

DEVELOPMENT OF A SMARTPHONE-BASED DIGITAL IMAGE COLORIMETRY (DIC) METHOD FOR FISH FRESHNESS DETERMINATION

Pengembangan Metode Digital Image Colorimetry (DIC) Untuk Penentuan Kesegaran Ikan Berbasis Smartphone

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ABSTRACT

Fish is a highly perishable commodity that experiences rapid quality deterioration after being caught, thus requiring a rapid, accurate, and practical freshness detection method. Conventional methods such as organoleptic tests have limitations due to their subjective nature, thereby necessitating the development of alternative methods based on digital technology. This study aims to develop a smartphone-based Digital Image Colorimetry (DIC) method to detect fish freshness using natural dye from butterfly pea extract (*Clitoria ternatea*), and evaluate the accuracy of DIC results compared to conventional organoleptic tests. This research employed an experimental quantitative approach by utilizing indicator paper labeled with butterfly pea extract. Anthocyanins contained in the extract functioned as pH indicators that respond sensitively to volatile compounds (ammonia) produced during fish storage. Color changes were analyzed through RGB values obtained using a smartphone application and compared with panelist-based organoleptic evaluations. The results showed that the DIC method was successfully developed using butterfly pea extract as a natural dye on indicator paper. The observed color changes during fish deterioration were consistent with the RGB value patterns. Furthermore, the DIC analysis demonstrated strong consistency with organoleptic test results, indicating that the DIC method is accurate, practical, and potentially applicable as an alternative to conventional methods for determining fish freshness using a smartphone-based system.

Key words: Digital Image Colorimetry, Fish Freshness

ABSTRAK

Ikan merupakan komoditas perikanan yang mudah mengalami penurunan mutu setelah ditangkap, sehingga diperlukan metode deteksi kesegaran yang cepat, akurat, dan praktis.

Metode konvensional seperti uji organoleptik memiliki keterbatasan karena bersifat subjektif, sehingga perlu dikembangkan metode alternatif berbasis teknologi digital. Penelitian ini bertujuan untuk mengembangkan metode Digital Image Colorimetry (DIC) berbasis smartphone dalam mendeteksi nilai kesegaran ikan menggunakan pewarna alami ekstrak bunga telang (*Clitoria ternatea*), serta menguji keakuratan hasil DIC dibandingkan dengan metode konvensional uji organoleptik. Metode penelitian ini menggunakan pendekatan eksperimental kuantitatif dengan memanfaatkan kertas label indikator yang telah diberi ekstrak bunga telang. Antosianin pada ekstrak telang berfungsi sebagai indikator pH yang peka terhadap perubahan senyawa volatil (amonia) selama penyimpanan ikan. Data warna diolah melalui nilai RGB menggunakan aplikasi berbasis smartphone, kemudian hasilnya dibandingkan dengan data uji organoleptik dari panelis. Hasil penelitian menunjukkan bahwa metode DIC berhasil dikembangkan dengan memanfaatkan ekstrak bunga telang sebagai pewarna alami pada kertas label indikator. Perubahan warna yang terjadi akibat degradasi mutu ikan terbukti selaras dengan pola perubahan nilai RGB. Selain itu, hasil analisis DIC menunjukkan konsistensi dengan hasil uji organoleptik, sehingga dapat disimpulkan bahwa metode DIC cukup akurat, praktis, dan potensial sebagai alternatif metode konvensional dalam menentukan kesegaran ikan berbasis smartphone.

Kata Kunci: Kesegaran Ikan, Kolorimetri Gambar Digital

INTRODUCTION

Fish is a major source of animal protein widely consumed by people in both urban and rural areas. As a marine product, fish contains long-chain fatty acids such as omega-3 (DHA) and omega-6, which play an important role in supporting growth and maintaining body health, and these contents are rarely found in land-based animal or plant products (Dewi *et al.*, 2018). In addition to having high nutritional value and a relatively affordable price, fish is also an important food ingredient for humans, but its perishable nature makes it a commodity that requires special handling.

Fresh fish, or fresh fish, is fish that has not undergone any preservation process with any additional ingredients, except for cooling with ice. Fish is considered to be at an optimal level of freshness if its characteristics still resemble live fish, both in terms of appearance, aroma, taste, and texture. If fish is handled improperly, its quality will decline. Fresh fish handling encompasses the entire process from when the fish is caught until it reaches the consumer, involving various parties such as fishermen, traders, processors, distributors, retailers, and so on (Nurqaderianie *et al.*, 2016).

