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Systematic Literature Review: Isolation of Anthocyanin Compounds from Sweet Potato (*Ipomoea batatas*)

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ABSTRACT

Anthocyanins are natural pigments belonging to the flavonoid group, widely found in various plant parts, particularly fruits, flowers, and peels, where they are responsible for red, purple, and blue colors. These compounds possess extensive potential in the fields of food, health, cosmetics, and pharmaceuticals due to their bioactive properties, especially as antioxidants. However, anthocyanins exhibit low stability against environmental factors such as temperature, pH, light, oxidation, and processing conditions, which affects the effectiveness of their isolation and utilization in practical applications. Therefore, an appropriate modern technological approach and process optimization ranging from extraction and purification to product stabilization—are required. This Systematic Literature Review (SLR) aims to comprehensively analyze various isolation techniques for anthocyanins from sweet potatoes, including conventional and technology-assisted extraction methods, purification techniques, stability challenges, and opportunities for developing sustainable industrial methods. Literature searches were conducted on published scientific articles between 2016–2026 , initially yielding a total of 274 publications, from which 13 articles were selected according to the inclusion criteria. The majority of studies utilized the tubers as the source of anthocyanins. The review findings indicate that the optimization of extraction methods is proven to be crucial. Methods such as ASE, UAE, HPCD, and $SCCO_2$ offer significantly higher yields compared to conventional extraction. This review is expected to serve as a scientific reference for the development of efficient, eco-friendly, and commercially valuable anthocyanin isolation technology.

Keywords: anthocyanin, *Ipomoea batatas*, extraction, purification

I. INTRODUCTION

Anthocyanins are a group of water-soluble polyphenolic flavonoids that impart red, purple, and blue colours to plant tissues. They play a vital role in plant ecology (e.g., attracting pollinators, protection against oxidative stress and UV radiation) and offer health benefits for humans, such as antioxidant, anti-inflammatory activities, and potential metabolic/neurological effects (Yun, 2024). Structurally, anthocyanins are glycosylated forms of the anthocyanidin aglycone (e.g., cyanidin, peonidin, delphinidin), where variations in substituent groups, sugar types, and acylation patterns determine their colour spectrum, stability, and biological activity (Teixeira et al., 2024). Due to their chemical sensitivity to pH, temperature, oxygen, and light, the extraction and purification of anthocyanins necessitate optimized operational conditions to minimize degradation and loss of functional activity.

Purple sweet potato (*Ipomoea batatas* L.) is one of the most promising agronomic and commercial sources of anthocyanins. Purple sweet potato (PSP) varieties typically contain an

anthocyanin profile rich in acylated (esterified) peonidin and cyanidin derivatives. This acylation modification provides relatively better stability compared to some other sources (e.g., berries), offering potential for application as natural food colorants and functional active ingredients (Wang, 2022; Yun, 2024). Besides the tuber flesh, processing waste such as peels and residual materials has been shown to be a source of anthocyanin concentrate that can support the circular economy if utilized (Yun, 2024).

Despite the promising source, the isolation of anthocyanins from sweet potatoes faces several technical and scaling challenges. Firstly, anthocyanins are sensitive to extraction conditions: acidic pH (typically pH 1–3) and acidified hydro-alcoholic solvents are commonly chosen to enhance extraction and initial stability, but these conditions must be balanced with food safety and suitability (Teixeira et al., 2024). Secondly, conventional extraction methods (e.g., maceration, Soxhlet) often require long durations and environmentally unfriendly organic solvents. Therefore, emergent techniques like ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), enzymatic extraction, or technique combinations (e.g., sonotrode, enzyme + ultrasound) have been extensively studied because they can increase yield, reduce extraction time, and preserve the antioxidant activity of the extract (Teixeira et al., 2024; Wang, 2022).

Recent methodological advances highlight several key points: (1) parametric optimization (liquid-to-solid ratio, solvent composition, temperature, time, sonication intensity) using experimental designs (RSM/Box-Behnken) provides significant improvements in extraction yield and reproducibility; (2) non-thermal or semi-thermal technologies (UAE, MAE, modified supercritical CO_2-based extraction) allow for more selective extraction of phenolic compounds without severe thermal degradation ; and (3) purification steps such as Solid-Phase Extraction (SPE) or C18 column chromatography, along with characterization using HPLC-MS/UPLC-MS, provide an identified component profile, facilitating product standardization (Teixeira et al., 2024; Wang, 2022; Yue et al., 2024).

