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ANTHOCYANINS – METHODS OF EXTRACTION AND STABILIZATION

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Abstract. Anthocyanins, natural pigments present in plants which are of interest among researchers due to their antioxidant qualities and potential therapeutic advantages in certain contexts. Their occurrence in fruits, vegetables, and blossoms attributes to their unique hues. Once obtained, the dyes extracted from berries can serve as natural coloring agents in a variety of food items, displacing artificial dyes. Moreover, the antioxidative characteristics of anthocyanins position berry dyes as potential sources of functional components for creating healthier food alternatives. Overall, the extraction of pigments from berries shows considerable promise for both the food sector and health-conscious consumers. In this context, emphasis is placed on the identification of advantageous extraction methods from the point of view of the quality of the biologically active compounds obtained, the extraction yield and the impact of the respective methods on the environment. Directing the technological parameters for obtaining storage-stable phytochemical compounds is also important. The purpose of this paper is to deepen the methods of anthocyanin extraction, their advantages and disadvantages together with the condition of the berries subjected to the extraction processes. Moreover, it analyzes the stabilization methods of phytochemical compounds during storage and their use in the food industry.

Keywords: *anthocyanins, antioxidant properties, berries, extraction methods.*

Rezumat. Antocianinele, pigmenți naturali prezenți în plante, prezintă un interes considerabil datorită proprietăților lor antioxidante și a potențialelor avantaje terapeutice. Prezenţa lor în fructe, legume și flori se atribuie nuanțelor lor unice. Odată obținuţi, coloranții extrași din fructe de pădure pot servi ca agenți de colorare naturali într-o varietate de produse alimentare, înlocuind coloranții artificiali. În plus, caracteristicile antioxidante ale antocianilor poziționează coloranții de fructe de pădure ca surse potențiale de componente funcționale pentru crearea de alternative alimentare mai sănătoase. În general, extracția pigmenților din fructe de pădure este importantă atât pentru sectorul alimentar, cât și pentru consumatorii în căutare de opțiuni naturale și sănătoase. În acest context se pune accent pe identificarea metodelor de extracție avantajoase din punct de vedere a calităţii compuşilor biologic activi obţinuţi, a randamentului de extracţie şi a impactului metodelor respective asupra mediului înconjurător. De asemenea, este important de a dirija parametrii tehnologici pentru obţinerea compuşilor fitochimici stabili la păstrare. Scopul acestei lucrări a costat în evaluarea metodelor de extracție a antocianilor, avantajele și dezavantajele acestora, precum și metodele de stabilizare a compuşilor fitochimici în timpul depozitării și utilizării în industria alimentară.

Cuvinte cheie: *antociani, proprietăți antioxidante, fructe de pădure, metode de extracție.*

1. Introduction

Horticultural resources containing abundant anthocyanins, like blueberries, blackberries, jostaberry and beetroot, have become popular for their antioxidative characteristics. These flavonoid compounds not only impart vivid hues to fruits and veggies but also shield cells from oxidative stress and harm caused by free radicals [1,2]. Regular intake of anthocyanin-rich foods can promote overall well-being and ward off diverse aliments. The advantages of consuming horticultural resources abundant in anthocyanins:

- Shielding against cardiovascular aliments: Anthocyanins aid in preserving heart and circulatory system health by decreasing "bad" LDL cholesterol levels and lessening artery inflammation [3]. Blueberries, abundant in anthocyanins, are frequently utilized in complementary treatments to stave off cardiovascular illnesses.
- Enhancing cognitive function: Anthocyanins can positively influence brain function and memory. Research indicates that these compounds enhance attention, focus, and cognitive stamina [4].
- Anti-inflammatory attributes: Anthocyanins exhibit robust anti-inflammatory properties, potentially lowering the likelihood of developing persistent inflammatory aliments like arthritis and inflammatory digestive disorders [5]. Due to its elevated anthocyanin content, beetroot can be included in an anti-inflammatory regimen, aiding in alleviating symptoms associated with such conditions [6].
- Boosting the immune system: Ingesting horticultural resources rich in anthocyanins can fortify the body's immunity, thanks to these compounds' capacity to combat free radicals and infections [7].

