Jurnal Fisika 15 (1) (2025) 30-39
Jurnal Fisika
https://journal.unnes.ac.id/nju/index.php/jf/index

Synthesis and Characterization of Wall Paint Based on Red Beetroot Betacyanin Pigment with Maceration

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Article Info

Article History:

Received:
17 November 2024

Accepted:
30 April 2025

Published:
5 May 2025

Keywords: Betacyanin, Natural Pigment, Binder, Environmentally friendly wall paint.

Abstract

Every year, the paint industry in Indonesia continues to grow. This is due to the growth of the property and housing sectors, which increases the demand for paint nationwide. This research aims to develop environmentally friendly wall paint using betacyanin pigment from red beet tubers through a maceration process as an alternative paint color that is sustainable and beneficial for health and the environment. Betacyanin pigment extraction was carried out using the maceration method with 96% ethanol for 48 hours, then filtered using filter paper and evaporated. Binder and pigment are mixed in a ratio of 14.3:2, 14.3:5, 14.3:8, 14.3:11, 14.3:14, and 14.3:17 until homogeneous. Paint characterization is done through pH, color, density, and adhesion tests. The research results show that the sixth paint variation, with a binder and pigment composition ratio of 14.3 ml:17 ml, provides the most optimal results that closely align with SNI. The paint has a deep red color, pH 7.6, density of 1.18 g/cm^3, and adhesion of 100%.

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p-ISSN 2088-1509

INTRODUCTION

The need for property grows with an increasing population, resulting in an ever-increasing demand for building materials. One of the most sought-after building materials is paint, which is used in the final stage of painting the walls of a house to give an aesthetic impression (Malik, 2019). Every year, the paint industry in Indonesia continues to grow. This is due to the growth of the property and housing sectors, which increases the demand for paint nationwide. It is projected that the level of consumption of decorative paint, which includes wall paint and wood and metal paint, both wet and solvent, will be the most widely consumed (Listiyani & HS, 2021).

Wall paint is a liquid that coats a material's surface to beautify, strengthen, or protect the material. Paint consists of components or ingredients: binder, filler, pigment, solvent, and additives (Rahman & Mulana, 2014). Chemical paints that contain synthetic dyes are hazardous to health and can cause allergies and cancer. Therefore, wall paint is needed without containing synthetic pigment raw materials (Ghobakhloo et al., 2023). Natural pigments as dyes are a promising solution because they are easily degraded, renewable, and do not harm health (Permatasari & Lestari, 2023; Pujilestari, 2015).

Coloring substances derived from natural pigments include chlorophyll, carotenoids, tannins, anthocyanins, and betalains (Bahri et al., 2017). Two types classified under the betalain class are betaxanthin and betacyanin (Fatjria et al., 2022). Betaxanthin and betacyanin have different substituents; betaxanthin is a balsamic acid residue, and dihydroxyphenylalanine is a substituent of betacyanin (Hernández-Aguirre et al., 2021). Betacyanin is a derivative of betalain found in many fruits, flowers, and vegetative tissues. This pigment is red-violet and yellow-orange (Sandi et al., 2021).

Betacyanin is a natural pigment containing nitrogen that dissolves in water and is included in the betalain group (Nursyaqilah et al., 2021). Betacyanin can increase the aesthetic value of wall paint with attractive natural colors and resistance to UV rays. The stability of betacyanin pigment is influenced by temperature and pH. Suppose the water solvent used for extraction is hot. In that case, the concentration process can cause damage because the boiling point of water is relatively high (100 °C), and the stability of betacyanin decreases at temperatures of 70 °C and 80 °C (Halimfanezi & Asra, 2020). Betacyanin is stable at a pH of 3 to 7 (Jamro et al., 2021). This is in line with Asra, et al (2020), if the temperature and pH increase, the color will fade further. The red beetroot plant is the primary commercial source of betacyanin dye (Schneider-Teixeira et al., 2022).

World production of red beet tubers is estimated to be around 275 million metric tons in 2018. Betacyanin constitutes around 75–95% of beet pigment; the remaining 5–25% is betaxanthin. The betalain concentration in red beets is 200–2100 mg/kg fresh weight (Sadowska-Bartosz & Bartosz, 2021). Red beet tubers can be considered a good source of betacyanin because the betacyanin content is higher than in dragon fruit and is more stable (Islawati et al., 2021). It has many carbohydrates and antioxidants and levels of 1.98 mmol/100 grams (Wibawanto et al., 2014). Red beet tubers have many nutrients that help fight antibacterial diseases and cancer and increase free radical activity (Lembong & Lara Utama, 2021). Betacyanin pigment from red beet can be extracted using microwave-assisted methods (Cardoso-Ugarte et al., 2014; Pramudika & Paramita, 2024), maceration (Fu et al., 2020; Hernández-Aguirre et al., 2021; Putra et al., 2023), and other methods.