Identifying fish freshness is a crucial step in the fish processing process and must be carried out quickly and accurately, especially when handling large quantities of fish. Fish freshness can be determined by changes in the color of the fish's eyes. Conventional methods commonly used to detect fish freshness include chemical or biochemical analysis, microbiological examination, and sensory methods (Saputra *et al.*, 2022). Fish freshness is a crucial aspect in the fisheries industry because it affects the quality, taste, and selling value of the product, both for producers and consumers.

One method commonly used to evaluate fish freshness is a spectrophotometer, a scientific technique that analyzes the chemical and physical properties of fish by measuring the spectrum of light absorbed by the sample. Spectrophotometers offer highly accurate measurements by detecting changes in chemical compounds, such as Total Volatile Basic Nitrogen (TVB-N) and Tri-Methylamine Oxide (TMAO), which are often used as indicators of fish freshness. However, despite their accuracy, the use of spectrophotometers has several limitations.

These include high costs (Rp 300,000-500,000 per sample), long preparation times (6-24 hours) and destructive processes (Wojnowski *et al.*, 2017). Spectrophotometers range in price from tens to hundreds of millions of rupiah, and their use is not always practical in the field. Therefore, it is important to develop accurate and efficient methods for detecting fish freshness.

The development of smartphone technology with high-resolution cameras (>12MP) opens up new opportunities for developing more practical and affordable fish freshness analysis methods. Modern smartphones are equipped with sensitive color sensors, autofocus capabilities, and LED flashes, as well as powerful processors and on-device machine learning capabilities (Masawat *et al.*, 2015). With a smartphone penetration rate reaching 89% in Indonesia (GSMA, 2023) and relatively affordable prices, this technology offers an ideal platform for developing innovative analytical methods. Smartphones offer great potential in chemical analysis, as they allow wider access and more practical use. In this case, smartphones can be used as diagnostic tools using colorimetric methods (Firdaus *et al.*, 2025).

The Digital Image Colorimetry (DIC) method is a technique that uses digital image processing to measure the color or color components of an object or sample. The basic principle is to analyze the color values of digital images to produce quantitative data about color. The digital image analysis method uses RGB (Red, Green, Blue) data, an extension of the color system data called light reflection from an object with a value range of 0 to 255 units. The light reflection from an object is read by a charge-coupled device (CCD) on a digital camera (Dinata *et al.*, 2019). The freshness of fish is greatly influenced by various factors, such as storage, temperature, and time, which cause chemical and physical changes that can be detected through color.

Based on the above description, the development of a smartphone-based Digital Image Colorimetry (DIC) method for determining fish freshness has significant potential to provide a practical solution for monitoring fish quality throughout the supply chain. This research will focus on developing an integrated system, from image acquisition and data processing to result interpretation, that can be widely implemented in the fisheries industry. It is hoped that the results of this research will make a significant contribution to improving the efficiency and effectiveness of fish freshness determination in Indonesia.

RESEARCH METHODS

This research was conducted from April to August 2025 at the Fisheries Laboratory of the Marine Science Study Program, Faculty of Agriculture, University of Bengkulu. This research used an experimental method with quantitative data analysis. To measure the freshness of the fish, the data collection method used was Digital Image Colorimetry (DIC). This method is used to analyze color changes in fish through digital images captured using a smartphone camera. The data obtained from this method were then statistically analyzed to determine the correlation between color parameters and the freshness level of the fish.

Research Tools and Materials

Table 1. Tools Used in Research

No	Tool	Utility
1	Smartphone with a minimum 12 MP camera	To document color changes in samples.
2	Portable Light Box with LED	Provide lighting when taking sample images.
3	Transparent Glass Bottle	To place fish samples.
4	pH Meter	To measure the pH of flower extraction.
5	Dark Bottle	To store the flower extraction results.

6	Mortar	To refine flower samples in making extractions.
7	Glass Filter	To filter the flower extraction.
8	<i>Whatman Paper</i> No.42	As a base in filtering flower extraction.
9	<i>Whatman Paper</i> No. 1	As an indicator label for extraction absorbent media.
10	Drop pipette	To take the solution with the right volume.
11	Refrigerator	To store flower extraction before use.
12	Analytical Balance	To weigh materials with high accuracy
13	Measuring cup	To prepare a solution with a certain concentration.
14	Data Processing Software	To analyze data obtained from measurements, such as data from a spectrophotometer or digital images.