Raspberries, for instance, offer a rich reservoir of anthocyanins and vitamin C, bolstering immune system function and shielding the body from colds and infections [8]. Consuming anthocyanin-rich horticultural resources provides benefits such as safeguarding against cardiovascular aliments, supporting cognitive function, anti-inflammatory traits, and enhancing the immune system [9]. Fruits like blueberries, blackberries, jostaberry, beetroot, and raspberries exemplify foods abundant in anthocyanins that confer these advantages. Certain horticultural resources teeming with anthocyanins and antioxidative properties encompass:

- **Blueberries**. With their intense blue color derived from anthocyanins, blueberries are famed for their high anthocyanin content. They also boast other antioxidants such as vitamin C and vitamin E [10].
- **Blackberries.** Another anthocyanin-rich fruit, blackberries also offer a rich source of vitamins A and C, along with fiber.
- **Red cabbage.** A cruciferous vegetable brimming with anthocyanins, red cabbage also packs a punch with additional antioxidants, vitamins, and minerals.
- **Purple sweet potatoes**. These vibrant tubers owe their hue to anthocyanins and are rich in fiber, vitamins, and minerals.
- **Red grapes.** Particularly abundant in anthocyanins in their skin, red grapes also supply resveratrol, another potent antioxidant.
- **Elderberries.** Renowned for their copious anthocyanin content and medicinal properties, elderberries are also rich in vitamin C and dietary fiber.

- **Blackcurrants.** Small berries rich in anthocyanins and other antioxidants, blackcurrants are also laden with vitamin C and potassium.
- **Cherries.** Especially tart cherries, high in anthocyanins, also possess other antioxidants and anti-inflammatory characteristics. These anthocyanin-rich resources can be integrated into various dishes like smoothies, salads, desserts, or enjoyed as a snack to harness their antioxidative advantages [11].
- **Jostaberry.** The jostaberry hybrid *(Ribes × nidigrolaria)* is a fruiting shrub obtained by crossing the following species: the blackcurrant *Ribes nigrum*, the black gooseberry *Ribes divaricatum*, and the European gooseberry. The jostaberry hybrid varieties, are sources of notable nutritional value, due to their increased content of biologically active compounds, such as fiber, carbohydrates, phenolic compounds, vitamins, and minerals [2].

2. Berries pretreatment before hue extraction

Berries are known for their vibrant colors and delicious flavors, but they also pack a powerful punch when it comes to health benefits. Anthocyanins, the pigments that give berries their hues, are potent antioxidants with anti-inflammatory properties that may help reduce the risk of chronic diseases [12]. Berries can be used in various extraction processes to obtain juices, concentrates, bioactive compounds, extracts for food supplements, and others in fresh or pretreated form (Table 1).

Fresh. Ideal for ready-to-eat products, juices and smoothies.

Frozen. Good for processed foods and extracts of bioactive compounds.

Dried. Optimal for food supplements, tinctures and infusions.

Freeze-dried. Excellent for premium health and cosmetic products [13].

Depending on the final purpose of the product and the available resources, the choice of condition in which the pads are used will vary. Each method has its own advantages, and the right choice can optimize the quality and efficiency of the extraction process [14].

Table 1

Pretreatment methods of fruits and berries

State of berry	Advantages	Disadvantages	References
Fresh	High water content, which facilitates the extraction of soluble compounds. High extraction yield. The natural chemical composition is intact, without distortion.	High perishability, which can affect yield if not processed quickly. Seasonal variability and limited accessibility, that could influence the yield	[15,16]
Frozen	Preserves bioactive compounds, including anthocyanins, with minimal changes. Availability throughout the year.	Possible loss of bioactive compounds during the freezing and thawing process, but these are often insignificant.	[17,18]
	Freezing preserves the structural integrity and chemical composition of the berries, allowing a good extraction yield.	Need equipment for freezing and storage.	

