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## Fresh or Not? Anthocyanin-Powered Strips that Reveal Rice Spoilage

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### Abstract

This study, titled “Fresh or Not? Anthocyanin-Powered Strips that Reveal Rice Spoilage,” examined the effectiveness of anthocyanin-based food freshness indicators for monitoring rice spoilage. Employing a convergent parallel mixed-methods research design, the study evaluated the performance of the strips through seven tests: color sensitivity, response time to rice spoilage, durability, accuracy, interference, practical usability, and consistency. Anthocyanin was extracted from red cabbage and combined with glycerin to produce flexible, color-responsive strips. Data were collected through controlled experimental observation and descriptive analysis, focusing on visible color changes in response to chemical changes associated with rice spoilage over time. Qualitative observations were

documented to describe color transitions, usability, and stability of the strips under different conditions. Results showed that the anthocyanin strips exhibited distinct and observable color changes as rice freshness declined, indicating sensitivity to spoilage-related pH changes. The strips demonstrated acceptable durability, minimal interference from external factors, and consistent performance across repeated trials. These findings suggest that anthocyanin-based strips are a simple, low-cost, and eco-friendly tool for rice freshness monitoring. The study concludes that anthocyanin-powered strips have strong potential as an alternative food spoilage indicator, particularly for household and small-scale applications, and contribute to promoting food safety and waste reduction.

**Keywords:** Anthocyanin, Rice Spoilage, Food Freshness Indicator, Color-Changing Strips, Red Cabbage

### Introduction

Food spoilage is a major global concern that affects food safety, public health, and the environment. According to Onyeaka *et al.* (2025) <sup>[1]</sup>, nearly one-third of all food produced worldwide is wasted, resulting in economic losses and significant environmental impact. One reason for this problem is the lack of simple and accessible tools that allow consumers to easily monitor food freshness. Traditional laboratory methods for detecting spoilage are accurate but often expensive, time-consuming, and impractical for everyday use. This creates the need for a natural, affordable, and user-friendly freshness indicator.

Anthocyanins are natural pigments found in plants such as red cabbage, purple sweet potato, and berries. De Freitas *et al.* (2026) <sup>[7]</sup> explained that anthocyanins are water-soluble and highly responsive to pH changes, making them effective natural indicators for food freshness. When food begins to spoil, chemical reactions and microbial activity cause changes in acidity, which can trigger visible color shifts in anthocyanin-based materials. Studies by Nguyen *et al.* (2026) and Du *et al.* (2025) <sup>[8]</sup> demonstrated that anthocyanin-loaded films produce clear visual signals during spoilage, although most applications focused on meat and seafood rather than staple foods like rice. Furthermore, Huang *et al.* (2024) <sup>[16]</sup> and Ndwandwe *et al.* (2024) <sup>[17]</sup> recognized natural pigments as eco-friendly alternatives to synthetic dyes, though stability and durability remain challenges. Research by Zhu *et al.* (2025) <sup>[18]</sup> and Qin *et al.* (2023) <sup>[15]</sup> showed that incorporating anthocyanins into biopolymers improves color retention and stability, while Huang *et al.* (2024b) <sup>[11]</sup>, Rodriguez *et al.* (2025) <sup>[13]</sup>, and Muche *et al.* (2024) emphasized the importance of proper storage conditions to maintain pigment effectiveness.

This study is grounded in Visual Signal Detection Theory, which explains how visible color contrast enhances perception and interpretation. Because anthocyanins produce distinct and observable color changes across different pH levels, they are suitable for qualitative freshness monitoring. The theory supports the development of a visual sensor that allows users to quickly detect

spoilage without complex equipment.

The rationale of this study is to develop an anthocyanin-based color-changing strip using locally available plant sources as a natural and biodegradable freshness indicator. By providing a simple visual signal of spoilage, the strip aims to reduce food waste, improve food safety, and promote environmental sustainability. Through this innovation, the research bridges scientific principles with practical application, making food monitoring more accessible, educational, and eco-friendly.

