

Encapsulation of Purple Sweet Potato Anthocyanins Using Alginate and Pectin as Natural Food Colorants

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Article Information	ABSTRACT
Article History Received : December 02, 2025 Revised : December 25, 2025 Published : January 04, 2026	The use of non-food dyes is a problem in food safety. One of the efforts to solve this problem is the making of natural coloring products from purple sweet potato anthocyanin pigments. Anthocyanins are sensitive to oxidative damage, so encapsulation techniques need to be used to preserve bioactive compounds. Encapsulation with the coacervation method involves coating anthocyanins as the active ingredient with pectin and alginate as gel matrices, based on the principle of ionic gel formation. This study aimed to determine the optimal alginate concentration for the formation of anthocyanin encapsulates and to identify the color characteristics and interactions of the encapsulated anthocyanins from purple sweet potato. This study used various concentrations of alginate (0%, 0.5%, 1%, and 1.5%). The research parameters used were total anthocyanin and antioxidant activity (IC₅₀). The findings indicated that the optimal concentration of alginate for preserving the solubility and stability of anthocyanin, derived from the bioactive compounds in purple sweet potatoes, was 1% alginate. This concentration resulted in a total anthocyanin content of 20.77 mg/L and an antioxidant activity (IC₅₀) of 4049.73 ppm. A higher alginate concentration results in stronger gel formation; however, it simultaneously weakens the ability of alginate to bind anthocyanin as an active ingredient. This is attributed to the increase in viscosity, making the incorporation of the anthocyanin matrix into the encapsulates more difficult. Despite the very weak antioxidant activity, these anthocyanin encapsulates hold potential as natural food colorants for safe applications in acidic food products like beverages.
Keywords: <i>Anthocyanin;</i> <i>Antioxidant;</i> <i>Coacervation;</i> <i>Color;</i> <i>Encapsulated.</i>	

INTRODUCTION

The substrate content of purple sweet potato starch is relatively low at 7% by weight out of 100 g (Milind & Monika, 2015). Therefore, it is less effective for the development of derivative products of modified starch because large quantities of raw materials are required during production. According to Hatimah et al. (2023), the process of producing maltodextrin from purple sweet potatoes resulted in reducing sugars ranging from 27.4% to 32.65% and a total anthocyanin content between 0.33 mg/L and 1.4 mg/L. The anthocyanin value was relatively low because anthocyanins are hydrophilic and dissolve in the filtrate during the purple sweet potato starch extraction process. Although the filtrate is still used in the substrate mixing process, the anthocyanin content remains low in the maltodextrin product. Therefore, this consideration has

encouraged researchers to utilize anthocyanins as a natural coloring agent safe for consumption, considering the increasing use of non-food additives in the food industry.

According to BPOM (2019), an investigation was conducted into illegal food products using the non-food dye rhodamine B. Rhodamine B is also known as D and C Red No. 19, Food Red 15, ADC Rhodamine B, Aizen Rhodamine, and Brilliant Pink were also used. In line with the Ministry of Health Regulation No. 239/MenKes/Per/V/85 concerning certain dyes declared as hazardous substances, Rhodamine B is classified as a health hazard. Rhodamine B is a textile dye that poses a significant health risk when ingested. Rhodamine B is a synthetic dye that is present as a crystalline powder. It is green or reddish-purple, odorless, and appears bright red and fluorescent in solutions (Saigl, 2021). Rhodamine B belongs to the xanthene dye group and is used in the textile and paper industries as a dye for fabrics and papers. This type of non-food coloring is extremely hazardous when ingested (Hevira et al., 2020). Therefore, it is essential to develop natural food colorants as safe and healthy alternatives.

The purple sweet potato (*Ipomoea batatas* L.) serves as a natural source of anthocyanins. According to Montilla et al. (2011), the predominant anthocyanins present in purple sweet potatoes are the 3-sophoroside-5-glucoside derivatives of peonidin and cyanidin. Anthocyanins are sensitive to heat, light, pH, oxygen, and certain enzymes such as polyphenol oxidase, which limits their use in food processing (Li et al., 2019). Anthocyanins have many hydroxyl groups and are thus very unstable as polar compounds. Acylated anthocyanins can maintain their antioxidant activity (Matera et al., 2015). As food colorants, anthocyanins are highly susceptible to oxidation reactions. To increase anthocyanin stability, a stabilizing medium is required to bind the active ingredient to a carrier matrix via encapsulation. According to Ozkan et al. (2019), encapsulation is a method for coating or enveloping an active ingredient with a polymeric wall layer, resulting in small micro-or nanosized particles. The objective of microencapsulation is to safeguard active ingredients from environmental factors, including light, temperature, humidity, and interactions with other substances. Several encapsulation techniques are often used for natural colorants, including spray-drying, freeze-drying, coacervation, and emulsification.