Table 2. Materials Used in the Research

No	Material	Utility
1	Fresh Fish Samples	As a sample to be tested for freshness.
2	Telang flower extract	As an indicator of color change.
3	Buffer pH	To regulate the acidity level of the solution.
4	<i>Ethanol Absolute</i>	As a solvent to extract compounds.
5	<i>Natrium Hydroxide</i>	To adjust the pH of the solution.
6	<i>Hydrochloric Acid</i>	To lower the pH of the solution.
7	<i>Aquadest</i>	As a solvent and tool cleaner.

Sample Testing Using the DIC Method

1. Preparation of Natural Dye from Butterfly Pea Flower Extract

Pewarna The natural dyes used contain anthocyanins, pigments that are sensitive to pH changes. The natural dye extract is obtained from the anthocyanin-rich Butterfly Pea flower (*Clitoria ternatea*). The dye is extracted using a dyeing method and a buffer solution to maintain its stability.

How to make natural dye from butterfly pea flower extract:

- a. Prepare 20 grams of cleaned and dried butterfly pea flowers.
- b. Crush the flowers and extract them using a mortar and pestle, adding 100 ml of ethanol solvent to distilled water in a 7:3 ratio.
- c. After crushing, add the flower extract to a 1M hydrochloric acid (HCL) solution until the pH is 2.
- d. Then, place it in a dark bottle and let it sit in the refrigerator for 24 hours.
- e. After 24 hours, filter the extract solution using *Whatman Paper* No. 42.
- f. The resulting supernatant is then separated and stored in a dark bottle before being used as a natural dye for butterfly pea flower extract.

2. Colorimetric Label Creation

Cellulose paper is used as a substrate to absorb natural dyes. The cellulose paper used is *Whatman Paper* No. 1, cut into 6 cm x 1 cm pieces. The cut paper is then dipped in a pH 2 butterfly pea flower extract solution for 30 seconds, then dried at room temperature. Once dry, the label paper is ready to be used to detect color changes due to fish damage.

3. Testing with Fish Samples

Fresh fish pieces weighing 5 grams were placed in a closed container along with a colorimetric label. This container was stored at room temperature. The label's color change was monitored hourly for a period of 0 to 24 hours. In addition, an organoleptic test (SNI-01-2729.1-2006) was also carried out on the remaining fish pieces stored at room temperature. This organoleptic test was carried out hourly for a period of 0 to 24 hours.

4. Color Change Analysis

Color changes on the labels were documented using digital photography. Monitoring images were analyzed using ImageJ software to quantitatively measure color changes. The analysis results were compared with the level of fish spoilage through organoleptic testing to determine the correlation between label color changes and fish freshness.

5. Evaluation of Results

Label color changes are the basis for determining fish freshness. Increasing temperature generally accelerates color changes, indicating that storage temperature affects the rate of fish spoilage (Ayu *et al.*, 2022).

RESULTS AND DISCUSSION

Sample Characteristics

In this study, the samples used were mullet (*Mugilidae*) obtained through fishing activities at the Jenggalu River estuary, Bengkulu City. The fish obtained were still alive when caught, so it can be ensured that the initial quality was still fresh. The fish samples used had a total weight of 100 grams with a total length of approximately 22 cm. After being obtained, the fish belly meat was then filleted and cut into three parts with each piece of meat weighing 5 grams. The initial testing process (0 hours) was carried out directly in the field to obtain an overview of changes in freshness since the fish was first caught.

Mullet is an economically important fish found in coastal waters, estuaries, and brackish waters. Morphologically, this fish has a rather large and wide body, two dorsal fins, a rather flat and large head, and black scales on its back and silvery belly (Sukma and Hartono, 2024). The ability of mullet to survive in estuaries with fluctuating salinity makes it a readily available fishery resource for coastal communities (Okfan and Muskananfolo, 2015). Furthermore, this fish also has good nutritional value, especially in protein and fatty acid content (Hafiludin *et al.*, 2012), making its freshness very important to consider post-harvest.

