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Sources and Applications of Natural Food Colorant from Anthocyanin Rich Plant Flowers

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ABSTRACT:
Anthocyanins are flavonoid aqueous pigments that give red, purple and blue hues to different plant materials and have been well known due to both their pigmenting capability and their antioxidant and health benefits. The present review is dedicated to the uses of anthocyanin-based natural food colorants based on the plant flowers, the importance of their applications in food systems, functional foods, and intelligent packaging. Past research has shown that anthocyanins are conveniently utilized in drinks, dairy, bakery, and confectionary products because of their solubility in various food matrices and a wide range of colours. Flower-based sources e.g. butterfly pea,hibiscus, roselle, rose and torch ginger have been widely researched on the basis of their high pigment level, and colour versatility. Also, the stability and shelf life of anthocyanins have been found to be enhanced by the application of encapsulation methods during processing and storage. Another notable development in the recent years is the use of anthocyanins in smart and active packaging. The anthocyanins are also pH sensitive colour changing and this makes them be applied in the packaging of food as a freshness indicator enabling real time monitoring of the quality of the food. The use of anthocyanins is constrained by stability in different pH, temperature, light and oxygen conditions among others despite their benefits. Moreover, anthocyanins are useful in the production of functional foods because of the presence of antioxidant, anti-inflammatory, and disease-preventing functions. Nonetheless, there are issues involving bioavailability and stability that should be tackled to utilize them in support of their applications. All in all, the use of anthocyanin rich plant flowers as a natural food colorant source has a lot of potential in the food industry because their uses are diverse and sustainable. The review gives a broad spectrum of their application in food and packaging systems with recent developments and the future possibilities in the technology.

Keywords: Food Quality Natural food colorants, Anthocyanins rich Plants flower pigments, Butterfly pea, Hibiscus Roselle, Functional food Antioxidant activity, Smart packaging, Intelligent packaging, Clean-label foods Emerging food additives, Sustainable food additives**.**

I. INTRODUCTION

The demand of natural food additives has increased significantly within the past years as a result of the increased awareness of consumers about the health hazards associated with synthetic food colorants. This change of preference has made the food industry to find safer and natural derivatives. One group of water soluble flavonoid compounds with special interest has been anthocyanins containing red, purple and blue hues in many fruits, vegetables and flowers. Such pigments are not only used to improve the appearance of food but also have other health advantages, and therefore are very desirable as natural colorants. Their use as effective colouring agents, as well as sources of overall wellness is evidenced by the fact that anthocyanins have been widely used as a food ingredient, which makes them one of the primary pigments used in the food industry[7].

Although with their positive characteristics and extensive potential, the effective use of anthocyanins in food products and packaging materials is often limited by the fact that these biomolecules are often sensitive to a number of conditions. The pH, temperature, light and oxygen exposure may also play an important role in the stability and expression of anthocyanins. An example of this is that variations in pH can cause them to change in their molecular structure and cause a colour change or become colourless and the high temperature or extended exposure to light can speed up their decomposition. On the same note, oxygen is capable of enhancing oxidative reactions that reduce their workability and aesthetic beauty. These environmental sensitivities pose considerable problems to the food industry since they have the capacity of affecting the effectiveness of anthocyanins as natural colorants or active packaging compounds. Hence, there is a need to

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devise viable methods that will enable the stress levels of anthocyanins to be elevated in order to maximize their potential benefits in food processing and package food [2].

Processing conditions are also important in ascertaining anthocyanin stability. The food processing techniques and conditions surrounding food like heating, pasteurization, size, and storage conditions could highly influence the anthocyanins preservation and efficacy in food items and packing. Indicatively, temperature or long time effects increase the rate at which anthocyanins are destroyed and therefore result in loss of colour and loss of antioxidant activity. Also, they may also be exposed to processing conditions that diminish their stability by fostering chemical reactions or interaction with other foods. These issues reveal the need to design and establish suitable processing and preservation strategies that are highly specific to preserve the anthocyanins. With the optimization of these conditions, stability and functionality of anthocyanins can be improved and therefore the benefits of anthocyanins can be maximized and their stability ensured in the food systems and packaging applications [11].

Other than acting as natural colorants, anthocyanins are also being identified as having uses in intelligent food packaging. They are sensitive to environmental factors, which include pH and temperature, thus they are valuable pointers of food freshness and quality. This has increased the interest in incorporating anthocyanins into a packaging system that can deliver real-time data on the status of food products to improve the safety and consumer confidence [21].