This study employed an encapsulation approach based on anthocyanin entrapment using pectin and alginate as coating materials. Pectin forms stable films, whereas alginate gels in the presence of divalent cations provide emulsifying properties. Anthocyanin extract was used as the active core because of its potential as a natural colorant and antioxidant. Accordingly, this study aimed to evaluate the effect of alginate concentration on the total anthocyanin content and antioxidant activity (IC₅₀) of pectin–alginate encapsulates.

RESEARCH METHODS

Materials

The materials utilized in this study included purple sweet potato (*Ipomoea batatas* L.), which was sourced from Daya Market, Makassar City., technical citric acid, technical ethanol, food-grade apple pectin, food-grade alginate, technical calcium chloride (CaCl₂), and distilled water. The equipment used included an oven, centrifuge, cuvette, UV-VIS spectrophotometer, vortex, and a rotary shaker.

Encapsulation of Anthocyanins in Purple Sweet Potatoes

Purple sweet potato anthocyanins were encapsulated following the methodology outlined by Donthidi et al. (2010), with certain modifications. The anthocyanin encapsulation concentrations used were alginate (0%, 0.5%, 1.0%, and 1.5% w/v) and pectin 2.0% (w/v). The encapsulation process was initiated by preparing 100 ml of distilled water in a 250 ml beaker, with continuous stirring facilitated by a heated stirrer. Pectin was subsequently added, and the mixture was stirred for 5 minutes until a homogeneous solution was achieved at approximately 75°C. The suspension was subsequently maintained at ambient temperature for a duration of 30 minutes. The suspension was subsequently subjected to continuous stirring using a magnetic stirrer, without the application of heat. Alginate was added to the suspension according to the treatment concentration and stirred for 5 min until it was homogeneous. Finally, 1% (w/v) anthocyanin extract was added

to the suspension and mixed for 5 min until a homogeneous mixture was obtained. The purple sweet potato anthocyanin encapsulation suspension was placed in a 1 cc syringe. Next, 100 ml of 0.1 M CaCl₂ was prepared, and the suspension was added dropwise to this solution to produce the encapsulates.

Total Anthocyanin Analysis

The differential pH method was employed to assess the anthocyanin content, where 0.5 ml of anthocyanin extract was combined with 2.5 ml of a buffer at pH 1.0. Subsequently, an equivalent volume of the sample (0.5 ml) was combined with 2.5 ml of a pH 4.5 buffer and allowed to stand for 30 minutes. Following this period, the absorbance of the sample was measured at wavelengths of 510 nm and 700 nm. The absorbance was calculated using the following equation:

$$A = [(A_{530} - A_{700})_{pH\ 1.0} - (A_{530} - A_{700})_{pH\ 4.5}] \quad (1)$$

The anthocyanin pigment content in the sample was calculated using the following formula:

$$\text{Total anthocyanin (mg/L)} = \frac{A \times BM \times FP \times 1000}{\epsilon \times 1} \quad (2)$$

Explanation:

A = Absorbance

MW = Molecular weight = 449.20 (expressed as cyanidin-3-glucoside)

DF = Dilution factor

ϵ = Molar absorptivity coefficient = 26900 (expressed as cyanidin-3-glucoside)

IC₅₀ Antioxidant Activity Analysis

Antioxidant activity was analyzed according to the method described by Jiao et al. (2012). A sample with a mass of 15 mg was dissolved in 15 ml of methanol, resulting in a concentration of 1000 ppm, and subsequently homogenized using a plate stirrer for a duration of 15 minutes. This sample was referred to as the stock solution. Subsequently, serial solutions were prepared at concentrations of 200, 400, 600, and 800 ppm, each with a total volume of 2 ml. Each serial solution was mixed with 2 ml of 100 μ M DPPH solution. The mixture was incubated at ambient temperature in the absence of light for 30 minutes, and the absorbance was subsequently measured using a UV-Vis spectrophotometer at a wavelength of 517 nm. The absorbance of the control solution was evaluated to ascertain the percentage of inhibition.. The control solution was prepared by mixing 2 ml of methanol with 2 ml of a 100 μ M DPPH solution.