From an application perspective, sweet potato anthocyanin extracts have been explored not only as food colorants but also for pH-sensitive packaging films (smart packaging) and nutraceutical formulations; implementation into final products requires long-term stability studies, food matrix compatibility, and safety standards (Yun, 2024; Yue et al., 2024). Furthermore, studies on bioavailability and mechanisms of biological action are increasingly necessary so that functional claims can be supported by robust pharmacokinetic evidence and *in vivo* trials.

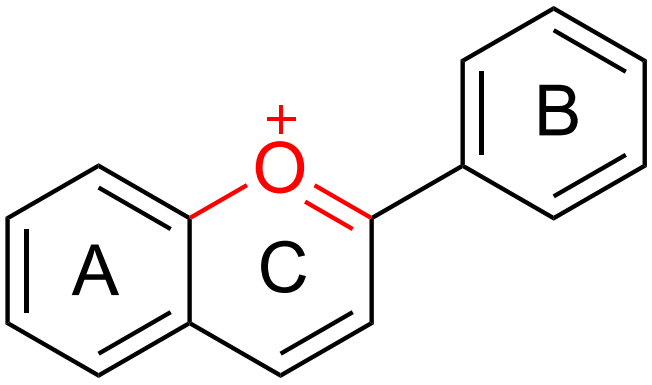

Figure 1. Structure of flavylium ion (2-phenyl chromenyl) with a positive electrical charge (cation) as a fundamental basis for anthocyanin diversity. Elaborated using Chemdraw 23.1.1.

Based on the description above, this systematic review focuses on: (1) the extraction and isolation techniques of anthocyanins from sweet potatoes in the last five years; (2) parameters affecting

yield and stability; and (3) research gaps for the transition from laboratory studies to food security and industrial applications. By combining experimental evidence and current reviews, this article is expected to map the best practices for sweet potato anthocyanin extraction and identify priority research directions for sustainable commercial scale-up.

II. METHODS

The process of drafting this systematic literature review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines as the international standard for the planning, execution, reporting, and tracking of transparency in the scientific article selection process (Page et al., 2021). The implementation of the PRISMA guidelines was carried out from the stage of formulating research questions, identifying scientific databases, recording the number of articles found, screening based on title and abstract, to final selection based on inclusion and exclusion criteria. To manage the review process in a more structured manner and reduce selection bias, the researchers utilized VOSviewer software version 1.6.17 (based on Java 10.0.2). This application was used as a tool for organizing articles, conducting quality assessment, recording bibliometric data, and extracting information related to anthocyanin isolation methods in each selected study.

A. Information Sources

In preparing the Systematic Literature Review on the isolation of anthocyanin compounds from plants, the selection of scientific data sources is a critical stage to guarantee the quality and credibility of the publications analyzed. In this study, the main database used is ScienceDirect, managed by Elsevier, because it provides broad access to current, peer-reviewed scientific research articles relevant to chemistry, plant biochemistry, food technology, and natural product sciences related to anthocyanins. ScienceDirect was chosen because it has the largest coverage of publications in the applied sciences and life sciences , enabling an in-depth review of isolation methods, extraction, purification, and characterization of anthocyanin compounds from various plant sources. The selection of ScienceDirect as the primary source is also supported by its credibility as a platform providing high-reputation journals and integrated indexing with the Science Citation Index Expanded (SCI-E) in the Web of Science. SCI-E is known as a scientific indexing system widely used in the assessment and mapping of global scientific developments. This integration ensures that the selected articles adhere to strong, internationally recognized academic standards, such that the results of the systematic review are methodologically and scientifically accountable. Besides the advantage of accessibility, ScienceDirect allows for the search of the most relevant studies through filters for keywords, publication year, and research focus, enabling a strict literature selection process in accordance with the study topic, namely anthocyanin isolation techniques from plant tissues. The available journals cover discussions on solvent selection, optimization of extraction conditions, comparison of conventional and modern methods, anthocyanin stability issues, and the potential application of isolated products at the laboratory and industrial scale. Thus, the use of the ScienceDirect platform in this research not only ensures data source accuracy but also supports the process of identifying the most relevant and influential scientific evidence in the study of anthocyanin compound isolation, without involving databases or information sources other than that platform.