The rich source of anthocyanins has also become a valuable source of natural colorants: plant flowers with high anthocyanin content, such as butterfly pea, hibiscus, and roselle, offer a rich number of colours and can be used in a wide range. Flower-extracted pigments are finding a growing application in foods of different categories, including beverages, dairy products, and baked goods. Their addition does not only add to the aesthetics of these products with the use of very colourful and attractive colouring, but also adds functional value, like antioxidant properties and even health benefits [22].

Also, anthocyanins have great antioxidant activity, which improves their usefulness in functional foods and health promotion. Anthocyanins among other natural products present in different plants are very important in the promotion of human health through inhibiting the adverse effects of the body free radicals. Free radicals are unstable molecules, which may result in oxidative stress, causing cellular damage, and proving to be the leading cause of the development of chronic diseases, including cardiovascular disorders, some cancer types, diabetes, and neurodegenerative disorders. This is because the antioxidant effects of these natural products allow them to counteract the free radicals, and in effect contain the oxidative stress and decrease the chances of these long term health complications. Through incorporation of such compounds into the diet, people can perhaps maintain their general health and increase the natural defence of their body against disease. Besides having direct health benefits associated with antioxidant activity, anthocyanins also play a major role in preserving and improving the quality of food products. Food can be spoiled by oxidative processes, which affect its taste, colour, texture as well as nutritional content. The anthocyanins inhibit oxidation and therefore produce shelf life of foods and preserve sensory properties. This qualifies them as natural preservatives, which some consumers would not like to use such as synthetic additives. Additionally, the anthocyanins possess more functional characteristics than preserve foods and help in disease prevention. They also make food products appealing to sight because of their bright colours, which vary between red and purple and also blue depending on their PH among other factors. Such visual improvement is significant to the food industry where colour plays a significant role in consumer acceptance and quality perception. The adoption of natural colorants such as anthocyanins is consistent with the rising popularity of clean-label foods which consumers are now concerned with foods that contain no artificial colours, ingredients, and additives. In addition, addition of anthocyanins and other naturally occurring antioxidants into functional foods is a viable technique in the development of products to add health value to them. Functional foods are foods which can be of additional benefit to basic nutrition, which can be an enhancement of health or a decrease in disease risks. Due to their antioxidant property anthocyanins are regarded as the most suitable candidates of such products. They can be applied to various types of foods such as beverages, dairy, baked goods and confectionery in order to improve their nutritional value and functionality. The current studies on anthocyanins are ongoing aiming to reveal more of the biological activities which include anti-inflammatory, antimicrobial and cardioprotective [20].Despite the numerous advantages of the anthocyanins, the

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challenges in making the anthocyanins to be widely utilized in industries still remain with their lack of stability and sensitivity to processing conditions. All this may influence their functionality and limit their integration into different food products and packaging systems. Consequently, there is a need to continue the studies to devise how to enhance the stability and functionality of anthocyanins.

II. STRUCTURE AND PROPERTIES OF ANTHOCYANINS

2.1. Chemical nature

The anthocyanins are soluble flavonoid pigments that belong to the polyphenolic group that has a basic flavylium cation structure (C6C3C6). This is a two aromatic ring (A and B) with a heterocyclic ring (C). Anthocyanin refers to anthocyanidin that is modified with glycosyl groups, in which case the sugar moieties are generally linked on the C3 site, improving and making them stable and soluble in aqueous conditions. These structural differences result because of variations in hydroxylation, methylation, and glycosylation patterns and therefore, their colour and functional properties are different[2]. The structure of anthocyanin is shown in Figure 1.

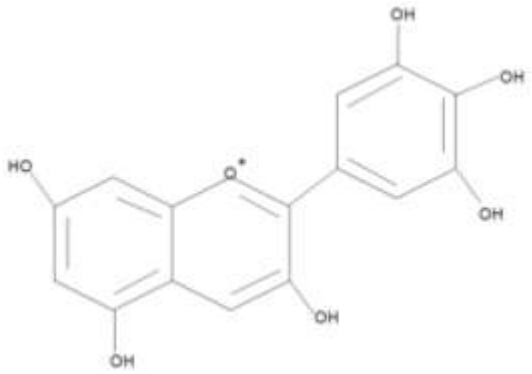

Figure 1. Structure of Anthocyanin

2.2. Types of Anthocyanins

Anthocyanins are categorized in accordance to their aglycone forms referred to as anthocyanidins. The most widespread are cyanidin, delphinidin, pelargonidin, peonidin, petunidin and malvidin. These compounds vary in terms of hydroxyl and methoxy groups on the B-ring. The most commonly distributed is cyanidin and the cause of blue and purple colouring is delphinidin and malvidin. Due to various sugar attachment and acylation patterns, the anthocyanins bring the diversity to the plants which leads to stability variations and colour intensity [8].