Mullet fish were selected as research samples based on their availability in the study area and their biological characteristics, which are suitable for fish quality studies. The initial condition of the fish, still alive when caught, provides a good basis for observing gradual changes in freshness. Using the Digital Image Colorimetry (DIC) method, it is hoped that changes in freshness resulting from the formation of volatile compounds such as ammonia can be detected through color changes in an indicator based on Butterfly Pea flower extract. Thus, this study not only describes the dynamics of post-harvest mullet freshness but also tests the potential of the smartphone-based DIC method as a simple technology for detecting fish freshness in the field.



Figure 1. Mullet fish

(Source: Personal Documentation)

The classification of Mullet Fish (*Mugil cephalus*) according to Kurniawan (2022) is as follows:

Kingdom : Animalia

Phylum : Chordata

Classis : Actinopterygii

Ordo : Mugiliformes

Familia : Mugilidae

Genus : *Mugil*

Species : *Mugil cephalus*

Butterfly Pea Flower Extract

The butterfly pea flower extract (*Clitoria ternatea*) used in this study acts as a natural indicator solution on indicator label paper. Butterfly pea flowers are known to be rich in anthocyanin pigments, flavonoid compounds that have a polyphenol structure with a chromophore group that can absorb light at certain wavelengths (Purwaniati *et al.*, 2020). Anthocyanins are very sensitive to changes in environmental pH, so the color displayed can change according to acidity or alkalinity (Yessica, 2023). In acidic conditions (low pH), anthocyanins tend to appear purplish red, while in neutral conditions they change to blue, and in alkaline conditions (high pH) they turn greenish (Angriani, 2019). This property makes butterfly pea flowers potentially used as an indicator of fish freshness, because protein degradation in fish during storage produces volatile base compounds such as ammonia that can increase pH.

The color change process of butterfly pea flower extract on indicator paper occurs due to the interaction between anthocyanin molecules and hydrogen ions (H^+) in the environment (Safitri and Findari, 2024). During decomposition, deamination of amino acids by microorganisms produces ammonia and volatile amines (TVB-N components). This increase in total ammonia/amines changes the acid-base balance (NH_3/NH_4^+) in the tissue, so that the system tends to become more alkaline (pH value increases). The increase in pH then causes a structural transformation of anthocyanins (*flavylium* \rightarrow *quinoidal/anion* \rightarrow *pseudobase* \rightarrow *chalcone*), which results in a color change that can be used as a pH/freshness indicator (Zhuang *et al.*, 2021). This mechanism explains why indicator paper dipped in butterfly pea flower extract will experience a color change as the ammonia content in fish meat increases.

The butterfly pea flower extraction process itself is generally carried out using polar solvents such as ethanol and distilled water, because anthocyanins dissolve well in polar solvents (Unawahi *et al.*, 2022). In this study, the resulting extract was then dipped into Whatman Paper No. 1 to produce a purplish-red indicator paper. When the paper was exposed to ammonia vapors produced by fish protein degradation, a gradual color change could be observed visually and through quantification of RGB values using the Digital Image

Colorimetry (DIC) method. Thus, the use of butterfly pea flower extract not only exploits the potential of safe and affordable natural ingredients but also supports innovation in color-indicator-based fish freshness detection technology.

Organoleptic Test Results

The organoleptic test in this study was conducted by eight semi-trained panelists, who assessed the freshness of mullet based on key sensory attributes: color, odor, texture, and general appearance. Each panelist assigned a score ranging from 1 to 9, with 9 indicating very fresh fish and 1 indicating unfit for consumption. The results of the eight panelists' assessments were then averaged to obtain a general overview of changes in the organoleptic quality of the fish during 24 hours of storage.

Table 3. Organoleptic Test Results

Time (Hour)	Average value	SD
0	9,00	0,00
2	7,88	0,64
4	7,13	0,35
6	6,63	0,52
8	6,00	0,53
10	5,00	0,53
12	4,75	0,71
14	4,25	0,71
16	3,38	0,52
18	2,50	0,53
20	1,88	0,35
22	1,00	0,00
24	1,00	0,00

Based on the organoleptic test results conducted by eight panelists on mullet, the average score ranged from 1 to 9, with 9 indicating very fresh and 1 indicating unfit for consumption. The assessment results showed a gradual decline in organoleptic values as the 24-hour storage period increased.

At 0 hours, the fish received an average score of 9, indicating very fresh condition, characterized by clear eyes, bright red gills, a natural fresh odor, and a firm and elastic flesh texture. After 2–4 hours, the organoleptic score began to decline to 7. Although the fish was still edible, panelists began to detect subtle changes, such as a more pronounced fishy odor and a slight change in the brightness of the flesh color.