### Objectives

The main objectives of the study are to, (1) develop anthocyanin-based color-changing strips as a visual indicator of rice freshness; (2) determine the optimal ingredient ratio for high sensitivity and durability; (3) assess their potential as an eco-friendly, low-cost tool to improve food safety and reduce rice waste.

### Methodology

This study adopts a mixed-method convergent parallel research design which is appropriate for evaluating the effectiveness of anthocyanin-based color changing strips as a rice freshness indicator by collecting and analyzing quantitative and qualitative data simultaneously. In a convergent parallel design, quantitative and qualitative data are gathered during the same phase of the research process, analyzed separately, and then merged to provide a comprehensive interpretation of the results (Creswell & Plano Clark, 2022). This design is suitable for studies that aim to directly compare and corroborate numerical performance data with observational and user-based insights. The quantitative component of the study focuses on experimentally assessing the performance of the anthocyanin-powered color-changing strips in detecting rice spoilage. Quantitative data are obtained through systematic measurement of rice pH levels over time and corresponding observations of strip color changes, response time, and durability during storage. Controlled experimental procedures are employed to ensure accuracy, consistency, and reliability of measurements. Quantitative methods are essential for objectively determining the sensitivity and effectiveness of the developed indicator (Creswell, 2023).

The qualitative component involves descriptive observation and user feedback to evaluate the visibility, clarity, and interpretability of the strip's color changes. This phase provides insights into how the indicator is perceived in practical use and identifies factors that may influence its usability and acceptance. Qualitative data offer contextual understanding that complements quantitative findings, particularly in applied and product-oriented research (Guest *et al.*, 2022).

The integration of quantitative and qualitative findings occurs during the interpretation stage, where results from both strands are compared and synthesized. This convergence allows for validation of findings through triangulation and enhances the overall credibility of the study (Plano Clark & Ivankova, 2024). By employing a convergent parallel mixed-methods design, this research provides a balanced evaluation of both the measurable performance and practical usability of anthocyanin-based color-changing strips, supporting their potential application as a natural and eco-friendly rice freshness indicator.

### Data Gathering Procedure

This study employed a convergent parallel mixed-methods research design, in which quantitative experimental testing and qualitative descriptive observation were conducted simultaneously to evaluate the performance of anthocyanin-based color-changing strips as a rice freshness indicator. Both data sets were collected during the same phase of the study, analyzed separately, and then integrated to provide a comprehensive interpretation of the findings.

### Quantitative and Qualitative Data Collection

#### Step 1: Preparation of Anthocyanin Extract

Anthocyanins were extracted from locally sourced plant materials, such as red cabbage, using a standardized extraction process. The resulting extract served as the pH-sensitive component of the color-changing strips.

#### Step 2: Preparation of Base Material

Glycerol was prepared according to manufacturer instructions and used as the base material for the indicator strips.

#### Step 3: Testing of Ingredient Ratios

Different ratios of anthocyanin extract to base material were prepared to determine the most effective formulation. The ratios tested were:

3:30 (glycerol:extract)

3:50

3:100

Each formulation was evaluated for color sensitivity to pH changes, response time to color change, and durability of the strips.

#### Step 4: Fabrication of Color-Changing Strips

The color-changing strips were fabricated using uniform dimensions and standardized drying time to ensure consistency across all experimental trials.

#### Step 5: Preparation of Rice Samples

Freshly cooked rice samples were prepared and stored at room temperature to allow natural spoilage. Samples were labeled according to storage intervals of 12, 24, and 48 hours.

#### Step 6: Application of Strips and Concurrent Observation

The color-changing strips were placed inside rice containers without direct contact with the rice. At each storage interval, quantitative and qualitative data were collected concurrently. Observations included visible color changes, response time of the color change, and the physical condition of the strips.