Continuation Table 1

Dried	Stability and long storage life Possibility of transport and easy handling.	Significant loss of anthocyanins and other phenolic compounds due to oxidation and high temperature used in the drying process, which lowers the extraction yield. The need for rehydration before extraction, which can complicate the process reduce efficiency.	[19,20]
Freeze-dried	Excellent preservation of bioactive compounds, including anthocyanins, due to the low temperatures and absence of oxygen in the freeze-drying process. High extraction yield due to the porous structure that facilitates the access of solvents.	High costs of the freeze-drying equipment and process. Requires carefully controlled storage conditions to prevent rehydration.	[21,22]

The extraction of anthocyanins from berries can vary significantly depending on the state in which they are used (fresh, frozen, dried or freeze-dried). Each preservation method has its own advantages and disadvantages in terms of anthocyanin extraction yield [23].

Table 2

Side-by-Side Comparison of Extraction Methods [24]

State of berry	Anthocyanin Levels	Preparation Time	Extraction Difficulty
Fresh	High	Short	Easy
Frozen	High	Medium	Easy
Dried	Moderate	Long	Moderate
Freeze-Dried	High	Medium	Easy

To achieve maximum anthocyanin extraction efficiency, it is recommended to use freeze-dried berries (Table 2). This preservation method ensures the preservation of bioactive compounds' integrity and allows for efficient extraction, although it involves higher costs and requires special equipment. If resources do not allow for freeze-drying, freezing can be a viable alternative, maintaining a good extraction yield at lower costs [25].

3. Phenolic Acids and Anthocyanidins in Red Fruits

In recent times, there has been a notable surge in research dedicated to the analysis of the composition and antioxidative characteristics of crimson fruits [26]. Scientists have delved into diverse extraction techniques, encompassing traditional solvent extraction and innovative methods like ultrasound, microwave, and pressure-assisted extractions, to procure products abundant in antioxidants [27]. Furthermore, investigations have been conducted on the impact of cultivar types, storage conditions, and drying methodologies on the extraction and efficacy of antioxidants. This overview seeks to collate and present the most recent discoveries in this domain to offer a thorough insight into antioxidant extraction from crimson fruits [28].

These parameters aid in evaluating the strength and efficiency of anthocyanins concerning their antioxidative potential and overall health advantages [29]. Through the utilization of these parameters, researchers can precisely gauge and contrast the caliber of various origins of anthocyanins [30], ultimately fostering advancements in comprehending their plausible therapeutic uses.

Indices for the quality of anthocyanins provide a mechanism to scrutinize the attributes and efficacy of these substances. By comprehending the concentration, configuration, and biological functions of anthocyanins, informed choices can be made regarding which foods to ingest to optimize the health benefits linked with anthocyanins [31].

Moreover, the extraction technique, solvent, duration, temperature, and pH levels also exert a pivotal role in determining the attributes of the extract. These factors can impact the output, resilience, bioactivity, and composition of the extract, including specific bioactive components [32,33]. Hence, thoughtful consideration of these elements is imperative to procure extracts with desired features and potential health gains from berries.

To enhance the extraction of antioxidant compounds from berries, researchers concentrate on regulating extraction procedures due to the challenges in controlling climatic conditions, sunlight exposure, water uptake from plants, and maturation stage [34]. The incorporation of substances or exposure to diverse light treatments such as ultraviolet or blue light can boost antioxidant compounds and capacity. The extraction procedure encompasses the crimson fruit, technique (chemical or physical assistance) [35], and influential variables like duration and temperature.

Regarding extraction methodologies, the conventional solvent extraction remains the prevalent approach for extracting antioxidant compounds from crimson fruits, particularly on an industrial scale [36]. Nevertheless, this method engulfs a substantial amount of energy due to the heating process and solvents needed for solid-liquid extraction [37]. Novel non-conventional approaches have surfaced as eco-friendly alternatives to the former technique, such as ultrasound, microwave, and pressure-assisted extractions, either applied individually or in conjunction with solvent usage, to diminish the energy and solvent requisites [38].

