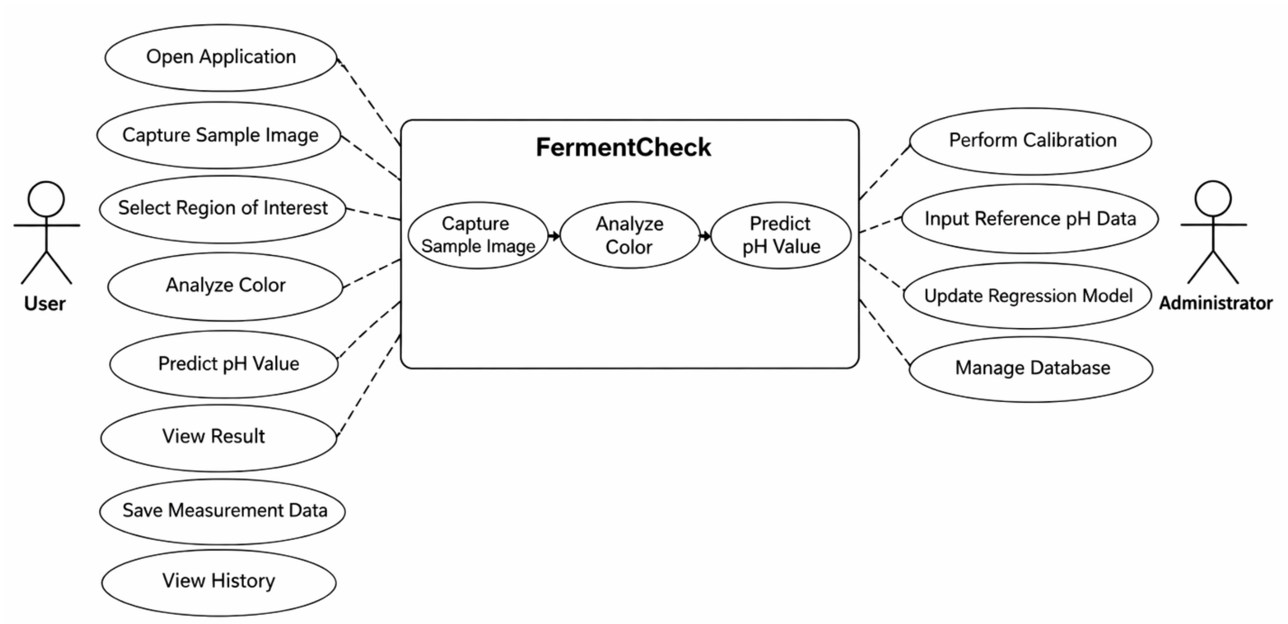

Figure 2. Use Case Diagram "FermentCheck"

Figure 2 describe a use case diagram for a system called FermentCheck, which is designed to monitor fermentation processes by predicting pH values from sample images. It shows two main actors: the User and the Administrator, each interacting with the system in distinct ways. The User engages with the application by opening it, capturing sample images, selecting regions of interest, analyzing color, predicting pH values, viewing results, saving measurement data, and accessing history. Meanwhile, the Administrator is responsible for more technical and maintenance-oriented tasks such as performing calibration, inputting reference pH data, updating the regression model, and managing the database. At the core of the system, FermentCheck integrates three central processes—capturing sample images, analyzing color, and predicting pH values—which form the backbone of its functionality. Overall, the diagram provides a clear visualization of how different roles interact with the system to ensure accurate monitoring and data management in fermentation analysis.

IV. RESULT AND DISCUSSION

The primary objective of this research was to design and prototype "FermentCheck," a smartphone application capable of estimating pH levels based on the colorimetric changes of hibiscus flower extract. The results of the system design and user interface prototyping are detailed below.