At 6–10 hours, the organoleptic score dropped to a range of 6–5, indicating the fish began to show signs of freshness loss. Panelists noted the flesh texture began to become less elastic, the fishy odor became stronger, and the gills appeared duller. At 12–16 hours, the score dropped further to 4–3, indicating the fish was at the limit of freshness, almost unfit for consumption. The odor changed to a sharper and more unpleasant odor, accompanied by a softer flesh texture.

After longer storage, 18–24 hours, the organoleptic score only reached 2–1, indicating the fish had undergone advanced decomposition. Panelists reported a distinct foul odor, very soft flesh texture, and a paler color. Therefore, it can be concluded that the mullet tested

experienced a significant decline in organoleptic quality within 24 hours, and based on the panelists' assessment, the fish was no longer fit for consumption after 18 hours of storage.

Looking at the Standard Deviation (SD) value, it can be seen that at hour 0 the SD value was 0, indicating that all panelists gave the same assessment of the sample's condition. However, at subsequent times, the SD value ranged from 0.35 to 0.71, indicating that there was variation in assessments between panelists, although not too large. For example, at hour 12 the average organoleptic value was 5 with an SD of 0.71, which means that some panelists considered it still quite acceptable, but others considered it to have declined in quality.

These results align with the theory that fresh fish is highly susceptible to postmortem spoilage due to enzymatic autolysis, bacterial activity, and lipid oxidation, which leads to the formation of volatile compounds such as ammonia and trimethylamine (Huss, 1995). These compounds contribute to the degradation of odor, flavor, texture, and color, thus affecting the overall organoleptic score.

Digital Image Colorimetry (DIC) Test Results

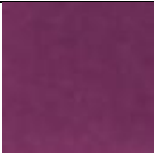
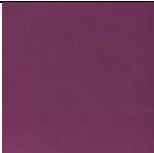

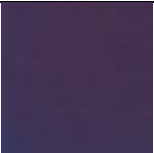

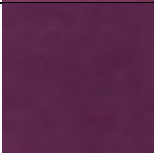
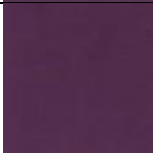
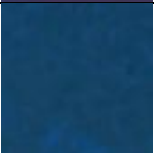
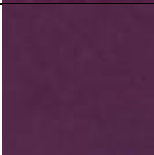
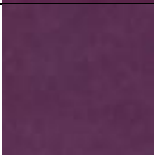
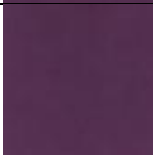

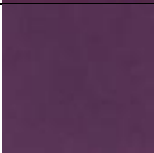

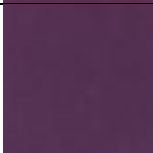
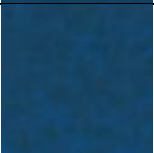
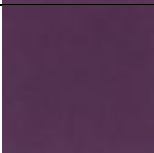
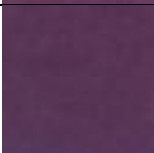
Time (Hour)	I ₀	I ₁	Time (Hour)	I ₀	I ₁
0			15		
3			18		
6			21		
9			24		
12					

Figure 2. Color Change on the Indicator Label

Based on visual observations on the indicator label paper (Figure 2), the color change becomes more apparent as the fish is stored. From 0 to 12 hours, the indicator paper is predominantly purplish red. This color indicates that the fish is still fresh, with low levels of volatile compounds such as ammonia (NH₃). At this stage, the pH is still relatively close to neutral, so the anthocyanins in butterfly pea flowers are in a structural balance between the flavylum cation form (red) and the base form (blue), producing a distinctive purple hue. According to Herfayati *et al.* (2020), the red color is formed by the flavylum cation, where the number of methoxy groups in the anthocyanin structure is more dominant than the hydroxyl groups.

Entering the 15th to 24th hour, the indicator paper showed a stronger color shift towards purplish blue to dark blue. This shift occurs due to the increasing concentration of volatile base compounds resulting from protein decomposition by microbial activity, so that the system pH increases. Under more alkaline conditions, anthocyanins undergo a structural shift from the flavyllium cation form to the more stable basic quinoidal form, so that the color that appears tends to be bluer. According to Herfayati *et al.* (2020), under alkaline conditions the extract turns bluish due to the carbinol pseudobase structure.