2.3. Colour variation with pH

Anthocyanins show wonderful colour variations with change of pH of media. They are red in the acidic (low PH) conditions as the predominant cation is the flavylium cation. On raising the pH to a neutral condition, the structure is changed to quinoidal base to produce purple or blue coloration. The anthocyanins may assume colourless or yellowish chalcone structures at alkaline pH owing to degradation. Such a pH-dependent behaviour renders anthocyanins very appropriate to be used in the application of intelligent food packaging and pH indicators [21].

2.4. Stability factors

Various environmental factors affect the stability of anthocyanins, pH being the most important of them, where their stability is higher when the environment is acidic. Degradation is influenced by temperature because the pigment is broken up faster as the temperature increases. Light can also cause photodegradation which causes a loss in colour. Also, oxygen facilitates oxidative reactions that decrease the stability of anthocyanin. Stability variations are also caused by other factors like enzymes and metal ions and co-pigmentation. Hence, these parameters should be regulated in order to preserve the quality of anthocyanins in food systems [11].

III. SOURCES OF ANTHOCYANINS

3.1. Plant-based sources

Anthocyanins are ubiquitous in fruits and vegetables in abundance, especially those with red,

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purple and blue hues. Typical examples are berries (blueberries, strawberries, and blackberries), grapes, and cherries, red cabbage, eggplant, and purple sweet potatoes. The sources that can be mentioned here are a rich source of various varieties of anthocyanins, which not only make them colourful but also endows them with antioxidant properties. The level and the proportion of anthocyanins depend on the variety of the plant, maturity and the climate. Since their origin is natural and healthier, these sources are widely used in the food industries as natural colorants and as functional ingredients [7].

3.2. Flower-based sources

3.2.1. Butterfly pea

Butterfly pea flower is also a good source of anthocyanins especially ternatins which make it have its deep blue colour. These pigments have got robust pH sensitive colour variations thus making them very good to use in drinks and desserts as well as smart packaging systems. Butterfly pea flower extract is becoming a popular natural food colorant because it does not destabilize in aqueous systems and has attractive colours. It further has antioxidant properties, which increase its value in the functional foods[1].

3.2.2. Hibiscus

The flowers of this plant are a valuable source of anthocyanins (primarily delphinidin and cyanidin derivatives) that give the flowers a rich red hue. These pigments are usually applied in drinks, jam, and herbal. Control products because they have bright colour and bioactive effects. The Hibiscus anthocyanins have been characterized by antioxidant and antimicrobial properties hence they can be used in the food and nutraceutical industries. Nevertheless, heat and pH are some of the processing conditions that may influence their stability [3].

3.3.3. Roselle

Roselle calyces are also known to be rich in anthocyanins and these are mainly cyanidin-3-glucoside and delphinidin-3-glucoside. The compounds are bright red in colour and are normally applied in juices, teas and food products. Roselle anthocyanin enjoys high antioxidant properties and health benefits. They have been used in food systems more often because consumers prefer natural colorants even though their stability is affected by the environmental conditions like pH and temperature [22].

IV. EXTRACTION OF ANTHOCYANINS FROM PLANT FLOWERS

4.1. Conventional Methods

Maceration and Soxhlet extraction are traditional methods that are largely used in extracting anthocyanins of plant flowers. Maceration is the process of saturating the plant material with one of the solvents such as ethanol, methanol or acidified water at either room temperature or slightly higher temperatures so that the pigments can be diffused into the solvent. Soxhlet extraction is an alternative, however, which relies on continuous reflux of solvent and it is more effective in extracting bound anthocyanins. Nonetheless, they tend to be less efficient in speed of extraction, high volumes of solvents used and can cause the degradation of heat-sensitive anthocyanins. Notwithstanding these shortcomings, they are still popular because of their simplicity and the cost-effectiveness[2].

4.2. Advanced Methods

Such sophisticated methods of extraction as microwave-assisted extraction (MAE) and ultrasound-assisted extraction (UAE) have become of interest because they are more efficient and do not require so much time to process. MAE involves the incidence of microwave energy to damage plant cell structures, which leads to more penetration of solvent and anthocyanin release. UAE uses ultrasonic waves to develop the cavitation that ruptures cell walls and gives way to swift extraction. These techniques use less solvent, less time is spent on extraction and increased yield is obtained as well as stability of anthocyanin is maintained. Consequently, they are regarded as greener and capable of use in industrial scale [11].