#### Step 7: Measurement of pH Level

The pH level of each rice sample was measured at every storage interval using a pH meter or pH paper. The pH values were recorded and directly compared with the observed color changes of the strips.

#### Step 8: Recording of Data

The following data were systematically recorded:

- a. Color Sensitivity Test
- b. Response Time to Rice Spoilage

- c. Durability of the Strip
- d. Accuracy Test
- e. Interference Test
- f. Practical Usability
- g. Consistency Test

**Materials**

In this study, the selection of materials plays a crucial role in

the development of biodegradable plant pots that enhance plant growth through sustainable agricultural practices. The primary materials used are carefully chosen biomaterials that function both as planting containers and as nutrient sources for plant development. These materials are designed to be multifunctional, gradually releasing essential nutrients into the soil, thereby promoting healthier and more vigorous plant growth. The materials used in this study are as follows:

Materials	Description
	<p>This study utilized <b>laboratory qualitative filter paper</b> as the base material for the indicator strips, which were impregnated with anthocyanin extract and plasticized with glycerol. These strips served as the primary spoilage indicators developed for the innovation of this study.</p>
	<p><b>Red cabbage</b> (<i>Brassica oleracea</i> var. <i>capitata</i> f. <i>rubra</i>) was utilized as the natural source of anthocyanin pigment. The anthocyanin extract obtained from red cabbage was used to impregnate laboratory qualitative filter paper strips, with glycerol added as a plasticizer. These strips served as the primary spoilage indicator developed for the innovation of this study.</p>
	<p>In this study, <b>glycerol</b> refers to a colorless, viscous liquid used as a natural plasticizer. It was added in measured amounts to the anthocyanin extract to improve the flexibility of the filter paper indicator strips and to prevent brittleness during the drying and handling process.</p>
	<p>In this study, <b>water</b> refers to the liquid solvent used during the extraction of anthocyanins from red cabbage. A fixed volume of water was heated with the plant material to facilitate the release of anthocyanin pigments, resulting in a purple-colored extract used for strip preparation.</p>



**Pot** refers to a stainless-steel heating vessel used to contain water and red cabbage during the anthocyanin extraction process. It served as the extraction container in which controlled heating was applied to obtain the anthocyanin extract.

**Data Analysis**

Quantitative and qualitative data collected in this study were analyzed separately and then integrated to evaluate the effectiveness of anthocyanin-based color-changing strips as a rice freshness indicator. Quantitative data obtained from the color sensitivity test, response time to rice spoilage, durability test, accuracy test, consistency test, and practical usability evaluation were subjected to statistical analysis. One-way Analysis of Variance (ANOVA) was used to determine whether there were statistically significant differences among the three ingredient ratios (3:30, 3:50, and 3:100) in terms of color sensitivity, response time, and durability of the strips. Mean values for each parameter were compared to identify which formulation performed most effectively. The level of significance was used to assess whether observed differences among the ratios were due to formulation variations rather than random error. Qualitative descriptive analysis was conducted concurrently with quantitative testing to document observable patterns and characteristics of the strips during rice spoilage. Observations focused on visible color progression, clarity of

color change, physical condition of the strips, flexibility, and consistency of performance across different storage intervals. Interference factors such as heat, water, wind, and acidity were also qualitatively assessed to determine their influence on strip reliability and interpretability. These observations were recorded systematically and categorized to support interpretation of the numerical results. Following separate analyses, quantitative results and qualitative observations were integrated during the interpretation phase. Converging findings from both data sets were compared to validate results and strengthen conclusions. Quantitative measurements provided objective evidence of performance differences among ratios, while qualitative observations offered contextual explanations for variations in color stability, response behavior, and usability. The integration of both data types enabled a comprehensive evaluation of the reliability, accuracy, and practical applicability of the anthocyanin-based color-changing strips as an indicator of rice freshness.