The color changes in this table align with the organoleptic test results, which indicate a decrease in freshness scores, and are supported by the results of Digital Image Colorimetry (RGB) analysis. Red values tend to decrease, while Blue values increase in the final hours, consistent with the visual transition from purple to blue. Thus, the anthocyanin-based indicator label paper from butterfly pea flowers can simply represent the freshness level of fish, with purple indicating fresh fish, while blue indicates that the fish has lost its freshness.

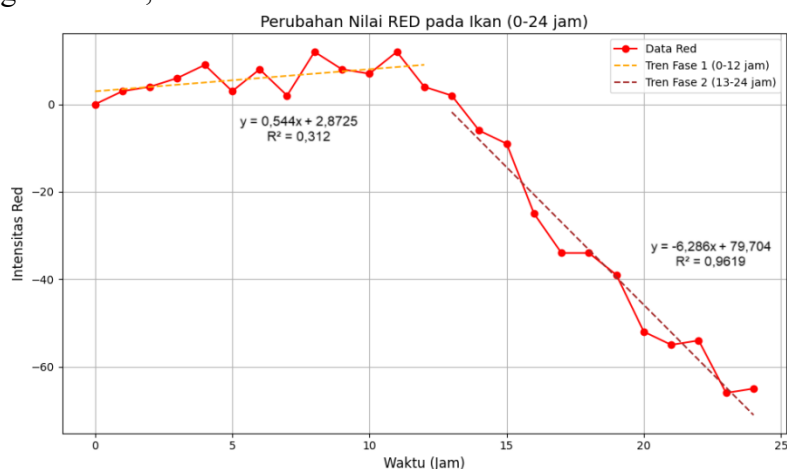


Figure 3. RED Value Graph

In the initial phase (0–12 hours), the Red intensity value showed a slight increase with a linear regression equation of $y = 0.544x + 2.8725$ ($R^2 = 0.312$). This indicates that the red color is relatively stable and even increased at the beginning of storage. However, after 12 hours to 24 hours, the Red intensity decreased sharply with the equation $y = -6.286x + 79.704$ ($R^2 = 0.9619$). This significant decrease illustrates the presence of color changes related to the decline in fish quality due to the accumulation of volatile compounds such as ammonia (NH_3) and trimethylamine (TMA) which increase the surface pH (Byrne *et al.*, 2002).

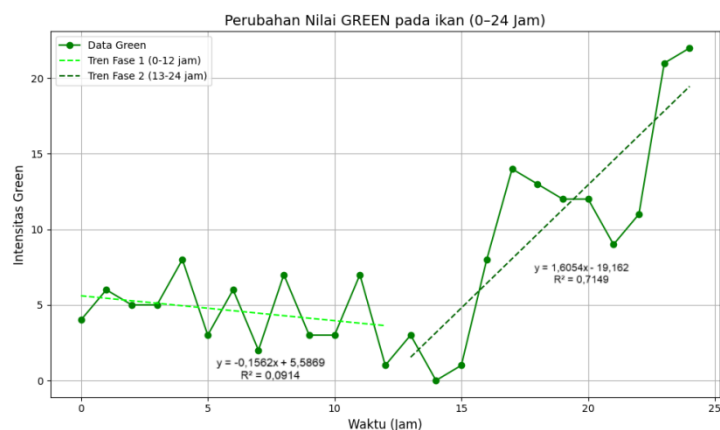


Figure 4. GREEN Value Graph

The Green intensity fluctuated relatively at 0–12 hours with a downward trend ($y = -0.1562x + 5.5869$; $R^2 = 0.0914$), where the indicator paper was still purple. This change was relatively small because the purple color composition was formed from a combination of red and blue with Green still contributing. In the 13–24 hour phase, the Green value increased ($y = 1.6054x - 19.162$; $R^2 = 0.7149$), as the indicator color shifted to blue. This phenomenon occurs because the visually visible blue color still contains Green components in the RGB system, so that even though it is not clearly visible as green, the increase in Green value is still detected digitally. Thus, the shift in the indicator color from purple to blue is also reflected in the increase in Green intensity, which indicates the dynamics of changes in pigment composition due to increased pH and the formation of volatile base compounds during fish storage. According to Fadhli *et al.* (2022), the decomposition process in fish meat results in the formation of volatile base compounds which will react with the smart label and cause a color change in the indicator.

