Comparative Evaluation of Natural Color-Changing Films for Food Spoilage Detection Using Digital Color Analysis

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ABSTRACT

This research was conducted to study the use of natural plant pigments as indicators of food spoilage in the form of color-changing films. Natural extracts that are sensitive to environmental changes and pH variations were selected and developed into food freshness indicator films, including purple cabbage, butterfly pea flower, and dragon fruit peel. The objectives of this study were to: (1) develop color-changing films from natural pigments for use as food spoilage indicators; (2) compare the effectiveness of films made from different natural pigments in detecting food spoilage; (3) analyze and compare color changes using digital color analysis techniques; and (4) investigate the relationship between film color changes and the level of food spoilage.

The results of this study showed that the developed films were able to respond to volatile compounds released during food spoilage, such as ammonia and volatile nitrogen compounds. These compounds caused changes in the pH within the packaging environment, resulting in color changes in the films according to the properties of the natural pigments used. The findings of this study will provide important information for the development of intelligent packaging systems for monitoring food quality and freshness.

Keywords: Color-changing film/ Natural pigment/ Food spoilage indicator/ Intelligent packaging/ Digital color analysis

1. INTRODUCTION

Nowadays, fresh foods such as meat, seafood, and processed food products can easily spoil if they are stored improperly or kept for too long. Spoiling food releases volatile substances, such as ammonia, which can cause changes in pH [7]. Although the food may still appear normal on the outside, it may no longer be safe for consumption. Therefore, consumers cannot accurately determine the freshness of food simply by visual inspection or by relying only on the expiration date [6, 7].

Natural pigments found in plants, such as purple cabbage, butterfly pea flowers, and dragon fruit peels, contain anthocyanins, which can change color in response to changes in pH [2, 6]. Therefore, these natural pigments have the potential to be used as indicators of food spoilage. However, pigments extracted from different plants respond differently to changes in pH [2]. Therefore, it is necessary to study and compare which type provides the most effective results.

For this reason, the researchers are interested in studying and comparing the effectiveness of color-changing films made from natural extracts, including purple cabbage, butterfly pea flowers, and dragon fruit peels. The study will observe changes in color when food begins to spoil and compare the ability of each film to indicate food freshness. The aim is to identify the most suitable natural pigment for future applications in smart packaging. The objectives of this study were to 1) To develop natural color-changing films using purple cabbage, butterfly pea flowers, and dragon fruit peels for potential food spoilage indication 2) To analyze changes in film color using the RGB color model through a Web Scanner system 3) To investigate the relationship between changes in film color and the duration of

food storage and 4) To compare the color-changing patterns of films produced from the three natural extracts to identify their potential for food spoilage indication.

Hypothesis: The natural color-changing films developed from purple cabbage, butterfly pea flowers, and dragon fruit peel extracts were evaluated for their potential to indicate food spoilage through digital color analysis using the RGB color model. The results showed that the films exhibited different color-changing patterns over time. In particular, the butterfly pea film demonstrated a continuous increase in red (R) and green (G) values, accompanied by a decrease in blue (B) values, indicating its potential for monitoring color changes associated with food spoilage.

The findings suggest that natural pigment-based films, especially those containing butterfly pea extract, could serve as a potential alternative to conventional food freshness indicators [3]. By combining natural plant extracts with cassava starch and glycerol, the developed films offer an approach to creating color-responsive materials from natural sources [5]. Furthermore, the integration of a Web Scanner system enables digital color analysis and comparison of RGB values, supporting more systematic observation of color changes over time.

The use of natural plant extracts may contribute to the development of biodegradable, plant-based food monitoring materials [2, 7]. However, further testing is required to confirm the films' accuracy, reproducibility, biodegradability, and reliability in detecting food spoilage under different conditions before they can be considered a practical alternative for everyday food packaging applications [2].

2. METHODOLOGY

2.1 Duration of the Study

The study was conducted from June 3, 2026, to August 15, 2026.

2.2 Expected Benefits

1) To obtain natural color-changing films made from plant extracts that can be used to indicate food spoilage.

2) To reduce the risk of consuming spoiled food by providing an alternative method for monitoring food freshness.