The antioxidant activity of each extract sample was quantified as the percentage of free radical inhibition, referred to as percent inhibition, and was determined using the following formula:

$$\% \text{ inhibition} = \frac{(\text{blank absorbance} - \text{sample absorbance})}{\text{blank absorbance}} \times 100\% \quad (3)$$

Data Analysis

The data obtained were subjected to Analysis of Variance (ANOVA) to assess the impact of treatments involving different alginate variations. Subsequently, Duncan's Multiple Range Test (DMRT) was applied to assess the effects of each treatment at a 95% confidence level ($\alpha = 0.05$), utilizing Microsoft Excel 2019 and SPSS version 25.

RESULTS AND DISCUSSION

Total Anthocyanins

Anthocyanins are secondary metabolites of the flavonoid family, a group of pigments responsible for reddish coloration, located within the cell sap, and soluble in water. Consequently, the extraction of anthocyanins employs polar solvents such as methanol, ethanol, or chloroform, which are acidified with hydrochloric acid or formic acid. Anthocyanins, which appear red, magenta, blue, or purple, have a maximum wavelength of 600 nm (Candela et al., 2021), (Lydia

et al., 2001). Analytical studies have identified nine cyanidin- and peonidin-based anthocyanins, which involve modifications such as caffeoyl, p-coumaroyl, feruloyl, and p-hydroxybenzoyl. The biosynthesis of anthocyanins is governed by structural genes and transcription factors that regulate their accumulation (Park et al. 2016).

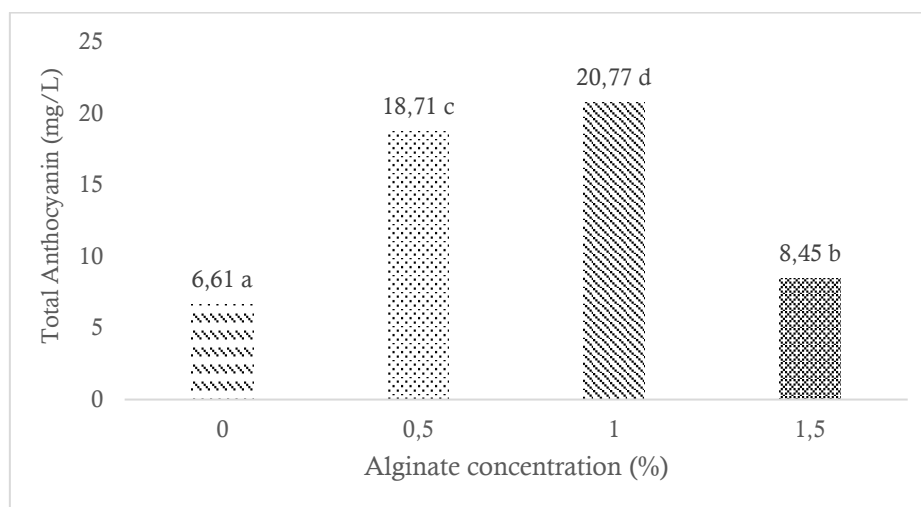


Figure 1. Total Anthocyanins in Encapsulated Purple Sweet Potato Anthocyanins

The concentration of alginate had a statistically significant impact ($p < 0.05$) on the total encapsulated anthocyanins. Figure 1 illustrates the mean total anthocyanin content in the encapsulated purple sweet potato anthocyanins. The encapsulation process without the use of alginate resulted in the lowest total anthocyanin content, measuring 6.61 mg/L. This demonstrates that alginate as a coating material can maintain the stability of encapsulated anthocyanins. However, the total encapsulated anthocyanins decreased to 8.45 mg/L at 1.5% alginate concentration. This alginate concentration represents a saturation point, as the increasing viscosity so reduces the alginate encapsulation efficiency. The interaction between anthocyanins and alginate forms a complex that reduces molecular mobility.

The optimal total anthocyanin content was obtained with 1% alginate encapsulation, reaching 20.77 mg/L. In a comprehensive study conducted by Shaddel et al. (2018), the optimal encapsulation of black raspberry anthocyanins was achieved using a gelatin: gum Arabic: black raspberry anthocyanins ratio of 1:1:1 through the complex coacervation method. This result is consistent with research data indicating that a 1% alginate concentration effectively encapsulates anthocyanins as the active ingredient. Furthermore, Pai et al. (2015) emphasized that the encapsulation efficiency increases with the addition of carrier (coating matrix) concentration, which also serves as a protector of the encapsulated material.