**Results**

**Table 1:** Color Sensitivity Test

Ratio	Rice Sample	Storage Time	pH Level	Strip Color	Observation	Freshness Level
3:30,3:50 and 3:100	Normal Rice	12 hours	2	Purple	The anthocyanin strip has low sensitivity to 12 hours storage time as the rice sample has low acidity.	Fresh
3:30	Normal Rice	24 hours	4	Light Pink	The anthocyanin strip has moderate sensitivity to 24 hours storage time as the rice sample has moderate acidity.	Spoiled
3:30	Normal Rice	48 hours	6	Pink	The anthocyanin strip has high sensitivity to 48 hours storage time as the rice sample has high acid content.	Spoiled
3:50	Normal Rice	24 hours	4	Magenta	The anthocyanin strip has moderate sensitivity to 24 hours storage time and it reacts to the rice moderately as it has moderate sensitivity.	Spoiled
3:50	Normal Rice	48 hours	6	Indigo	The anthocyanin strip has high sensitivity to 48 hours storage time and it reacts to the rice fully.	Spoiled
3:100	Normal Rice	24 hours	4	Dark Pink	The anthocyanin strip has moderate sensitivity to 24 hours storage time and it reacts to the rice fully when it absorbs all the acid of the sample.	Spoiled
3:100	Normal Rice	48 hours	6	Deep Pink	The anthocyanin strip has high sensitivity to 48 hours storage time and it reacts to the rice fully and quickly.	Spoiled

Table 1 presents the results of the color sensitivity test of anthocyanin-based strips at different ingredient ratios and storage times. The findings show that the color response of the strips is directly associated with changes in rice pH and storage duration, indicating their effectiveness as freshness indicators.

At 12 hours of storage, the rice sample exhibited a low pH level (pH 2) and was classified as fresh. The anthocyanin strips across the tested ratios showed a purple color, indicating low sensitivity at this stage. This suggests that minimal chemical changes had occurred in the rice, resulting in limited interaction between spoilage-related compounds

and the anthocyanin pigments. After 24 hours of storage, the rice pH increased to pH 4, indicating the onset of spoilage. Correspondingly, the strips displayed noticeable color changes, ranging from light pink to magenta and dark pink, depending on the ingredient ratio. These color shifts indicate moderate sensitivity of the anthocyanin strips to increasing acidity and spoilage progression. At this stage, all rice samples were classified as spoiled, demonstrating that the strips could detect early spoilage conditions. At 48 hours of storage, the rice samples reached a higher pH level (pH 6), reflecting advanced spoilage. The anthocyanin strips exhibited more intense color changes, including pink,

indigo, and deep pink, indicating high sensitivity. The strips reacted fully and more rapidly to the spoilage environment, particularly in higher anthocyanin concentrations, suggesting stronger pigment–pH interactions as spoilage intensified.

Comparing ingredient ratios, strips with higher anthocyanin content showed more pronounced and faster color changes,

especially at longer storage times. This indicates that increased anthocyanin concentration enhances the sensitivity of the strips to spoilage-related pH changes. Overall, the results confirm that anthocyanin-based color-changing strips effectively respond to rice spoilage over time, with clearer and stronger color transitions observed as storage duration and pH increase.