3) To provide a new alternative for monitoring food freshness using natural pigments and digital color analysis.

4) To add value to local natural resources and promote the utilization of natural plant pigments.

2.3 Definition of Terms

Natural Color-Changing Film is a film made from natural plant extracts containing pigments that change color in response to changes in the surrounding environment, particularly pH changes associated with food spoilage.

Anthocyanin is a natural pigment found in plants such as purple cabbage and butterfly pea flowers. It changes color in response to changes in pH and can be used as an indicator of food freshness.

Food Spoilage refers to the deterioration of food quality caused by microbial growth and chemical changes, which may result in changes in color, odor, texture, and the production of volatile compounds such as ammonia.

RGB Color Analysis is a digital image analysis method that measures the red, green, and blue components of an image to evaluate color changes in the films.

Web Scanner is a web-based system used to analyze the color of the films from photographs and display the corresponding RGB values for monitoring changes over time.

2.4 Red cabbage, Butterfly Pea, and Dragon Fruit Peel

“Red cabbage” is a type of vegetable that belongs to the Brassicaceae family. It is a herbaceous plant with purple or reddish-purple leaves that overlap to form a compact head. The purple color of the

leaves is caused by a natural pigment called anthocyanin, which can change color according to the acidity or alkalinity (pH) of the environment [1]. Therefore, it has properties suitable for use as an indicator of changes in acidity and alkalinity. In addition, anthocyanin extracted from purple cabbage can be applied to produce color-changing films for detecting food spoilage [1, 4, 5]. When food deteriorates and changes occur in the surrounding environment, the film changes color according to the changes in pH (Figure 1a).

"Butterfly pea" is a type of flowering plant that belongs to the Fabaceae family. It is a herbaceous climbing plant with blue or purple flowers. The blue-purple color of the flowers is caused by natural pigments called anthocyanins, which can change color according to the acidity or alkalinity (pH) of the environment [3]. Therefore, it has properties suitable for use as an indicator of changes in acidity and alkalinity. In addition, anthocyanin extracted from butterfly pea flowers can be applied to produce color-changing films for detecting food spoilage [3]. When food deteriorates and changes occur in the surrounding environment, the film changes color according to the changes in pH (Figure 1b).

"Dragon fruit peel" is the outer covering of the dragon fruit, which belongs to the Cactaceae family. It is characterized by a bright red or pink color, which is caused by natural pigments, particularly betalains, including betacyanins [7]. These pigments have the ability to change their color under different environmental conditions, including changes in pH. Therefore, dragon fruit peel has potential for use as a source of natural pigments. In addition, pigments extracted from dragon fruit peel can be applied to produce color-changing films for detecting food spoilage. When food deteriorates and changes occur in the surrounding environment, the film changes color according to the changes in pH (Figure 3c).

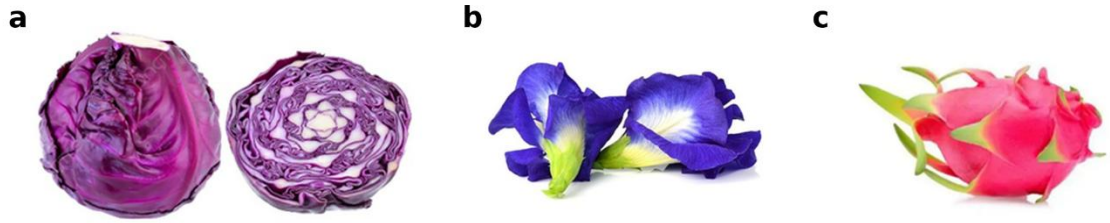

Figure 1. a) Red cabbage, b) Butterfly Pea, and c) Dragon Fruit Peel

The research project entitled "Evaluation and Comparison of the Effectiveness of Natural Pigment-Based Color-Changing Films for Detecting Food Spoilage Using Digital Color Analysis" was conducted by studying and collecting relevant theories, academic information, and previous research studies to serve as guidelines for carrying out the project [1–7].

2.5 Preparation of Color-Changing Films from Natural Extracts

Extraction of Pigments from Purple Cabbage: Ten grams of dried purple cabbage was weighed and ground or blended until finely crushed. The crushed material was then mixed with 100 mL of distilled water and heated to approximately 60–70 °C under continuous stirring for 20–30 min, with vigorous boiling avoided. After heating, the extract was allowed to cool and was subsequently stored in a clean, covered container.