In this study, the maceration method was chosen because Setiawan, et al (2015) reported that the betacyanin content among the three solvents was maximum in the ethanol: HCl solvent, with a value of 2.4535 mg/100g. Beetroot contains a lot of betacyanin. However, because the red pigment from beetroot is unstable, only a few researchers use it to make wall paint. Temperature and pH affect the stability of betacyanin. This research aims to synthesize and characterize wall paint based on betacyanin pigment from red beet tubers.

Betacyanin pigment is extracted using the maceration method. Wall paint characterization includes pH testing using a pH meter, color testing using a colorimeter, density testing using a measuring cup, and adhesion testing using the cross-cut tape test method. The characterization results were then compared with SNI 3564:2009 concerning wall paint specifications. This wall paint will likely become an alternative color that is sustainable and beneficial for health and the environment.

METHOD

The tools and materials used in this study can be represented in Table 1 and Table 2.

Table 1. Tools and functions.

Tools	Function
Glass jar	Maceration container for red beet tubers with 96% ethanol
Filter paper	Filter the maceration results
Rotary evaporator	Used to make ethanol extract more concentrated by evaporating solvent
Beaker glass and stirrer	To mix betacyanin pigment and binder (adhesive) into wall paint
Colorimeter	Measure the color coordinates of wall paint
pH meter	Measure the pH of wall paint

Table 2. Materials and functions.

Materials	Function
Red beetroot	Main ingredient
Ethanol 96%	Used as a solvent in the maceration of red betroot
Binder	Function as a binder in wall paint formulation

Betacyanin pigment was extracted by preparing the sample, namely 500 g of red beet tubers, and then cutting them into small pieces. Red beet tubers cut into small pieces are dried using an oven and hot sun until the water content in the beet tubers is no longer there. The dried beet tubers weighing 100 g and were put into a glass jar. Add 96% ethanol solvent to the glass jar in a ratio of 1:10 (w/v) (Sari & Damayanti, 2020). Close the glass jar tightly and let it sit for 48 hours. The extraction results are filtered using filter paper, and a filtrate separated from the dregs is obtained. The filtrate was concentrated using a rotary evaporator at 40 °C (Lembong & Lara Utama, 2021).

Paint-making was done by preparing 14.3 ml of binder. Then, 2 ml of concentrated pigment extract solution was added (Variation 1). Repeat the steps above for sample ratios of binder to pigment extract solution, namely 14.3:5 (Variation 2), 14.3:8 (Variation 3), 14.3:11 (Variation 4), 14.3:14 (Variation 5), and 14.3:17 (Variation 6) (Effendy et al., 2019). Several tests, namely 1, carry out the characterization of wall paint) pH test using a pH meter. 2) Test the color using a colorimeter. 3) Test the density empirically using a measuring cup. 3) Adhesion test using the cross-cut-tape method.

RESULTS AND DISCUSSION

This research divided the data collection process into several testing stages: color, pH, density, and adhesion. The test results can provide the best comparison of the composition of the binder and pigment. The testing process was conducted at the Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang.

Betacyanin Pigment Extraction

Extraction of betacyanin pigment from red beet tubers using the maceration method with 96% ethanol solvent. The extraction results are then filtered, and the filtered results are evaporated to produce pigment extract. The pigment produced is deep red because red beet tubers contain pretty high levels of betacyanin pigment (Sadowska-Bartosz & Bartosz, 2021). The results of the betacyanin pigment extraction can be seen in Figure 1.

Figure 1. Betacyanin Pigment Extraction.

This betacyanin pigment is acidic, with a pH of 5.1. This acidic property is caused by the betacyanin pigment containing the dihydroxyphenylalanine substituent, which is a weak acid (Hernández-Aguirre et al., 2021). The stability of betacyanin pigments is strongly influenced by temperature. The results of measuring the pH of betacyanin pigment can be seen in Figure 2.

Figure 2. Measurement of the pH of betacyanin pigment.