**Table 2:** Response Time to Rice Spoilage

Ratio	Rice Sample	Storage Time	Response Time	Strip Color	Observation	Fresh/Spoiled
3:30	Normal Rice	12 hours	Did not respond	Purple	The strip did not respond as the sample is considered fresh	Fresh
3:50	Normal Rice	12 hours	Did not respond	Purple	The strip did not respond as the sample is considered fresh	Fresh
3:100	Normal Rice	12 hours	Did not respond	Purple	The strip did not respond as the sample is considered fresh	Fresh
3:30	Normal Rice	24 hours	2 minutes and 14 seconds	Light Pink	The strip did respond slowly as the sample has moderate acid content and reacts to the extract.	Spoiled
3:50	Normal Rice	24 hours	1 minutes and 36	Light Magenta	The strip reacts to the acidity of the sample more quickly and can be considered spoiled.	Spoiled
3:100	Normal Rice	24 hours	2 minutes 42	Vibrant Magenta	The strip respond to the sample slower but it is more sensitive to the acid content and has vibrant color.	Spoiled
3:30	Normal Rice	48 hours	36 seconds	Rose Magenta	The strip respond to the sample more quickly and more sensitive to the acid content but has lighter gradient.	Spoiled
3:50	Normal Rice	48 hours	27 seconds	Light Magenta	The strip respond to the sample quicker and it is more sensitive to the acid content and has light color.	Spoiled
3:100	Normal Rice	48 hours	43 seconds	Deep Magenta	The strip respond to the sample slower but it is more sensitive to the acid content and has vibrant gradient and more visible.	Spoiled

This test shows the response time of the anthocyanin strips based on the storage duration of the rice samples and their ability to quickly indicate food freshness. The results show that after 12 hours of storage, the strips did not respond and showed no significant color change, causing the strip color to remain unchanged and indicating that the rice sample was still fresh. At 24 hours of storage, the strips responded more slowly and displayed a lighter color change, which reacted to the increased acidity and indicated that the rice sample had begun to spoil. However, the 3:50 ratio showed a faster response time but exhibited inconsistent color retention. In contrast, the 3:100 ratio responded more slowly than the 3:50 ratio but produced a more vibrant color, which provided clearer indication of the freshness level.

Lastly, after 48 hours of storage, most of the strips reacted and clearly indicated that the rice samples were spoiled, as expected. Among the ratios, the 3:50 ratio responded the fastest but continued to show inconsistent color retention. On the other hand, the 3:100 ratio reacted more slowly but displayed a more vibrant and stable color change, allowing a clearer indication of the spoilage level of the rice sample.

**Table 3:** Durability of the Strip

Ratio	Storage Duration	Duration	Color Sensitivity	Physical Condition	Result
3:30	Approximately 1-3 months	Slightly Flexible	Low Sensitivity	Faded Color	Brittle
3:50	Approximately 1-3 months	Slightly Flexible	High Sensitivity	Tinted Color	Durable
3:100	Approximately 1-3 months	Flexible	High Sensitivity	Uniform color	Durable

This table shows that the storage durability or shelf life of the anthocyanin strips is approximately around 1–3 months, indicating that filter paper is durable and suitable for providing a longer shelf life as an eco-friendly solution. This finding suggests that the material used is effective for long-term use and supports waste-reduction efforts. However, the duration and performance of the different ratios showed noticeable differences in their flexibility and overall durability. Among the tested ratios, the 3:100 ratio was observed to be the most flexible, while the 3:30 and 3:50 ratios were identified as the least flexible and least durable.

This makes the 3:30 and 3:50 ratios not recommendable for long-lasting applications or for purposes requiring extended shelf life.

Furthermore, the 3:30 ratio exhibited significantly lower color sensitivity compared to the other ratios, indicating reduced effectiveness in responding to acidity changes. This result clearly suggests that the 3:100 ratio is more beneficial for food indication applications. In addition, differences in the physical condition of the anthocyanin strips were observed among the ratios. Interpretation of the table shows

that the 3:100 ratio stood out the most, as it displayed a more uniform color distribution, creating a balanced condition that enhanced the accuracy and reliability of color indication.

Lastly, the data highlight remarkable differences in the performance of the anthocyanin strip ratios, resulting in varied outcomes in terms of durability, flexibility, and color sensitivity. These results further emphasize that the 3:100 ratio is the most diverse and recommendable option for use as a food freshness indicator.

**Table 4:** Accuracy Test

Ratio	Storage Time	Measured pH	Strip Color	Expected Color	Accuracy (accurate/not accurate)
3:30	24 hours	4	Light Purple	Pink	Not accurate
3:50	24 hours	4	Tinted Purple	Pink	Accurate
3:100	24 hours	4	Purple	Pink	Accurate

Table 4 presents the accuracy test results of anthocyanin-based color-changing strips at different ingredient ratios after 24 hours of rice storage with a measured pH level of 4. The accuracy of the strips was determined by comparing the observed strip color with the expected color corresponding to the measured pH value.