3. Common Methods for the Extraction of Antioxidants from Berries

The use of emerging procedures for extracting biologically active compounds from plant raw materials remains a current technological problem, considering the importance of their use in different branches of industry. The correct choice of temperature and the appropriate solvent will ensure the complete extraction of biologically active compounds from the plant based materials, and the extraction time and the optimal hydromodule can save energy and expensive solvents, without the loss of the extracted compounds [39].

3.1. Mechanical Extraction

An ancient method of extraction known as cold press extraction is commonly used to extract antioxidant-rich inner fruit liquids without the use of heat or additional solvents. This technique, widely employed in the production of fruit juices and oil extraction, involves a screw press to obtain the initial liquid, followed by multiple extractions of the residual press cake to enhance the overall extraction yield [40].

3.2. Traditional Extraction Methods

Within traditional extraction methods, two primary techniques are maceration and solvent extraction. Maceration involves the gradual release of substances into a solvent over extended periods without the application of heat [41]. Conversely, solvent extraction utilizes heat and various solvents to expedite the extraction process, with stirring often employed to enhance mass transfer. Soxhlet extraction, a cost-effective method commonly used at the laboratory scale, eliminates the need for subsequent filtration [42].

Solvents such as water, ethanol, methanol, and acetone, either individually or in combination, are typically utilized in these extraction processes [43]. Acidulated solvents, containing around 1% acid like HCl or acetic acid, may be employed to improve extraction efficiency. Water-alcohol mixtures have shown enhanced extraction efficiency compared to single-component solvents, with 50% ethanol demonstrating optimal results at different temperatures [44].

The solvent used will be chosen considering the following characteristics:

- Selectivity, which includes the solubility of target compounds and their purity.
- Reactivity, chemical interaction with target compounds is undesirable.
- Chemical and thermal stability under extraction conditions.
- Low viscosity, which increases substance transfer by increasing the diffusion coefficient.
- Low boiling point.
- Flammability, prohibited.
- Toxicity and environmental and health problems.
- The price of the solvent, which is directly exposed to the manufacturing costs on an industrial scale [39].

Numerous studies [45,46,47] have highlighted ethanol as the preferred solvent for extracting antioxidant compounds due to its effectiveness when compared to water, acetone, hexane, ethyl acetate, and methanol. The ideal composition of ethanol-water mixtures is generally found to be between 40% and 70%, as it is economically feasible and derived from a renewable source, aligning with green chemistry principles.

Traditional methods using ethanol, methanol or acetone give a good yield, but can be improved by optimizing the conditions (temperature, time, solvent/material ratio) [48].

3.2.1. Impact of Solid-to-Solvent Ratio

The solid-to-solvent ratio is crucial in extraction processes, as it influences the concentration of antioxidant compounds in the final extract. While a higher ratio results in increased compound concentration, an inadequate solvent volume can impede mass transfer, necessitating a balance between the two [49].

3.2.2. Influence of Temperature and Duration

Temperature and extraction time are interrelated factors affecting the extraction process. Elevated temperatures can reduce extraction time, leading to higher yields of antioxidants. However, excessive temperatures may cause thermal degradation of certain compounds, such as anthocyanins, impacting antioxidant content. The optimal balance between temperature and time is essential to maximize extraction efficiency [50]. Currently, sustainable extraction methods, ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) could replace conventional methods, being sustainable extraction methods which are more efficient: economical, require less time, energy, and reagents. On the other hand, phytochemical compounds extracted by these methods are safe and harmless for the use in food industry.

3.3. Application of Ultrasound in Extraction (UAE)

UAE is a non-thermal technique utilizing frequencies above 20 kHz to disrupt cell walls and enhance mass transfer [51]. This environmentally friendly method has gained popularity for its cost-effectiveness and efficiency compared to traditional solvent extraction processes [52]. Ultrasound-induced cavitation aids in the extraction of intracellular compounds, such as anthocyanins, from plant material [53].

The efficacy of sonication has been demonstrated in improving extraction yields, although the frequency and duration of ultrasound exposure must be carefully controlled to prevent degradation of target compounds. While UAE has shown promising results in various studies [54,55], its impact on the extraction of antioxidant compounds may vary depending on the fruit type and processing conditions.