4.3. Factors affecting Extraction Efficiency

Several factors such as the type of the solvent, pH, temperature, time of extraction and the type of plant matrix affect the efficiency of anthocyanin extraction. In commerce, usually acidic solvents (e.g. ethanol in which hydrochloric acid is added) are the solvents of choice to preserve the anthocyanins. Extractions at high temperatures are likely to yield more but also cause pigments to be destroyed. Equally, the longer the extraction duration the higher the yield to a point where degradation can take place. The size of particles and the ratio of solid/solvent are also of essence in enhancing the effectiveness of extraction. The management of these parameters should be done

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correctly in order to get quality anthocyanin extracts [7]. Table 1 shows the different methods of anthocyanin extraction and limitations from plant flowers.

TABLE 1: Methods of anthocyanin extraction and limitations from plant flowers:

CATEGORY	METHOD	LIMITATIONS	REFERENCES
Conventional methods	Maceration	Time consuming, high solvent usage, lower efficiency	[2]
	Soxhlet Extraction	High temperature may degrade anthocyanins, energy-intensive	[2]
Advanced methods	Microwave-Assisted Extraction	Requires specialized equipment, possible thermal degradation if uncontrolled	[11]
	Ultrasound-Assisted Extraction	Limited scalability, equipment cost	[11]

V. APPLICATIONS OF ANTHOCYANINS IN FOOD SYSTEMS

5.1. Beverages

A wide range of applications of anthocyanins in beverages are the use of natural colorants and functional ingredients because of their bright-red, purple, and blue colours. They are usually added in the fruit juices, soft drinks, functional drinks in order to improve the appearance and give antioxidant properties. Also, the anthocyanins have pH-reactive colour changes hence it can be used in novel beverage formulations like colour changing beverages. Nevertheless, the light, temperature and oxygen can influence their stability during processing and storage [23].

5.2. Dairy Products

Anthocyanins are applied in milk products to enhance colour, taste and nutrition. They are usually used in the yogurt, flavoured milk, and fermented dairy products to give them their natural pigment and antioxidant qualities. Nonetheless, anthocyanins-milk protein interactions can have an impact on the colour stability and bioavailability. Their stability under dairy systems is usually improved by using encapsulation techniques[9].

5.3. Bakery Products

Anthocyanin finds use in the bakery systems like cakes, bread and pastries as functional ingredients and as a natural food colorant. They impart attractive values and can enhance nutritionally the baked goods. Nonetheless, baking has the potential to cause deterioration of anthocyanins which influences color, and antioxidant capabilities. These losses are reduced depending on strategies like microencapsulation and optimum conditions of baking [13].

5.4. Confectionary

Anthocyanins are also used in confectionary products such as candies, jellies, gummies and desserts as a natural substitute of synthetic dyes. They offer appealing colours and give added values in terms of antioxidant activity. When used in sugar-based systems, engineering of their pH and processing conditions is vital to ensure stability of colour, and no degradation takes place during the heating and storage processes [19].

5.5. Staple foods

The anthocyanins have been added to the staple food like rice and cereal products to improve their functional properties as well as nutritional value. This can be seen in the coloured types of rice, fortified breakfast cereals and extruded food products which are all advantaged by the bright colours due to the anthocyanin. In addition to visual attractiveness, these natural pigments add to the antioxidant properties of the staple foods, which may have health benefits to the end consumers. Nevertheless, the question of anthocyanins being retained in the process of food processing is a problematic issue. Anthocyanins may also be lost immensely by physical processing, e.g. through extrusion and cooking, thus diminishing their functionality and nutritional value. Such techniques are known to be associated with elevated temperatures and mechanical forces onto food, which anthocyanins are highly vulnerable to. This means that processing parameters must be optimized cautiously in order to achieve the highest level of stability of anthocyanins and to maintain

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the positive characteristics. Manufacturers can enhance the anthocyanin retention in processed products by modifying aspects like temperature, processing duration and moisture among other factors. However, the key in the triumphant incorporation of anthocyanins into the staple foods, lies in the ability to balance the quest to preserve desired sensory characteristics and the quest to gain maximum benefit of the health promoting potential of these valuable compounds[5]. Table 2 presents the applications of anthocyanin in various food sectors.