B. Search Strategy and Information

The search for scientific literature was conducted through the ScienceDirect database as the sole data source, and all searches were restricted to articles published in English. The search process utilized Boolean Logical Operators (AND, OR, NOT) and truncation to broaden the scope of relevant term variations. Search filters on the ScienceDirect interface were used to exclude publication types other than peer-reviewed scientific articles, meaning conference proceedings, book chapters, monographs, theses, and dissertations were not included in the

analysis. The search focused on the topic of isolating anthocyanin compounds from plants, including extraction methods, purification, compound characterization, and their relation to technical factors affecting isolation success. The search was performed between November 23–28, 2025, with a publication year range limit of 2016–2026, to ensure that the information obtained represents the latest research findings. The keyword strategy was developed based on a combination of primary descriptors and derivative terms, including:

- "anthocyanin" AND "isolation" AND "*Ipomoea*"
- “anthocyanin” AND “isolate” AND “plant material”
- “anthocyanin” AND “purification” AND “chromatography”
- “pigment” AND “natural colorant” AND “extraction”

Truncation (“) was used on the terms *anthocyanin* and *extract* to capture variations such as anthocyanins, anthocyanidin, extraction, extracted, etc. In addition, the OR operator was used to combine synonymous terms, and the AND operator was used to narrow the search focus to remain aligned with the research objective. Articles obtained through the search process were evaluated by reading the title, abstract, and keywords to ensure relevance to the main theme. Only studies that explicitly describe anthocyanin isolation techniques covering the stages of extraction, purification, and characterization were selected for further analysis.

C. Preliminary Data Processing

The initial stage of this research began with the collection and processing of bibliographic data from the literature search results related to anthocyanin compound isolation methods from various plant sources. The obtained bibliographic data were then combined and analyzed to identify inter-article connections based on common references used and the proximity of the research topics. This data integration process aims to determine scientific relationships, research development trends, and to map the contributions of authors and institutions in the field of study.

Furthermore, the relationships between documents were analyzed using a bibliometric approach through *co-citation analysis* and *bibliographic coupling*. This analysis allows for the identification of developing primary research clusters, commonly used isolation methodologies, and research gaps that still need further exploration. The visual mapping results of the bibliometric network are presented in the form of a network visualization map, created using VOSviewer software version 1.6.17 (based on Java 10.0.2), as recommended by van Eck & Waltman (2021). This visualization serves to illustrate the structure of the scientific relationships between articles and helps in comprehensively understanding the evolution of research on anthocyanin extraction and purification from plants.

D. Data Sorting and Information Categorization

Data acquisition and management in this systematic review were conducted sequentially through three main procedures: (i) article eligibility assessment, (ii) the screening process, and (iii) final selection and extraction of relevant information. Each stage was performed systematically to ensure that only studies meeting methodological quality standards and thematic relevance were included in the final analysis. Formal bias risk assessment was not performed at this stage.