The use of ultrasonic waves can increase the extraction yield by effectively breaking the cells and releasing the anthocyanins. This method can reduce the extraction time and the amount of solvent required [56,57].

3.4. Microwave-Assisted Extraction (MAE)

MAE is characterized by rapid heating and reduced solvent usage, making it a favorable option for extraction processes. MAE's ability to utilize intrinsic moisture within fruits, coupled with its efficient heat transfer mechanism, results in shorter extraction times and lower environmental impact [54,55]. Optimal solid-to-solvent ratios are essential for maximizing extraction efficiency, with specialized techniques like Microwave Hydro diffusion and gravity offering enhanced extraction yields compared to traditional solvent extraction methods [58].

Microwaves heat the material quickly and evenly, facilitating the release of anthocyanins and increasing the extraction yield. This method is efficient and can reduce processing time. Main factors affecting yield are the microwave frequency, types of solvent and sample size [59].

The main steps of microwave enhanced extraction process included:

- Heat energy created by microwave radiation;
- Heat energy absorbed by samples;
- Creation of high vapor pressure due to moisture evaporation;
- Disruption of cell wall of matrices;
- Release of desired compound into solvents [60].

3.5. Pulsed electric Assisted Extraction

In order to increase the yield of biologically active compounds by increasing the permeability of the cell membranes of the raw material of vegetable origin, due to the phenomenon of electroporation, the extraction assisted by the pulsating electric field (Pulsed Electric Field - PEF) is used. It is an athermal method involving repeated high voltage pulses for several milliseconds on a plant sample placed between two electrodes [61]. Several authors have demonstrated the high efficiency of the extraction of biologically active compounds, especially polyphenols, using PFE from raw and secondary plant materials [62,63], possibly due primarily to the temperatures of the process that varies between 20°C - 50°C, which contributes to the breaking of the cell membranes in the apple skin, allowing the extraction of soluble intracellular components due to increased diffusion [64].

3.6. Supercritical CO_2 extraction (SFE-CO_2)

Supercritical fluid extraction (SFE), a temperature- and pressure-dependent technique, is valued for the extraction yield and quality of natural chemical compounds obtained (flavonoids, essential oils, seed oils, carotenoids and fatty acids) from natural plant based materials. This technique is a sustainable alternative to traditional extraction systems. Research has shown the considerable benefits of SFE over conventional techniques. Carbon dioxide (CO_2) is a valued solvent in this technique because it is chemically inactive, economical, easily accessible, separable from extracts, non-toxic, approved as a food grade solvent.

Supercritical carbon dioxide is frequently used in SFE due to its gas-like and liquid-like properties, low critical temperature and pressure, and has the selectivity and potential to extract heat-sensitive compounds.

They can also extract compounds with different molecular sizes. Low polarity compounds and small molecules are easily dissolved in SC-CO_2, but large molecules and polar compounds are extracted with the addition of a co-solvent to improve the extraction yield, which can be ethanol, methanol or water [65]. Some authors [66, 67] used SC-CO_2 extraction of carotenoids, phenols and flavonoids from plant raw materials in combination with other methods of extraction, for example stage II including the use of pressurized ethanol extraction [68]. Qualitative comparison of extraction methods is shown in Table 3.

Table 3

Qualitative comparison of extraction methods

Extraction Method	Pros	Cons	References
Maceration	No additional energy needed	Very long extraction times.	
Solvent extraction	Easy industrial scale-up. Well known technique. One of the most prevalent approaches for anthocyanin extraction. Use of organic solvents. Adaptable for various plant sources.	Long extraction times. Potential flammability or toxicity of solvents necessitating specific safety precautions. Risk of losing valuable compounds due to solvent interactions	[3, 30, 69, 70-72]
Ultrasound assisted	Higher efficiency (less extraction time and solvent consumption requirements). Safe extraction of heat labile compounds.	Expensive scale-up	[73,74]