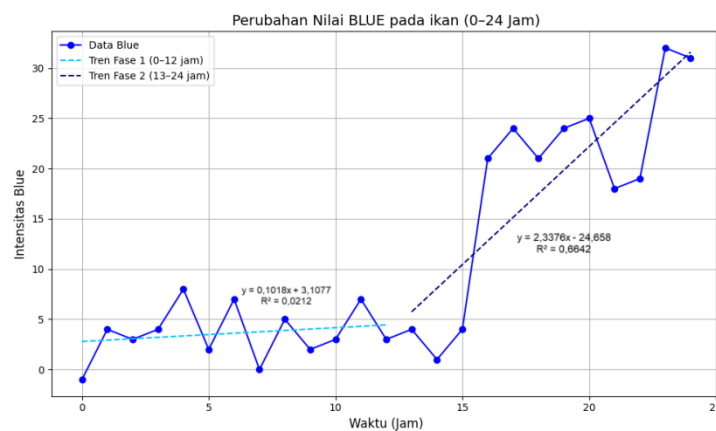


Figure 5. BLUE Value Graph

The Blue intensity also showed a similar pattern to Green. At the beginning of storage (0–12 hours), the intensity was relatively stable with a slight increase ($y = 0.1018x + 3.1077$; $R^2 = 0.0212$). However, after 12 hours, there was a significant increase ($y = 2.3376x - 24.658$; $R^2 = 0.6642$), indicating a shift in the indicator color towards blue. This further strengthens the evidence that the increase in pH due to microbial activity and the formation of ammonia compounds directly affects the intensity of the blue color on the indicator label (Apriliani *et al.*, 2022).

CONCLUSION

Based on the results of the research that has been conducted regarding the Development of a Smartphone-Based Digital Image Colorimetry (DIC) Method for Determining Fish Freshness, it can be concluded that: This research has succeeded in developing a smartphone-based Digital Image Colorimetry (DIC) method by utilizing butterfly pea flower extract (*Clitoria ternatea*) as a natural dye on indicator label paper. Anthocyanins in butterfly pea flowers have been shown to be sensitive to pH changes triggered by an increase in volatile compounds such as ammonia during fish storage, so that color changes in indicator paper can be used as an indicator of fish freshness. The results of the DIC analysis obtained through processing RGB values show a color change pattern that is consistent with the results of organoleptic tests using panelists. This proves that the DIC method can be an accurate and practical alternative compared to conventional methods in detecting fish quality decline during storage.