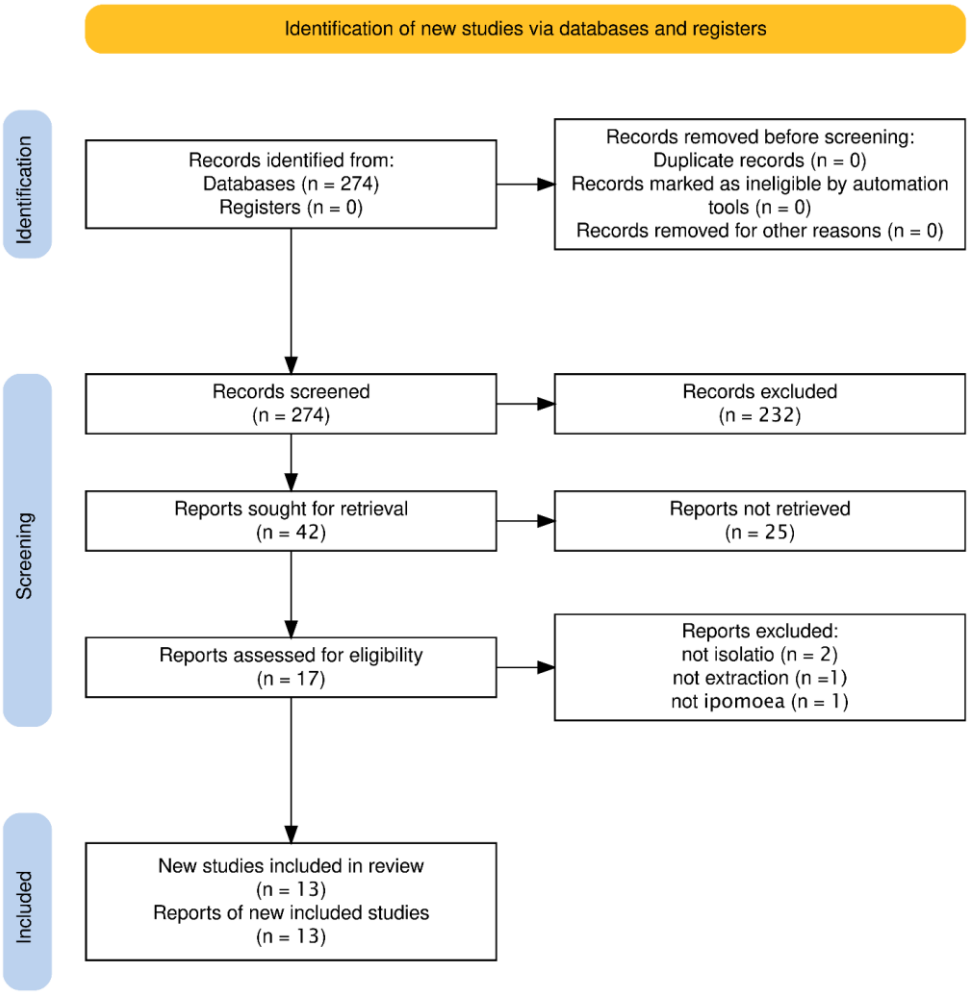

Figure 2. Flow chart of the article selection process. Elaborated usingv PRISMA

Based on a review of previous studies, the following research questions (RQs) were formulated:
RQ1: What extraction and isolation methods have been most commonly used to obtain anthocyanins from sweet potatoes over the past five years, and how effective are they in terms of yield, processing time, energy efficiency, and degradation of bioactive compounds?
RQ2: How do extraction process variables (solvent type, pH, temperature, time, material-to-solvent ratio, and energy activation method such as ultrasonic or microwave) affect the structural stability and concentration of anthocyanins produced from sweet potatoes?
RQ3: What purification and characterization technologies are used in the study of anthocyanin isolation from sweet potatoes, and to what extent are these methods capable of producing standardized anthocyanin extracts suitable for food and health applications?

The eligibility of articles was determined based on eight initial screening criteria that had to be fully met (100%; n=8), as follows:

- The article was published within the publication range of 2011 to 2024.
- The research objective is clearly and easily identifiable.
- The research utilizes *Ipomoea* or parts of the plant (fruit, flower, peel, leaf, tuber, etc.) as the source of anthocyanins.
- The procedure for anthocyanin isolation or extraction is described in detail, including the technique, solvent, and operational conditions.
- There is an explanation or data related to anthocyanin purification or characterization (e.g., SPE, column chromatography, HPLC, or spectroscopy).

- If color analysis is performed, an instrumental colorimetric measurement system such as CIE Lab or an equivalent system is clearly used.
- The measurement results for anthocyanins or color parameters are reported in numerical or tabular form.
- The study results and conclusions are consistent with the main research objective.

Article Screening Stages

Stage (i): Articles that do not meet one or more eligibility criteria are excluded from the selection process.

Stage (ii): Full-text screening is performed based on the reviewer's evaluation in a single-blind peer review system. If there is a difference in assessment between the two reviewers, a third reviewer is involved to reach a decision.

Stage (iii): Articles that pass the selection are included in the final analysis. From these articles, core information is then extracted, covering:

- Plant source of anthocyanins (species, specific plant part)
- Isolation/extraction method (technique, solvent, pH, temperature, time, yield, total anthocyanin)
- Purification method (type of chromatography, separation technique, and structural characterization)
- Compound analysis technique (UV-Vis, HPLC, FT-IR, NMR, MS)
- Result parameters (purity, anthocyanin concentration, stability)
- Colorimetric analysis or color parameters, if available
- Anthocyanin applications and biological activity (e.g., antioxidant, antibacterial, natural colorant)

E. Information Categorization

Subsequently, all collected data are classified into several main thematic categories as the basis for discussion preparation:

- Primary sources for anthocyanin isolation from plants
- Methods and parameters of isolation and extraction techniques
- Purification processes and compound characterization techniques
- Efficiency and challenges of isolation methods
- Results of color analysis and compound stability
- Biological activity of anthocyanins
- Applications and potential development in the food, cosmetic, and pharmaceutical industries

F. General Characteristics and Bibliographic Linkage

The initial analysis of bibliographic relationships is presented in the network map (Figure 3). To create this map, articles with at least one citation were used, totaling 120 documents. The total link strength was estimated for each article, and articles with the largest total link strength were selected. 26 clusters were formed, containing 2–12 interconnected references sharing a common bibliography.