Continuation Table 3

Microwave assisted	Quicker heating. Reduced equipment size. Cost-effective and straightforward technique. No added solvent needed. Higher efficiency (heat leads to the breaking of weak bonds that allow the release of bioactive components in the solvent).	Risk of burning the sample and denaturalizing compounds	[75-77]
Aqueous extraction	Environmentally friendly and safe, using a common and harmless solvent. Minimizes the risk of adverse interactions between the solvent and pigments. Suitable for obtaining extracts rich in water-soluble anthocyanins.	Challenges in achieving high anthocyanin concentrations. Susceptibility to pigment degradation under specific conditions like high temperature and pH. Selective extraction of specific types of anthocyanins based on their water solubility.	[78-81]
Supercritical CO_2 extraction ($SFE\text{-}CO_2$)	CO_2 no toxicity, extraction in absence of air and light. Pure extracts.	The complexity of the extraction process	[65,82]
Pulsed electric fields	Already acquired by some food industries to scale-up processes.	Need of specialized equipment	[30,69]

The choice of extraction method and technology depends on the initial state of the berries and the resources available. Freeze-dried berries generally offer the highest anthocyanin extraction yield due to the preservation of structure and bioactive composition. Depending on the available equipment and costs. Ultrasound and microwave-assisted methods can also improve yield while reducing time and solvent quantity required. The optimal extraction method choice should consider both the desired yield and available resources [2,57].

4. Influence of technological regimes on anthocyanins antioxidant and coloring properties

Anthocyanins extracted from berries offer a wide range of applications in the food industry. These beneficial compounds can be incorporated into various food items such as juices, soft drinks, ice creams, and baked goods [83]. Consumption of foods enriched with berries anthocyanins can provide health benefits due to their antioxidant and anti-inflammatory properties [84].

The impact of technological factors, including temperature, pH, and ionic strength, on the antioxidant activity and color attributes of natural dyes is a crucial area of study. These variables can significantly influence the stability and functionality of natural dyes commonly utilized in different sectors like food, textiles, and cosmetics [85].

Temperature. Alterations in temperature can impact the antioxidant activity and color attributes of natural dyes. Higher temperatures may lead to the degradation or loss of antioxidant properties and changes in color intensity or hue. Conversely, lower temperatures can aid in preserving the antioxidant activity and color stability of natural dyes [86, 87].

pH. The pH level of a solution can profoundly affect the antioxidant activity and color properties of natural dyes. Different pH conditions can modify the chemical structure of dyes, influencing their stability and color characteristics [88,89]. Some natural dyes may exhibit enhanced antioxidant activity or color intensity at specific pH ranges, while others may demonstrate greater stability or vibrancy under different pH conditions [90,91]. Thus, controlling and optimizing pH conditions during the technological process is crucial to maximize the antioxidant potential of natural dyes [92].

Ionic strength. The ionic strength of a solution, determined by the concentration of ions present, can impact the antioxidant activity and color attributes of natural dyes [93]. Changes in ionic strength can influence the solubility, stability, and interactions of dyes with other components in a system, thereby affecting their antioxidant capacity and color properties [94,95]. Increasing ion concentration in a solution can reduce the antioxidant activity of natural dyes. This reduction can occur through direct interaction with reactive oxygen molecules or by modifying the chemical environment where the antioxidant reaction occurs [96]. However, the effect of ionic strength on antioxidant activity can vary based on the specific dye and chemical system being used [97].

Comprehending the influence of these technological factors on natural dyes is crucial for optimizing their application in diverse industries. Researchers and manufacturers can leverage this knowledge to develop suitable processing conditions, storage methods, and formulation strategies to maximize the antioxidant activity and retain the desired color properties of natural dyes [98]. The examination of how technological factors impact the antioxidant activity and color attributes of natural dyes is particularly critical in the food industry [99]. As concerns over synthetic dye consumption grow, natural dyes are increasingly viewed as a safer and more consumer-accepted alternative [100].

5. Methods of stabilizing anthocyanin during storage

Manufacturers must focus on research and development to discover effective techniques for stabilizing dyes and prolonging their shelf life. This can involve selecting dyes with enhanced stability characteristics, incorporating protective coatings or additives, and implementing proper storage and handling practices [101]. By addressing this issue, manufacturers can ensure that their products retain their desired color and attractiveness, leading to increased customer satisfaction and product success.