Extraction of Pigments from Butterfly Pea Flowers: Ten grams of dried butterfly pea flowers was weighed and ground or blended until finely crushed. The crushed material was then mixed with 100 mL of distilled water and heated to approximately 60–70 °C under continuous stirring for 20–30 min, with vigorous boiling avoided. After heating, the extract was allowed to cool and was subsequently stored in a clean, covered container.

Extraction of Pigments from Dragon Fruit Peel: Ten grams of dragon fruit peel was weighed, washed thoroughly, and cut into small pieces. The pieces were then blended until finely crushed and mixed with 100 mL of distilled water. The mixture was heated to approximately 60–70 °C under continuous stirring for 20–30 min. After heating, the extract was allowed to cool and was subsequently stored in a clean, covered container.

2.6 Preparation of Film-Forming Solutions

The same formulation was used for each of the three natural extracts. Each batch consisted of 10 g of cassava starch, 100 mL of distilled water, 1 mL of glycerol, and 20 mL of natural extract. Distilled water (100 mL) was added to a beaker, and 10 g of cassava starch was weighed and gradually added to the water under stirring to prevent clumping. The beaker was then placed on a hot plate with a magnetic stirrer and heated to approximately 75–80 °C. Stirring was continued until the starch gelatinized and the solution became uniformly thick. Glycerol (1 mL) was added and stirred until evenly distributed throughout the solution. The heat was then reduced, and the solution was allowed to cool slightly before 20 mL of the natural extract was added. The mixture was stirred using the magnetic stirrer until the extract was uniformly distributed.

2.7 Testing the Response of the Extracts to pH

The extracts were tested to determine whether they could change color under acidic and basic conditions. Each extract was divided into equal volumes. A control sample was prepared by mixing the extract with distilled water, while test samples were prepared by mixing the extracts with lemon juice, vinegar, and baking soda solution. The color changes were observed, and the colors before and after testing were recorded. The samples were photographed under the same lighting conditions. The extract showing the clearest color change was then selected for film preparation.

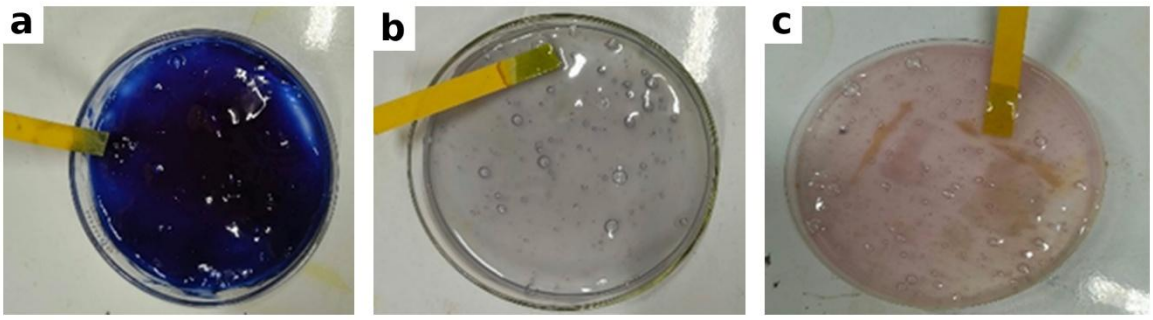

Figure 2. pH testing of a) the dried butterfly pea flower mixture, b) purple cabbage mixture, and c) the dragon fruit peel mixture

The chemical properties of the natural herbal extract-based color-changing film were evaluated in terms of acidity and alkalinity using pH paper as an indicator (Figure 2). The recorded values were found to be consistent with standard safety requirements for food-related applications, as the measured pH values were close to the natural equilibrium conditions of food, which are generally slightly acidic. These empirical findings suggest that the main ingredient, dried butterfly pea flower extract, when developed into a film, may be suitable for food-related applications. However, further testing is required to confirm its safety for human use and to determine whether it causes skin irritation.