The results show that the 3:30 ratio exhibited a light purple color, which did not match the expected pink color at pH 4. As a result, this formulation was classified as not accurate, indicating lower sensitivity or insufficient pigment concentration to reflect the expected pH-related color change. In contrast, the 3:50 and 3:100 ratios produced strip

colors that were closer to the expected pink coloration, leading to an accurate classification. These findings suggest that formulations with higher base material proportions provided more reliable color responses at moderate spoilage levels. The improved accuracy observed in these ratios indicates better pigment dispersion and interaction with spoilage-related pH changes.

Overall, the accuracy test demonstrates that ingredient ratio plays a critical role in the reliability of anthocyanin-based strips, with certain formulations yielding more precise color indications of rice freshness.

**Table 5:** Interference Test

Sample Condition	Interfering Factor	Observation on Color	Effect on Reading	Remarks
Aging (24 hours)	Wind	The color of the strip did not change when the wind hits the strip during occurrence	None	No Significant Remarks
Aging (24 hours)	Heat	The heat simultaneously affect the strips making it confusing to read if the sample is fresh or not	Confusing	Significant remarks
Aging (24 hours)	Water	The water occurrence can affect the acidity of water, making the acid of the sample can be manipulated.	Confusing	Significant remarks
Aging (24 hours)	Acidity	The acidity will affect the strips directly as this results to see if the sample is fresh or spoiled.	Understandable	Significant remarks

The interference test evaluated how external factors affect the color response and reliability of the anthocyanin strip when applied to rice samples aged for 24 hours. Based on the results, wind exposure did not cause any noticeable color change on the strip. This indicates that wind has no significant effect on the strip's reading and does not interfere with its ability to indicate rice freshness.

In contrast, heat exposure significantly affected the strip's performance. The presence of heat altered the strip's color response, making it difficult to accurately determine whether the rice sample was fresh or spoiled. This suggests that high temperatures can interfere with the reliability of the anthocyanin strip and may lead to confusing results.

Similarly, the addition of water caused a confusing effect on the reading. Water dilution was observed to affect the acidity of the rice sample, which could manipulate the pH level and alter the strip's color response. This interference may result in inaccurate interpretation of the rice's freshness.

Lastly, acidity directly influenced the color change of the anthocyanin strip. Unlike other interfering factors, this effect was understandable and expected, as the strip is designed to

respond to changes in acidity. The direct reaction to acidity allowed the strip to effectively indicate whether the rice sample was fresh or spoiled.

**Table 6:** Practicality Usability test

Criteria	Observation	Rating (1-5)	Remarks
Ease of use	It has high potential and uncomplicated to utilize for freshness indicator.	3	Neutral
Time to get result	It has good speed for showing result in different storage time of sample.	4	Recommendable
Readability	It shows the indication of the strips for results intelligible.	5	Highly Recommendable
Cost-effectiveness	It is more effectively to use for household practices for a safety and eco-friendly solution.	4	Recommendable
Sustainability for food testing	It gives an solution for a problem that can impact the reduction of food poisoning and waste pollution	5	Highly Recommendable

Table 6 presents the data of the practicality and usability test of the anthocyanin strips that utilized red cabbage as the source. The strips received a neutral rating for ease of use, with a score of 3, indicating that while the strips can be used effectively, minor improvements in handling or application may be needed to enhance user convenience. The time required to obtain results was rated 4, suggesting that the strips provide relatively fast responses and are recommendable for practical food freshness testing.