Wall paint is made using betacyanin pigment by mixing the betacyanin pigment with the prepared binder. Betacyanin pigment-based wall paint was then characterized and compared with SNI 3564:2009 regarding wall paint specifications. The results of making wall paint can be seen in Figure 3.

Figure 3. Betacyanin pigment-based wall paint.

Wall Paint Characterization

Wall paint is characterized by testing pH, color, density, and adhesion.

pH Test

The pH test in this experiment was carried out using a pH meter. Each variation of wall paint was tested for pH and then compared with SNI 3564:2009. It is known that the SNI pH is 7-9.5. The stability of betacyanin is known to be in the pH range between 3 and 7 (Jamro et al., 2021). The results of the wall paint pH test can be seen in Figure 4.

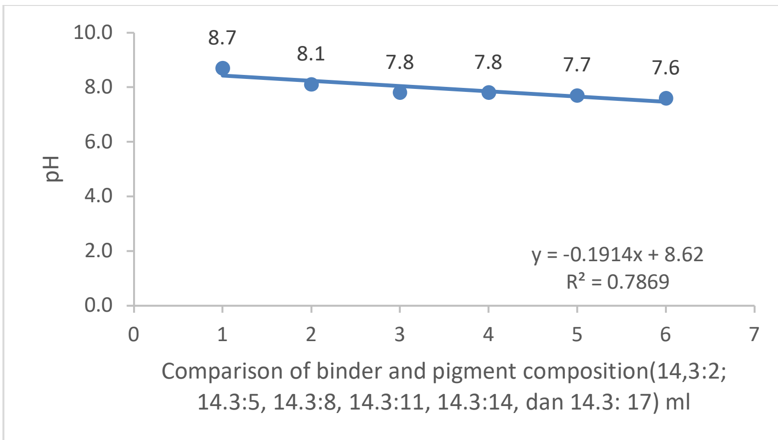

Figure 4. Graph of the relationship between the composition of binders and pigments and the pH of wall paint.

Figure 4 shows a negative linear relationship with a coefficient of determination $R^2 = 0.7869$, approaching a perfect value because it is still in the same order as $R^2 = 1$. The regression line equation is $y = -0.1914x + 8.62$, which illustrates a strong relationship between the independent (pigment solution concentration) and the dependent (paint pH) variables. It can be seen that the wall paint at the addition of a solution concentration of 2 ml with a pH of 8.7. With the addition of a pigment solution concentration of 5 ml, the pH of the wall paint dropped to 8.1. For the addition of a pigment solution concentration of 8 ml and 11 ml, the pH of the wall paint dropped to 7.8. The wall paint has a pH that drops to 7.7 with the addition of a pigment solution concentration of 14 ml. The last addition of a pigment solution concentration of 17 ml lowered the pH to 7.6.

Increasing the concentration of the pigment solution causes a decrease in pH. This is because the betacyanin pigment from the extraction results has a natural pH of around 5.1. From the results of Figure 4, it can be seen that the variation of wall paint 6 is closest to the SNI wall paint, namely 7.6. Betacyanin pigments are weak acids that tend to affect pH equilibrium because they contain dihydroxyphenylalanine substituents (Hernández-Aguirre et al., 2021).

Color Test

Color is an essential component of paint; the ratio of binder and pigment composition can affect the accuracy and stability of the color. The quality and consistency of the color produced from the LAB color code can be assessed using a colorimeter. The parameters L^* (brightness), a^* (green-red axis), and b^* (blue-yellow axis) provided by the LAB code for color measurement indicate the accurate color of the wall paint variation samples (Schneider-Teixeira et al., 2022). The working principle of the colorimeter is to measure the intensity of light transmitted or reflected by the sample at a specific wavelength (Farida et al., 2021). The results of color testing using a colorimeter can be seen in Table 3.

Table 3. Testing the color of wall paint variations using a colorimeter

Paint Variations	Color Coordinates		
	*L**	*a**	*b**
1	+95.7	+3.3	+1.9
2	+92.7	+2.3	+4.9
3	+90.0	+6.5	+3.8
4	+89.6	+6.6	+6.3
5	+89.7	+6.4	+6.4
6	+89.8	+6.3	+5.1

The effect of betacyanin pigment concentration on color was measured using the LAB system. At a pigment concentration of 2 ml, the brightness value (*L*) reached +95.7 with *a* value of +3.3 (positive value indicating red) and *b* of +1.9 (positive value indicating a slight yellow tone). With the addition of pigment concentration (5 ml), there was a decrease in brightness (L) to +92.7, the *a* value to +2.3 (positive value indicating red), and the *b* value increased to +4.9 (positive value indicating yellow). When the pigment concentration was increased to 8 ml, the brightness decreased significantly to +90, with the *a* value increasing drastically to +6.5 (positive value indicating red) and the *b* value dropping to +3.8 (positive value indicating yellow).