2.8 Film Casting and Drying

A tray or flat surface was prepared for film casting and was cleaned and dried thoroughly. When baking paper or a silicone sheet was used, it was placed on the tray before the solution was poured. An

equal amount of the film-forming solution was poured onto the tray and spread evenly to obtain a uniform thickness. The tray was then placed in an oven at approximately 40–50 °C and checked periodically until the film was completely dry and no longer sticky. After drying, the film was allowed to cool and was carefully peeled from the tray. The film was cut into equal-sized pieces (e.g., 2 × 2 cm) and stored in a clean, dry container before testing. The same procedure was performed for all three natural extracts: purple cabbage, butterfly pea, and dragon fruit peel.

2.9 Testing the Color-Changing Film

Films from each extract were prepared with the same dimensions. Before testing, the films were photographed to establish their initial color. Baking soda solution was prepared as the test substance, and each film sample was tested with it under the same conditions. The color changes were observed, and the films were photographed again after testing, with the lighting, background, and distance from the camera controlled. The changes in color were then recorded.

2.10 Development of the Color Analysis System Using a Web Scanner

A digital system was developed to analyze the color of the film from photographs. First, the website interface for the color analysis system was designed, and a user interface for accessing the device camera was created. The system was developed to receive images either from the camera or from images selected by the user. The area of the film to be analyzed was then defined, and the pixel values within the specified area were read and converted into RGB values. The Red (R), Green (G), and Blue (B) values were displayed on the website. The system was tested using actual film samples, and the values obtained from the system were compared with the visible color of the film. Finally, the system was improved to ensure consistent color detection.

2.11 QR Code System Integration

A QR code linked to the Web Scanner page was created, and its scanning was tested using a mobile phone. It was verified that scanning the QR code successfully directed the user to the Web Scanner page. Camera access on the device was then tested, followed by RGB value measurement using actual film samples. The QR code was subsequently used as the access method for the color analysis system.

3. RESULTS AND DISCUSSION

3.1 Color Analysis Using the RGB System

Photographs of the films were taken before and after testing and uploaded to the Web Scanner. The area of the film to be analyzed was specified, and the R, G, and B values were measured. The values obtained at each time interval were recorded, and the RGB values before and after testing were compared. The RGB values of films prepared from the three different plant extracts were also compared. The obtained data were then used to create tables and graphs showing the changes in film color (Table 1).

Table 1. RGB Color Analysis of Films Using Web Scanner

Film Type	Color characteristics of the film	R	G	B
Butterfly pea	Purple / dark blue	72	96	158
Purple cabbage	Light blue	118	87	143
Dragon fruit	Red / Pale pink	181	103	112

The RGB (Red, Green, Blue) color model represents colors using three components: red (R), green (G), and blue (B), with each value ranging from 0 to 255. The RGB system allows the observed colors of the films to be converted into numerical data, making it possible to clearly compare color changes over time and between different types of films.

The analysis results revealed that the butterfly pea flower film had the highest B value of 158, exhibiting a dark purple/blue color. Meanwhile, the purple cabbage film had a B value of 143, while the dragon fruit peel film showed the highest R value of 181. Based on these findings, the butterfly pea flower film demonstrated the most distinctive color characteristics and the greatest potential for use as a color-changing film, as it exhibited clear color characteristics and allowed color changes to be quantitatively analyzed.

3.2 Testing with Food Samples

Food samples to be studied were prepared. The film was attached or placed inside the food packaging without allowing it to come into direct contact with the food [3, 4]. The observation time intervals were set, and photographs of the film were taken at each interval and uploaded to the Web Scanner. The obtained RGB values were recorded, and the changes in RGB values over time were compared. The results were also compared among the three types of films to determine which type showed the clearest color change and was most suitable for use as an indicator of changes in food quality.

The RGB analysis of color changes in films exposed to fresh chicken revealed that the butterfly pea flower film exhibited an increase in R values from 72 to 83 and 98, and in G values from 96 to 104 and 112, while the B values decreased from 158 to 146 and 131 at 0, 6, and 12 hours, respectively. These results indicate a continuous change in color values over time.