A. System Architecture and Use Case Realization

Based on the system requirements, the functionality was divided into two primary actors, as established in the Use Case Diagram: the User and the Administrator. User Flow (Front-end): The system successfully simplifies the complex process of color analysis into a linear, step-by-step workflow. Users can easily capture a sample image, select the specific region of interest, and immediately view the predicted pH value. Administrator Flow (Back-end): The diagram dictates a separate flow for administrators to perform calibration, input reference pH data, and update the regression model. This distinct separation of roles is critical. By isolating the complex calibration and database management tasks to the Administrator, the end-user interface remains highly accessible and intuitive, reducing the learning curve for standard users who only need to perform quick pH checks.

B. User Interface (UI) Prototype and Workflow

The visual prototype of FermentCheck was designed to reflect the functional requirements defined in the use case diagram. The UI utilizes a clean, minimal design with a color palette inspired by hibiscus extract (deep reds and purples) to reinforce the application's specific use case. The developed user workflow consists of five primary screens (1) Home Screen (Open Application): Serves as a straightforward entry point. The prominent "New Measurement" button ensures that the user's primary goal—testing a sample—is visually prioritized. (2) Capture Sample (Capture Sample Image): Integrates with the smartphone's camera. A graphical overlay (guidelines) assists the user in centering the sample tube, which is vital for maintaining consistent focal length and lighting conditions during image capture. (3) Select Region (Select Region of Interest): This screen addresses a major challenge in smartphone colorimetry: background interference. By allowing the user to drag a bounding box strictly over the liquid sample, the application discards irrelevant background pixels (like shadows, reflections, or the glass tube itself). This manual region selection acts as a crucial pre-processing step, drastically improving the accuracy of the subsequent RGB/HSV color extraction.

(4) Result Screen (Analyze Color, Predict pH Value): This interface represents the core output of the system. It displays an isolated swatch of the detected color alongside the boldly formatted predicted pH value (e.g., pH 4.5). Translating the mathematical regression model into a simple, highly readable numerical output bridges the gap between complex biochemical reactions (anthocyanin color shifts in hibiscus) and practical user application. (5) Measurement History (View History): Fulfills the requirement for data retention. Users can track the fermentation process over time by reviewing timestamped historical data, which is essential for monitoring long-term fermentation stability.

C. Practical Implications for pH Monitoring

Traditionally, monitoring pH with natural indicators like hibiscus extract relies on subjective visual comparison against a physical color chart, which is prone to human error and environmental lighting discrepancies. The FermentCheck prototype demonstrates that a smartphone can successfully digitize this process. By capturing the image, isolating the color data, and running it through a calibrated mathematical model, the app provides an objective, quantified pH reading. This transforms a basic smartphone into a viable, low-cost analytical tool for food science, agriculture, or home fermentation monitoring.

V. Conclusion

The development of the "FermentCheck" prototype successfully demonstrates the feasibility of utilizing smartphone technology to digitize and enhance colorimetric pH monitoring. By leveraging the natural color-shifting properties of hibiscus flower extract, the application provides a low-cost, accessible alternative to traditional pH meters. The system's architecture effectively separates the complex, back-end calibration processes (managed by Administrators) from the front-end measurement tasks, resulting in a highly intuitive User Interface. The inclusion of a manual "Region of Interest" selection tool addresses one of the primary challenges in mobile color analysis by allowing users to isolate the sample and discard background interference. Ultimately, FermentCheck removes the subjectivity of human visual estimation, translating raw image data into objective, quantifiable pH readings that can be saved and tracked over time.

Future Work from this research while the prototype establishes a strong foundational design, future research should focus on physical implementation and testing. This includes calibrating the mathematical regression model across various smartphone camera sensors, testing the app's accuracy under different environmental lighting conditions, and conducting user acceptance testing (UAT) with real-world fermentation practitioners to refine the interface further.

Author Contributions

N.S conceptualized the study, supervised the research process, and coordinated the overall research activities. K.T.A. contributed to analysis, manuscript preparation and data collection. A.S.A contributed to analysis and design prototype. U.P. contributed to data analysis, system validation, and interpretation of evaluation results.

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