- **Incorporation of antioxidant additives.** Antioxidant additives are capable of delaying or preventing product deterioration resulting from oxidative reactions [102]. Utilizing antioxidant additives can safeguard dyes against degradation processes that may occur during storage.
- **Protective packaging**. Packaging plays a crucial role in preserving dyes during storage. Opting for opaque packaging that shields against ultraviolet light can prevent dye damage due to light exposure [103]. Hermetic packaging can also aid in preventing oxidation and the ingress of oxygen into the product.

- **Control of temperature and humidity**. Proper regulation of temperature and humidity is essential for dye stabilization during storage [104]. Extreme temperatures can alter the chemical properties of dyes, leading to modification or discoloration. Excessive humidity levels can promote mold growth and other forms of damage.
- **Incorporation of preservatives.** In cases where the product containing dyes has an extended shelf life, the addition of preservatives can be considered [105]. This measure can inhibit the growth of bacteria and other microorganisms that could harm the dyes during storage.
- **Conducting stability assessments.** To validate the efficacy of the stabilization methods employed, conducting stability tests is imperative [106]. These tests aid in evaluating the resilience of dyes under various storage conditions, including temperature variations, humidity levels, light exposure, and oxidative environments [107].

To uphold the stability of dyes during storage, a range of strategies can be implemented. Incorporating antioxidant additives can counteract degradation due to oxidative reactions, while protective packaging, temperature and humidity control, and preservative incorporation can safeguard against chemical alterations, damage, and microbial growth. Furthermore, stability tests are essential for assessing the dyes' resilience to diverse storage conditions [108].

6. Conclusions

The extraction of anthocyanins from berries has shown promising potential in the food sector. Techniques such as soaking, fermenting, and pressing enable the production of concentrated extracts suitable for various food items. Anthocyanins possess antioxidant and anti-inflammatory properties, rendering them a valuable component in promoting consumer well-being. Consequently, berries are progressively gaining recognition as a significant source of anthocyanins in the contemporary food industry.

Solvent extraction entails utilizing organic solvents to extract anthocyanins, providing high extraction efficacy and adaptability in extracting anthocyanins from different plant sources. Nonetheless, it may necessitate additional steps to eliminate solvents from the extract and could lead to the loss of certain volatile compounds. Conversely, water extraction is a straightforward and eco-friendly approach applicable to specific plant materials. Nevertheless, it might exhibit lower extraction efficiency compared to solvent extraction and could be less suitable for plants with low water solubility of anthocyanins.

The selection of the extraction method should be meticulously assessed based on the specific requirements and characteristics of the anthocyanins to be extracted. The article underscores the importance of understanding anthocyanin extraction techniques, as it plays a crucial role in the processing of raw materials and acquiring valuable extracts utilized in the food, pharmaceutical, and cosmetic sectors.

As final thoughts, maintaining the stability of colorants during storage is crucial for the production of goods that rely on them. Techniques such as incorporating anti-oxidizing agents, appropriate packaging, regulation of temperature and moisture, and conducting endurance evaluations are essential in preserving the quality and hue of the colorants. These actions are imperative for meeting consumer demands and guaranteeing their contentment.

Anti-oxidizing agents aid in preventing the decomposition of colorants due to exposure to oxygen, whereas proper packaging, like hermetic containers or light-blocking materials, serves to shield colorants from external elements that could impact their stability.

Regulating temperature and humidity is vital to prevent colorants from deteriorating under extreme circumstances.

The addition of preservatives can hinder the proliferation of microorganisms that might lead to spoilage or deterioration of colorants. Endurance tests are carried out to evaluate the efficiency and durability of colorants under different storage conditions, ensuring that they uphold their intended hue and quality over time. By implementing these measures, producers can boost the stability of colorants, prolong their shelf life, and ultimately enhance consumer satisfaction by offering products with consistent and vivid hues.

The article provides a comprehensive and enlightening overview of the various technologies used in the extraction and stabilization of anthocyanins, highlighting their importance in research and development initiatives.

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