The purple cabbage film showed an increase in R values from 118 to 132 and 148, while the B values decreased from 143 to 135 and 124. The G values fluctuated, decreasing from 87 to 69 before increasing to 107. Meanwhile, the dragon fruit peel film exhibited a decrease in R values from 181 to 169 and 153, while both G and B values increased continuously.

A comparison of all three film types revealed that the butterfly pea flower film exhibited clearly observable changes in RGB values, particularly the continuous decrease in the B value from 158 to 131 (Table 2). This suggests its potential for use as a color-changing film to monitor changes in food quality. The purple cabbage and dragon fruit peel films also demonstrated changes in RGB values, although their patterns varied depending on the type of film.

Table 2. RGB Analysis of Color Changes in Films Exposed to Fresh chicken

Film Type	Time (hours)	R	G	B
Butterfly pea	0	72	96	158
Butterfly pea	6	83	104	146
Butterfly pea	12	98	112	131
Purple cabbage	0	118	87	143
Purple cabbage	6	132	69	135
Purple cabbage	12	148	107	124
Dragon fruit	0	181	103	112
Dragon fruit	6	169	112	116
Dragon fruit	12	153	121	123



Figure 3. Color change testing of films using fresh pork: (a) butterfly pea flower film, (b) purple cabbage film, and (c) dragon fruit peel film.

The RGB analysis showed that all three types of films exhibited changes in color values over time (Figure 3). The butterfly pea flower film showed an increase in R from 72 to 83 and 98, and G from 96 to 104 and 112, while B decreased continuously from 158 to 146 and 131 at 0, 6, and 12 hours, respectively. This continuous change, particularly in the B value, indicates a clear change in the color characteristics of the film over time [3].

The purple cabbage film showed an increase in R from 118 to 132 and 148, while B decreased from 143 to 135 and 124. The G value decreased from 87 to 69 and then increased to 107, indicating a fluctuating pattern [1, 4]. In comparison, the dragon fruit peel film showed a decrease in R from 181 to 169 and 153, while G increased from 103 to 112 and 121, and B increased from 112 to 116 and 123. These differences indicate that each type of film responded differently during the testing period.

When comparing the changes from 0 to 12 hours, the butterfly pea flower film showed a total RGB change of 69 units, while the purple cabbage and dragon fruit peel films showed changes of 79 and 57 units, respectively. Although the purple cabbage film had the largest overall numerical change, its G value fluctuated. The butterfly pea flower film showed a more consistent pattern, particularly the continuous decrease in B from 158 to 131 (Table 2).

The initial RGB values were also consistent with the observed colors of the films. The butterfly pea flower film had the highest B value at 158 and appeared dark purple/blue, while the purple cabbage film had a B value of 143 and the dragon fruit peel film had the highest R value at 181, corresponding to its red/pale pink appearance. Overall, the results demonstrate that the Web Scanner can detect and quantify changes in film color using RGB values. The butterfly pea flower film showed a clear and consistent color-change pattern, suggesting its potential for further development as a food-change indicator. However, RGB values should be considered together with other food-quality observations when evaluating food spoilage [2, 7].

4. CONCLUSIONS

The research study entitled “Comparative Evaluation of Natural Color-Changing Films for Food Spoilage Detection Using Digital Color Analysis” successfully achieved its intended objectives. Natural extracts from purple cabbage, butterfly pea, and dragon fruit peel were successfully incorporated with cassava starch and glycerol to produce color-changing films. The resulting films exhibited different colors depending on the type of extract used and showed color changes under different acidic and alkaline conditions. The films containing purple cabbage and butterfly pea extracts tended to exhibit more noticeable color changes than the dragon fruit peel film, which is consistent with the properties of anthocyanin pigments that respond to changes in pH.

In addition, a Web Scanner was developed to analyze the color of the films from photographs. The system was able to detect and display RGB values (Red, Green, and Blue), allowing changes in film color to be recorded and compared as numerical data. The obtained data could also be presented in

tables and graphs for analysis of the experimental results. Furthermore, the use of a QR Code provided convenient access to the Web Scanner through a mobile phone [1, 3, 6].

Acknowledgement

The authors would like to express their sincere gratitude to Betong Wiraratprasan School, our advisors, teachers, and all individuals who provided valuable support, guidance, and laboratory facilities for the successful completion of this research project.

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