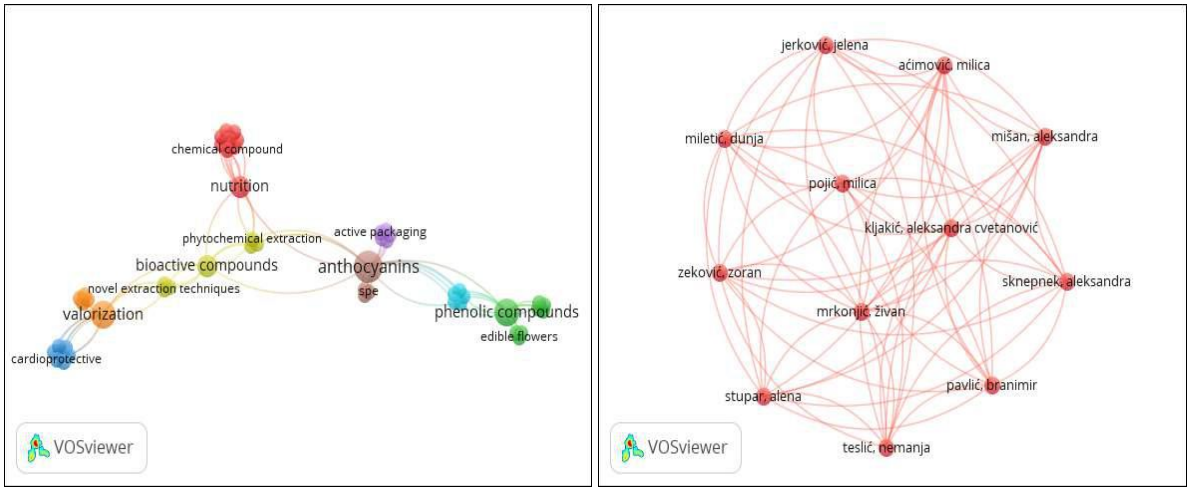

Figure 3. Network map for bibliographic incorporation in ScienceDirect regarding anthocyanins as natural colorants extracted from sweet potatoes.

G. Systematic Review

In the initial stage, 274 articles were found in the ScienceDirect Core Collection (Figure 2). In the first stage, 42 articles were selected from the 274, and 232 articles were discarded. In the second stage, 25 articles were discarded after full-text reading, resulting in 17 articles. Finally, 13 articles were selected in the third stage, and their information was extracted, grouped, and discussed. Data concerning the anthocyanin source, extraction, and microencapsulation are presented in Table 1.

H. Comprehensive Analysis of Anthocyanins in Purple Sweet Potato (*Ipomoea*)

Table 1 summarizes various studies on the extraction, identification, and quantification of anthocyanin compounds derived from purple sweet potatoes. Anthocyanins are natural pigments belonging to the flavonoid class, responsible for the purple color in sweet potatoes (generally the tubers).

Table 1. Anthocyanin extracted from *Ipomoea batatas*.

No	*Ipomoea* source part	Extraction method	Solvent	Anthocyanin content	Anthocyanin result	Ref.
1	tubers of *Ipomoea*	conventional extraction (CE), ultrasound-assisted extraction (UAE), and accelerated-solvent extraction (ASE)	aqueous ethanol	diacyl anthocyanins and less nonacyl and monoacyl anthocyanins	ASE>UAE>CE for anthocyanins (218–244mg/100g	(Fu et al., 2016)
2	tubers of *Ipomoea*	extraction	water, aqueous methanol, aqueous ethanol and aqueous acetone		(36.5mg c-3-gE/100g DM)	(Cai et al., 2016)
3	tubers of *Ipomoea*	extraction	acidified ethanol (A. EtOH)			(Velmurugan et al., 2017)