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REFERENCES

- Angriani, L. (2019). Potensi ekstrak bunga telang (*Clitoria ternatea* L.) sebagai pewarna alami lokal pada berbagai industri pangan. *Canrea Journal: Food Technology, Nutrition, and Culinary Journal*, 32–37.
- Aprilliani, F., Ayuningtyas, L. P., & Lestari, H. A. (2022). Bunga telang (*Clitoria ternatea* L.) sebagai indikator pH dalam sistem kemasan pintar. *Agroteknika*, 5(2), 87–97.
- Ayu, D. F., Efendy, R., Nopiani, Y., Saputra, E., & Haryani, S. (2022). Pendugaan umur simpan ikan patin salai menggunakan metode akselerasi dengan kemasan HDPE dan teknik pengemasan aluminium foil. *Jurnal Teknologi dan Industri Pertanian Indonesia*, 14(2), 88–96.
- Byrne, L., Lau, K. T., & Diamond, D. (2002). Monitoring of headspace total volatile basic nitrogen from selected fish species using reflectance spectroscopic measurements of pH sensitive films. *Analyst*, 127(10), 1338–1341.
- Dewi, P. F. A., Widarti, I. G. A., & Sukraniti, D. P. (2018). Pengetahuan ibu tentang ikan dan pola konsumsi ikan pada balita di Desa Kedongan, Kabupaten Badung. *Jurnal Ilmu Gizi: Journal of Nutrition Science*, 7(1), 17–20.
- Dinata, A. A., Firdaus, M. L., & Elvia, R. (2019). Penerapan kemometrik pada metode citra digital untuk analisis ion merkuri (II) dengan indikator nanopartikel perak. *Alotrop*, 3(1).
- Fadhli, I., Dewi, E. N., & Fahmi, A. S. (2022). Aplikasi methyl red sebagai label indikator kesegaran ikan bandeng (*Chanos chanos*) pada suhu penyimpanan dingin yang berbeda. *Jurnal Ilmu dan Teknologi Perikanan*, 4(1), 15–23.
- Firdaus, M. L., Marlina, N., & Shabrina, A. N. (2025). *Pemanfaatan citra digital untuk analisis di dunia riset dan pendidikan*. Penerbit Wawasan Ilmu.
- Hafiludin, H., Zainuri, M., & Wahyudi, S. R. (2012). Analisis kandungan gizi dan logam berat ikan belanak (*Mugil* sp.) di sekitar perairan Socah. *Jurnal Kelautan: Indonesian Journal of Marine Science and Technology*, 5(2), 132–141.
- Herfayati, P., Pandia, S., & Nasution, H. (2020). Karakteristik antosianin dari kulit buah nipah (*Nypa fruticans*) sebagai pewarna alami dengan metode soxhletasi. *Jurnal Teknik Kimia USU*, 9(1), 26–33.
- Huss, H. H. (Ed.). (1995). *Quality and quality changes in fresh fish* (Vol. 348). FAO.
- Kurniawan, A. J. (2022). *Pendugaan stok ikan belanak (Mugil cephalus) hasil tangkapan nelayan di Muara Sungai Kakap Kabupaten Kubu Raya Kalimantan Barat* (Disertasi doktor). Universitas Tanjungpura.
- Nurqaderanie, A. S., Metusalach, M., & Fahrul, F. (2016). Tingkat kesegaran ikan kembung lelaki (*Rastrelliger kanagurta*) yang dijual eceran keliling di Kota Makassar. *Jurnal IPTEKS Pemanfaatan Sumberdaya Perikanan*, 3(6).
- Okfan, A., & Muskananfolo, M. R. (2015). Studi ekologi dan aspek biologi ikan belanak (*Mugil* sp.) di perairan Muara Sungai Banger, Kota Pekalongan. *Management of Aquatic Resources Journal (MAQUARES)*, 4(3), 156–163.
- Purwaniati, P., Arif, A. R., & Yuliantini, A. (2020). Analisis kadar antosianin total pada sediaan bunga telang (*Clitoria ternatea*) dengan metode pH diferensial menggunakan spektrofotometri visible. *Jurnal Farmagazine*, 7(1), 18–23.

- Safitri, R. E., & Findari, H. (2024). Analisis kualitatif senyawa hidrokuinon menggunakan ekstrak bunga telang (*Clitoria ternatea* L.) sebagai indikator warna. *Jurnal Crystal: Publikasi Penelitian Kimia dan Terapannya*, 6(2), 82–86.
- Saputra, S., Yudhana, A., & Umar, R. (2022). Identifikasi kesegaran ikan menggunakan algoritma KNN berbasis citra digital. *Krea-TIF: Jurnal Teknik Informatika*, 10(1), 1–9.
- Sukma, D. M., & Hartono, D. (2024). Identifikasi ikan belanak (Mugilidae) hasil tangkapan nelayan di Kecamatan Kota Mukomuko, Kabupaten Mukomuko. Dalam *Prosiding Seminar Nasional Hasil Penelitian Kelautan dan Perikanan* (Vol. 2, hlm. 127–133).
- Unawahi, S., Widyasanti, A., & Rahimah, S. (2022). Ekstraksi antosianin bunga telang (*Clitoria ternatea* Linn) dengan metode ultrasonik menggunakan pelarut aquades dan asam asetat. *Journal of Tropical Agricultural Engineering and Biosystems*, 10(1), 1–9.
- Wojnowski, W., Majchrzak, T., Dymerski, T., Gębicki, J., & Namieśnik, J. (2017). Electronic noses: Powerful tools in meat quality assessment. *Meat Science*, 131, 119–131.
- Yessica, Y. (2023). Pemanfaatan antosianin sebagai indikator pada smart film packaging untuk mendeteksi kesegaran produk pangan. *ZIGMA*, 38(2), 60–72.
- Zhuang, S., Liu, X., Li, Y., Zhang, L., Hong, H., Liu, J., & Luo, Y. (2021). Biochemical changes and amino acid deamination and decarboxylation activities of spoilage microbiota in chill-stored grass carp (*Ctenopharyngodon idella*) fillets. *Food Chemistry*, 336, 127683.