Further addition of pigment concentration up to 11 ml decreased brightness to +89.6, the a value increased to +6.6 (positive value indicating red), and the b value increased to +6.4 (positive value indicating yellow). At a pigment solution concentration of 14 ml, the brightness decreased significantly to +89.7, the *a* value decreased to +6.4 (positive value indicating red), and the *b* value decreased to +6.4 (positive value indicating yellow). The addition of the last pigment solution concentration at 17 ml resulted in a brightness value of +89.7, with *a* value of +6.3 (positive value indicating red) and *b* value of +5.1 (positive value indicating yellow). From these results, adding pigment concentration can reduce the brightness and reddish color of the wall paint. The pH also influences the color change in this wall paint; the more neutral it is, the more stable the color of the wall paint, which is in line with (Schneider-Teixeira et al., 2022).

Based on the results of the LAB color coordinate conversion in Table 4, it can be seen that the colors produced by adding the concentration of the pigment solution vary greatly. Adding 2 ml of pigment concentration produces the color "Seashell." Adding 5 ml of pigment concentration produces the color "Eggshell." Adding 8 ml of pigment concentration produces the color "Pale pink." At 11 ml and 14 ml pigment concentrations, the resulting color is "Champagne pink." With pigment concentrations up to 17 ml, the color changes to "misty rose." The color changes in this wall paint have several variations but are still in the red spectrum and do not resemble the red color of the betacyanin pigment. Although there is no formal standard for the specific brightness of betacyanin pigments in paint, the HEX code #f5dcd6 ("Misty Rose") is considered the most appropriate based on LAB values obtained through a colorimeter. This visually represents the betacyanin pigments extracted and stabilized in the final paint formulation.

Table 4. Colorimeter conversion table for wall paint variations.

Paint Variations	HEX	Color Name	Color
1	#fcf0ee	Seashell	
2	#f4e8de	Eggshell	
3	#f5ddda	Pale pink	
4	#f6dcd3	Champagne pink	
5	#f6dcd3	Champagne pink	
6	#f5dcd6	Misty rose	

Density Test

The density of a paint is determined by the components contained in the paint. Determining the density of each sample affects the paint's hiding Power or covering Power when applied to the media. One way to increase the density of paint is to choose the suitable binder and dye composition. Density testing is carried out by calculating the mass and volume of the solution. Then, the mass and volume of the sample are measured to determine its density (Effendy et al., 2019).

The mass (m) of an object divided by the volume (V) it occupies is called density (ρ). Mathematically, density (ρ) is defined as (Gumilar et al., 2016):

$$\rho = \frac{m}{V} \tag{1}$$

where ρ is density (g/cm^3), m is the mass of object (g) and V is the volume of object (cm^3)

Density measurement was carried out using a measuring cup for wall paint with variations in pigment solution concentration, which was then compared with SNI 3564:2009; it is known that the density of SNI wall paint is 1.2 g/cm^3. Density was measured by filling the measuring cup with wall paint liquid and measuring its total mass. The density was calculated based on the difference in mass between the empty measuring cup and the measuring cup containing wall paint.

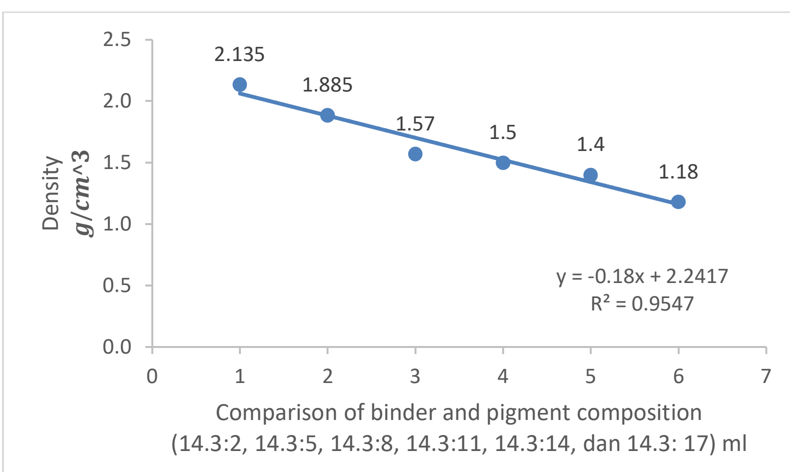

Figure 5. Comparative relationship graph of binder and pigment composition to paint density.