No	*Ipomoea* source part	Extraction method	Solvent	Anthocyanin content	Anthocyanin result	Ref.
4	tubers of *Ipomoea*	polyethylene glycol based ultrasonic-assisted green extraction (PEG-UAE)	polyethylene glycol	Cyanidin-3-caffeoyl-p-hydroxybenzoylsophoroside-5-glucoside (25.9%), peonidin-3-caffeoyl-p-hydroxybenzoylsophoroside5-glucoside (14.9%) and peonidin-3-caffeoylsophoroside-5-glucoside (12.6%)	(83.78 mg CE/100 g DW)	(Huang et al., 2019)
5	tubers of *Ipomoea*	high pressure carbon dioxide (HPCD) comparing to classical water and ethanol extraction	high pressure carbon dioxide - water and ethanol	• peonidin 3-sophoroside-5-glucoside • cyanidin 3-p-hydroxybenzoyl sophoroside-5-glucoside • peonidin 3-p-hydroxybenzoyl sophoroside-5-glucoside • cyanidin 3-(6″-caffeoyl sophoroside)-5-glucoside • peonidin 3-(6″-feruloyl sophoroside)-5-glucoside • cyanidin 3-(6″,6″-dicaffeoyl sophoroside)-5-glucoside • cyanidin 3-caffeoyl-p-hydroxybenzoyl sophoroside-5-glucoside • cyanidin 3-(6″-caffeoyl-6″-feruloyl sophoroside)-5-glucoside • peonidin 3-(6″,6″-dicaffeoyl sophoroside)-5-glucoside	45.58%–83.20%	(Zuleta-Correa et al., 2020)

No	*Ipomoea* source part	Extraction method	Solvent	Anthocyanin content	Anthocyanin result	Ref.
				• peonidin 3-(feruloyl-p-coumaroyl sophoroside)-5-glucoside • peonidin 3-caffeoyl-p-hydroxybenzoyl sophoroside-5-glucoside • peonidin 3-caffeoyl-feruloyl sophoroside-5-glucoside • peonidin 3-sophoroside-5-glucoside derivetive		
6	tubers of *Ipomoea*	extraction	acetone, butanol, and ethanol	anthocyanidins concentrations including cyanidin (cy), peonidin (pe), and pelargonidin (pl)		(Lao et al., 2020)
7	leaves	extraction	ethanol/ water (6:4)			(Fang et al., 2022)
8	tubers of *Ipomoea*	hydrothermal treatment assisted with microwaves	flour-to-water ratio of 1:10 (w/ v)	• cyanidin-3-phydroxybenzoylsoph-5- glc • peonidin-3-phydroxybenzoylsoph-5-glc • cyanidin-3-(6″-feruloylsoph)-5-glc • peonidin-3-(6″-feruloylsoph)-5-glc • cyanidin-3-(6″-caffeoyl-6‴-feruloylsoph)-5-glc • peonidin-3-(6″-caffeoyl-6‴-p-hydroxybenzoyl soph)-5-glc • peonidin-3-(6″-caffeoyl-6‴-feruloylsoph)-5-glc	(1017 mg CGE/kg db)	(Cui et al., 2022)

No	*Ipomoea* source part	Extraction method	Solvent	Anthocyanin content	Anthocyanin result	Ref.
9	tubers of *Ipomoea*	ultrasound technique	water		9.76 ± 0.22 mg cya-3-glu/g	(Rodríguez-Mena et al., 2023)
10	tubers of *Ipomoea*	ultrasound-assisted extraction method utilizing natural deep eutectic solvent (NADES)	water		1.73 mg GAE/g	(Bernabeu et al., 2024)
11	tubers of *Ipomoea*	maceration extraction	ethanol-water-modified SC–CO2	23 anthocyanin	136.0 mg cyanidin-3-glucoside (C3G)/100g	(De Barros et al., 2024)
12	tubers of *Ipomoea*	supercritical carbon dioxide (SCCO2)	CO2-ethanol	23 different anthocyanins were identified in the encapsulated purple sweet potato extract, primarily cyanidin- and peonidin-based anthocyanins	Peonidin-3-caffeoyl-p-hydroxybenzoyl sophorside-5-glucoside (46 % of total anthocyanins)	(Moraga-Babiano et al., 2025)
13	tubers of *Ipomoea*	Ultrasound-assisted extraction			7,2 mg gallic acid equivalent/g, respectively	(Abouzeid et al., 2025)

III. RESULTS AND DISCUSSION

A. Result Source and Main Anthocyanin Types

The majority of the studies in the table use the tubers of *Ipomoea* (purple sweet potato) as the primary source of anthocyanins , although one study used the leaves.