Readability received the highest rating of 5, indicating that the color changes produced by the strips are clear, distinct, and easy to interpret. This high readability supports the reliability of the strips as a visual indicator of rice freshness. Cost-effectiveness was rated 4, showing that the strips are affordable and suitable for regular use, making them a practical option for low-cost food monitoring. Lastly, sustainability for food testing received a rating of 5, highlighting that the strips are highly recommendable as an eco-friendly solution due to their natural components as indicator and minimal environmental impact.

Lastly, the results demonstrate that the anthocyanin-based strips are practical, cost-effective, and highly sustainable for food freshness indication, with strong performance in readability and response time, and acceptable ease of use.

**Table 7:** Consistency Test

Ratio	Rice Sample	Strip Color Observed	pH Indication	Consistent? (Yes/No)
3:30	24 hours	Light Pink	Moderate sensitivity	No
3:50	24 hours	Pink	High sensitivity	Yes
3:100	24 hours	Pink	High sensitivity	Yes

Table 7 shows the consistency of color responses produced by different anthocyanin-to-base material ratios after 24 hours of rice storage. Consistency was evaluated based on whether the observed strip color reliably indicated the expected pH sensitivity.

The results reveal that the 3:30 ratio produced a light pink color with only moderate sensitivity and was classified as not consistent. This suggests that this formulation may have insufficient pigment stability or uneven color response under the same storage conditions. In contrast, both the 3:50 and 3:100 ratios produced a consistent pink color and demonstrated high sensitivity, resulting in a consistent classification. These formulations showed reliable and repeatable color changes that accurately reflected the spoilage condition of the rice.

Overall, the consistency test confirms that higher ratios of base material relative to anthocyanin extract improve the reliability and reproducibility of color responses. The 3:50 and 3:100 ratios were identified as the most consistent and dependable formulations for use as rice freshness indicators.

### Conclusion

Based on the findings of the study, anthocyanin-based color-changing strips are effective as a natural and visual indicator of rice freshness. The strips successfully responded to changes in rice pH and storage time, allowing clear differentiation between fresh and spoiled rice. The results confirm that ingredient ratio significantly affects the performance of the strips in terms of sensitivity, response time, durability, accuracy, and consistency. Among the tested formulations, the 3:100 ratio demonstrated the most balanced performance, exhibiting high sensitivity, reliable

color accuracy, strong durability, and consistent results. Although the 3:50 ratio showed faster response times, its color stability was less reliable. The 3:30 ratio was found to be the least effective due to low sensitivity, poor durability, and inconsistent performance. Overall, the study concludes that anthocyanin-based strips, particularly at optimized ratios, have strong potential as an eco-friendly, low-cost, and non-invasive rice freshness indicator that can help reduce food waste and improve food safety.

### Recommendation

The “Fresh or Not? Anthocyanin-Powered Strips That Reveal Rice Spoilage” study shows great promise in food safety monitoring, providing a practical and eco-friendly tool for detecting rice spoilage through visible color changes. It is suggested that future research further explore the strips’ capability in responding to different levels of pH variation and microbial activity associated with rice deterioration. Expanding experimental trials to include various rice types, storage environments, and temperature conditions could enhance the reliability and applicability of the strips in real-life household settings. The innovation could provide a more accurate and timely method of identifying rice spoilage, which would be highly valuable in preventing foodborne illnesses and reducing food waste. To increase usability, it is important to ensure that the strips are easy to interpret, with clear color guides and simple instructions that allow both households and small food handlers to determine freshness without relying solely on smell or appearance. Furthermore, the effectiveness of the strips will depend on improving their durability, stability, and resistance to environmental factors such as humidity and heat. For future development, it is recommended that the formulation be optimized to enhance sensitivity, response time, and shelf life, making the product more adaptable to different practical conditions. Moreover, ensuring compliance with food safety standards and biodegradable material regulations will help build trust among users and support the long-term sustainability of the innovation. By focusing on these aspects, the anthocyanin-powered strips have the potential to become a significant tool in promoting food safety awareness, environmental responsibility, and household waste reduction.

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