Antioxidant Activity IC_{50}

Antioxidants are compounds that donate electrons or act as reducing agents. These compounds, characterized by their low molecular weight, are capable of inhibiting oxidation reactions by preventing radical formation. DPPH is a free radical compound that can be inhibited by extract materials and bioactive compounds. The half-maximal inhibitory concentration (IC_{50}) refers to the amount of an antioxidant necessary to achieve a 50% reduction in free radical activity. Chen et al. (2013) assert that the DPPH method is an optimal approach for assessing the antioxidant capacity of biological substrates, with IC_{50} indicating the percentage inhibition of free radical compounds by antioxidant compounds. According to Molyneux (2004), antioxidant activity is categorized into five levels based on IC_{50} values: less than 50 ppm indicates very strong activity, 50-100 ppm is considered strong, 100-150 ppm is moderate, 150-200 ppm is weak, and values over 200 ppm are classified as very weak. A higher IC_{50} value corresponds to weaker antioxidant activity.

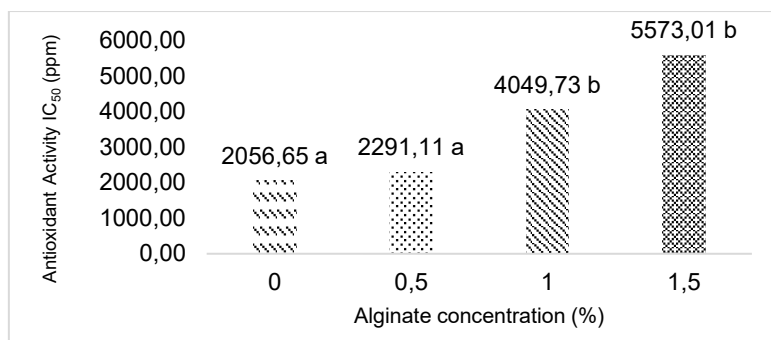


Figure 2. IC₅₀ Antioxidant Activity of Encapsulated Purple Sweet Potato Anthocyanin

The concentration of alginate significantly influenced ($p < 0.05$) the IC₅₀ antioxidant activity in the encapsulated samples. Figure 2 displays the average IC₅₀ values for these encapsulated antioxidants. The findings indicated that the IC₅₀ values for antioxidant activity rose, suggesting a reduced capacity of the extract to inhibit 50% of free radical activity. This observation aligns with the findings of Laga et al. (2019), who demonstrated that a lower IC₅₀ value is indicative of enhanced antioxidant activity in purple sweet potato starch.

Based on Figure 2, the IC₅₀ antioxidant activity values obtained are considered very weak, ranging from 2056.65 to 5573.01 ppm. Higher alginate concentrations resulted in higher IC₅₀ values, indicating reduced antioxidant activity. This is because the encapsulated anthocyanins undergo several processing steps, including extraction, evaporation, and drying, making them highly susceptible to the damage of bioactive compounds, and thus their antioxidant activity is very low. According to Hatimah et al. (2023), instability in antioxidant activity values is found in derivative products that undergo various processing and heating steps. Then heating during coacervation and drying accelerates first-order degradation kinetics, with reaction rates rising at pH >3 and temperatures >60°C; purple sweet potato anthocyanins (e.g., peonidin, cyanidin derivatives) lose 20-50% activity per processing stage (Chen et al., 2019). The IC₅₀ value for the antioxidant activity of anthocyanin extract from purple sweet potato is notably high at 65.35 ppm (Arifuddin 2010). Alginate-pectin matrices increase viscosity, hindering uniform anthocyanin dispersion and causing uneven coating; higher alginate (>1%) forms rigid gels that trap but partially denature core material via hydrogen bonding or incomplete ionic gelation (Lin et al., 2023). Another study describes maltodextrin via spray drying as the best encapsulation wall materials for anthocyanins based on high encapsulation efficiency (92.5%), superior antioxidant activity retention (IC₅₀ 250-450 ppm post-encapsulation), and thermal stability (Chen et al., 2019).

CONCLUSION

The encapsulation of purple sweet potato anthocyanin using alginate as a coating material maintained the stability of the encapsulate. The optimal concentration of alginate for maintaining the stability of the bioactive anthocyanin compound in purple sweet potatoes was determined to be 1%, yielding a total anthocyanin content of 20.77 mg/L. The IC₅₀ values obtained suggest a low level of antioxidant activity, with measurements ranging from 2056.65 to 5573.01 ppm. It was observed that an increase in the concentration of alginate within the encapsulate corresponded to a decrease in the IC₅₀ values. A higher alginate concentration results in stronger gel formation; however, it simultaneously weakens the ability of alginate to bind anthocyanin as an active ingredient. Although its antioxidant activity is very weak, this encapsulate has the potential to be used as a stable natural colorant in fermented food products. Further research is recommended to combine alginate with maltodextrin to improve encapsulation efficiency (>50%) and antioxidant activity retention, as well as to test its application in food products.

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