B. Dominant Chemical Structure

Studies show that anthocyanins in purple sweet potatoes are dominated by cyanidin and peonidin derivatives. Specific findings include:

- Acylated Anthocyanins: Anthocyanins in purple sweet potatoes are often of the diacyl anthocyanins type (diacylated), followed by monoacylated and non-acylated forms. This type of acylation is important because it influences the stability of the color pigment.
- Main Derivatives: Specific compounds repeatedly identified are: cyanidin-3-caffeoyl-p-hydroxybenzoylsophoroside-5-glucoside; peonidin-3-caffeoyl-p-hydroxybenzoylsophoroside-5-glucoside; Peonidin 3-sophoroside-5-glucoside.

C. Variation in Extraction Methods and Solvents

The efficiency and type of anthocyanins obtained are highly dependent on the extraction method and solvent used, which are key variables in these studies.

D. Conventional vs. Modern Extraction Methods

Comparison of various extraction methods shows a significant difference in anthocyanin yield:

- Accelerated Solvent (ASE), Ultrasound (UAE), and Conventional (CE): Studies show that Accelerated-Solvent Extraction (ASE) yields the highest anthocyanin content, followed by Ultrasound-Assisted Extraction (UAE), and finally Conventional Extraction (CE) (ASE > UAE > CE). This indicates that modern methods, which utilize high temperature and pressure (ASE) or acoustic waves (UAE), are more effective in breaking down the cellular matrix and releasing the pigments.
- High-Pressure Extraction: High Pressure Carbon Dioxide (HPCD) and Supercritical Carbon Dioxide ($SCCO_2$) combined with co-solvents (water or ethanol) are also used to produce anthocyanin-rich extracts. The $SCCO_2$ method specifically identified peonidin-3-caffeoyl-p-hydroxybenzoyl sophoroside-5-glucoside as the major component (46% of total anthocyanins). Hydrothermal Treatment assisted with Microwaves also resulted in very high yields (1017 mg CGE/kg db).
- Green Extraction: The use of Polyethylene Glycol based Ultrasonic-Assisted Green Extraction (PEG-UAE) and Natural Deep Eutectic Solvent (NADES) assisted UAE indicates a trend toward more environmentally friendly methods.

E. Effect of Solvent

Commonly used solvents include:

- Aqueous Ethanol/Methanol/Acetone: Mixtures of water with organic solvents (ethanol, methanol, or acetone) are standard because anthocyanins are polar.
- Acidified Ethanol (A. EtOH): The addition of acid (as in acidified ethanol) is often used to enhance anthocyanin stability and extraction efficiency.
- Water: Some studies successfully used water or water at a specific ratio (e.g., *flour-to-water ratio of 1:10* or in *ultrasound technique*), although the yield may vary.

F. Anthocyanin Content and Quantification

The anthocyanin quantification data (Table 2) show wide variability, caused by differences in sweet potato variety, the part extracted, and the analysis method. Variation in quantification units (e.g., mg/100g, mg C3G/100g, mg GAE/g) makes direct comparison between studies difficult; however, the data indicate that purple sweet potato is a significant source of anthocyanins. Extraction efficiency is also evident, with yields varying from 45.58% to 83.20% in comparative studies.

Table 2. Anthocyanin quantification at various concentration ranges

Quantitative Metric	Concentration Range	Reference Study
Total anthocyanin (mg/100g)	218–244 mg/100g (ASE)	(Fu et al., 2016)
Cyanidin-3-Glucoside Equivalents (mg C3G/100g)	136.0 mg C3G/100g	(De Barros et al., 2024)
Cyanidin-3-Glucoside Equivalents per gram (mg/g)	9.76 ± 0.22 mg cya-3-glu/g	(Rodríguez-Mena et al., 2023)
Gallic Acid Equivalents (mg GAE/g)	1.73 mg GAE/g atau 7.2 mg GAE/g	(Bernabeu et al., 2024); (Abouzeid et al., 2025)
Cyanidin Equivalent (mg CE/100 g DW)	83.78 mg CE/100 g DW	(Huang et al., 2019)

These findings underscore the complexity of anthocyanins in purple sweet potatoes, which are dominated by cyanidin and peonidin derivatives, especially in acylated forms (diacyl) that contribute to their stability. The optimization of extraction methods is proven to be crucial; methods such as ASE, UAE, HPCD, and $SCCO_2$ offer significantly higher yields compared to conventional extraction. These studies provide a strong foundation for industrial applications, where the selection of an efficient and environmentally friendly extraction method is essential for the sustainable production of stable and abundant natural pigments. Future research can further focus on standardizing quantification methods and comparing the bioavailability and bioactivity of extracts produced by these various methods.