Figure 5 shows the sixth paint variation with a binder and pigment composition ratio of 14.3 ml: 17 ml, which has the best density. In SNI, the ideal density for paint quality is 1.2 g/cm³, where the value of 1.18 g/cm³ is close to perfect. The graph shows a negative linear relationship with R^2 = 0.9547, close to the perfect value of $R^2 = 1$. The equation of the regression line is $y = -0.18x + 2.2417$. Thus, the relationship between the dependent variable and the independent variable is very close. The addition of the independent variable (x-axis), namely the concentration of the pigment solution, significantly affects the quality of the paint density.

Figure 5 shows that the density of wall paint from betacyanin pigment decreases by adding betacyanin pigment solution concentration. With a pigment solution concentration of 2 ml, the density of the wall paint is 2.135 g/cm³. If the concentration of the pigment solution is increased to 5 ml, the density of the wall paint decreases to 1.885 g/cm³. If the concentration of the pigment solution is increased to 8 ml, the density of the wall paint decreases to 1.57 g/cm³. If the concentration of the pigment solution is increased to 14 ml, the density of the wall paint decreases to 1.4 g/cm³. The last addition, with a pigment solution concentration of 17 ml, has a density with a value that decreases to neutral, namely 1.18 g/cm³.

With the addition of the concentration of betacyanin pigment solution, the density of the wall paint decreased gradually. This shows that the betacyanin pigment is thinner and has a high water content, so each addition of pigment solution to the binder will reduce the density of the wall paint. This decrease shows that the concentration of the pigment solution plays a significant role in reducing the density of the wall paint towards the SNI wall paint. The density test results show that the sixth paint variation has the density closest to the SNI wall paint, with a density value of 1.18 g/cm³.

Adhesion Test

Adhesion is the ability of a paint to adhere to a substrate/surface coated with paint. Testing the adhesion of wall paint is carried out using the cross-cut tape test method (Effendy et al., 2019). The results of the adhesion test can be seen in Table 5.

Table 5. The relationship between variations in the concentration of wall paint pigment solutions and adhesion.

Paint Variations	Results
	Adhesive Power (%)
1	100
2	100
3	100
4	100
5	100
6	100

Table 5 shows the relationship between paint adhesion and binder variations and pigment composition variations. Making wall paint using beetroot as a color pigment produces optimal adhesion at all variations in pigment solution concentration with a binder concentration of 14.3 ml. The binder functions as a paint adhesive, so the higher the binder concentration, the higher the paint adhesion. This is in line with the research of Effendy, et al (2019).

To ensure that the wall paint based on betacyanin pigments is optimal, additional research must focus on various elements. First, the raw materials are dried longer until there is little water content. Additional tests are then carried out to test the viscosity and color stability. Third, to ensure that this wall paint is sustainable, cost-effective, and widely used, environmental and economic analysis must be carried out when producing it.

CONCLUSION

Based on the physical properties tests that have been carried out, namely color tests, pH tests, density tests, and adhesion tests of the research results, it can be concluded that the characteristics of wall paint that utilizes betacyanin pigments from red beets are colors that are easily oxidized and less concentrated; safe pH with a range of 7.6-8.7; density that decreases with the addition of pigment solution, and excellent adhesion. The sixth paint variation, with a binder and pigment ratio of 14.3 ml: 17 ml, gave the most optimal results. The paint has a Misty rose color, pH 7.6, a 1.18 g/cm^3 density, and 100% adhesion.

The characterization results of this wall paint comply with SNI 3564-2014. Betacyanin pigment from red beet can be a natural dye used to make wall paint, but it has several weaknesses, namely unstable color, poor color uniformity, and low pigment concentration. Therefore, further research is needed to overcome the problem of wall paint distribution. The results of this study indicate that wall paint has excellent potential as an alternative to sustainable wall paint.

ACKNOWLEDGEMENT

The researcher would like to thank the Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, for providing facilities for research on this article.

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