G. Supercritical Carbon Dioxide Extraction Method ($SCCO_2$)

The Supercritical Carbon Dioxide Extraction ($SCCO_2$) method is a "green extraction" technique attracting attention in food chemistry and pharmaceuticals because it uses a non-toxic solvent ($SCCO_2$), generates minimal residue, and operates at relatively low temperatures, which is ideal for heat-labile compounds like anthocyanins. In the context of purple sweet potato, $SCCO_2$ has been used, often with the aid of co-solvents such as water and ethanol, to extract anthocyanins. CO_2 becomes a supercritical fluid when it reaches or exceeds its critical point (around 31.1 ^oC and 73.8 bar), allowing it to possess the diffusion properties of a gas and the solvent power of a liquid.

Mechanism and Results: In studies comparing $SCCO_2$ with classical extraction, the $SCCO_2$ method modified with water and ethanol yielded a variety of anthocyanins. Another study identified 23 different anthocyanins in the $SCCO_2$ purple sweet potato extract, primarily cyanidin- and peonidin-based anthocyanins. Quantitatively, the most dominant anthocyanin identified was Peonidin-3-caffeoyl-p-hydroxybenzoyl sophoroside-5-glucoside, reaching 46% of the total anthocyanins in the extract produced using $SCCO_2$ with ethanol co-solvent. The efficiency of this method is demonstrated by yields that can reach 45.58%–83.20% of total anthocyanins, depending on the operational conditions.

Advantages: The main advantage of $SCCO_2$ is its ability to optimize selectivity and efficiency through precise control of pressure and temperature, as well as minimal thermal degradation of the pigment.

H. Structural Distinction: Cyanidin vs. Peonidin

Anthocyanins in purple sweet potatoes are dominated by derivatives of two main anthocyanidin (aglycone) molecules: Cyanidin (Cy) and Peonidin (Pe/Pn). Anthocyanidin is the fundamental core of the pigment; once a sugar group (glycosylation) or an acyl group (acylation) is added, it becomes an anthocyanin. The main structural difference between cyanidin and peonidin lies in the modification of the hydroxyl (OH) group at the C3' position of the B ring (refer to the C6–C3–C6 flavonoid basic framework structure).

Table 3. Main structural differences between cyanidine and peonidine

Structural Features	Cyanidine	Peonidine
Groups on Ring B (R3' & R4')	**R3** = OH (Hydroxyl)	**R3**= OCH_3 (Methoxyl)
Characteristic	anthocyanidin derivative	methylated derivative of Cyanidin
Color Implications	Tends to produce red/purple-red colors	Tends to produce pink/purple colors
Examples in Purple Sweet Potatoes	Cyanidin-3-caffeoyl-p-hydroxybenzoylsophoroside-5-glucoside.	Peonidin-3-caffeoyl-p-hydroxybenzoylsophoroside-5-glucoside.

IV. CONCLUSION

Overall, the findings from various studies indicate that purple sweet potato tubers (*Ipomoea*) are a rich source of anthocyanins, with a structural dominance of Cyanidin and Peonidin derivatives that are mostly diacylated. The presence of diacylation (e.g., caffeoyl and *p*-hydroxybenzoyl) on the sugar group (sophoroside-5-glucoside) is crucial because it significantly enhances the pigment's thermal and pH stability, making it a superior natural candidate for food colorant and pharmaceutical applications.

Optimization of extraction methods is proven to be a determining variable in anthocyanin yield. Modern methods such as Accelerated-Solvent Extraction (ASE), Ultrasound-Assisted Extraction (UAE), and Supercritical Carbon Dioxide ($SCCO_2$) with co-solvents (ethanol/water) consistently provide higher content and extraction efficiency compared to conventional methods. The $SCCO_2$ method was even able to identify up to 23 different types of anthocyanins, with a high percentage of Peonidin-3-caffeoyl-p-hydroxybenzoyl sophoroside-5-glucoside (46% of total). The success of this extraction paves the way for the standardization of industrial processes to utilize the functional potential of purple sweet potato as an effective natural antioxidant.

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