TABLE 2: Applications of Anthocyanin in various food systems:

FOOD CATEGORY	PRODUCTS	ROLE OF ANTHOCYANIN	ADVANTAGES	REFERENCES
Beverages	Soft drinks, juices and functional drinks	Natural colourant, antioxidant enrichment, pH-sensitive colour properties	Enhances visual appeal, provides health benefits, enable innovative products	[24]
Dairy products	Yogurt, flavoured milk, fermented dairy	Natural pigmentation, improves nutritional value	Adds antioxidant properties, consumer-friendly natural ingredient	[9]
Bakery products	Cakes, bread, pastries	Natural colouring agent, functional ingredient	Improves appearance and nutritional quality	[13]
Confectionary	Candies, jellies, gummies, desserts	Natural alternative to synthetic dyes	Provides attractive colours, adds functional benefits	[19]
Staple foods	Rice-based products, cereals, extruded products	Nutritional enhancement, natural colouring	Increases antioxidant intake, improves product appeal	[5]

VI. ROLE OF ANTHOCYANINS IN FUNCTIONAL FOODS

6.1. Antioxidant properties

It is also established that anthocyanins have high antioxidant properties because they mainly have the ability to donate hydrogen atoms or electrons and neutralize free radicals. These products are used in alleviating oxidative stress by scavenging the reactive oxygen species (ROS), and therefore, inhibiting cellular damage. Their antioxidant effect is important in the preservation of food as well as offers protective cover against chronic diseases when they are taken as a functional food [17].

6.2. Health benefits

Anthocyanins show great diversity in their health-promoting activities such as anti-diabetic or anti-inflammatory. They facilitate the control of inflammatory communities by suppressing pro-inflammatory factors and cytokines. Moreover, anthocyanins have been involved in the metabolism of glucose to enhance the sensitivity of insulin and lower blood glucose. Such biological activities make them useful components of functional foods to prevent lifestyle-related diseases [12].

6.3. Nutraceutical Applications

The bioactive capability of anthocyanins has led to their inclusion in nutraceutical preparations like dietary supplements, functional

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beverages, and fortified foods in large numbers. They are also included in the form of encapsulations to become stable, bioavailable as well as controlled release. The products that are made up of anthocyanins as nutraceuticals are getting a growing popularity due to their ability to promote good health, which includes cardiovascular protection, anti-aging effects, as well as immune support [16].

VII. ANTHOCYANIN IN SMART AND ACTIVE PACKAGING

7.1. pH-sensitive colour indicators

The anthocyanins are extensively utilized as a natural plant colour indicator of pH because it is a colour that can change depending on the change in pH. This effect is explained by structural changes of anthocyanin molecules at various acidic and alkaline pHs to produce colour changes of red to purple to green or yellow. These properties render anthocyanins very appropriate in the packaging materials as an indicator of the changes in the quality of food in the visual form [21].

7.2. Intelligent packaging system

Intelligent packaging systems are constructed on the principle of anthocyanin and they are used to monitor and give real time information on the status of the packaged food. Such systems incorporate anthocyanins into films or labels which react to environmental variations, e.g. pH, temperature, or gas composition. The colour alterations serve as an indicator to the consumer as they enhance the safety of food and minimize the use of expiration dates [15].

7.3. Food Fresheners Monitoring

In the freshness monitoring of foods, anthocyanins are essential in identifying any spoilage changes especially in perishable foodstuff such as meat and seafood. The decomposition of food results in the liberation of volatile compounds which changes the pH of the package causing a colour change in anthocyanin-based colour indicators to appear. This gives a non-invasive, easy procedure of determining freshness and eliminates the consumption of stale food [13].

7.4. Biodegradable Packaging Films

Bio-polymers like starch, chitosan, or gelatine can be used to manufacture biodegradable films with anthocyanins to advance the production of eco-friendly packaging materials. These films do not only minimize the environmental impact, but also offer functional advantages including antioxidant activity and colour changes at different pH. Anthocyanins have also been incorporated to increase the functionality of biodegradable packaging, hence suitable in sustainable food packaging usages [6].

VIII. ENCAPSULATION AND STABILITY ENHANCEMENT

8.1. Microencapsulation

Anthocyanins have been observed to be widely protected by microencapsulation of light, oxygen and temperature. In this method anthocyanins are encased with a protective layer material (e.g. maltodextrin, gum arabic or proteins), to form micro sized particles. Spray drying, freeze drying and coacervation are some of the methods that are frequently used. Microencapsulation enhances stability, solubility and controlled release of anthocyanins in food systems, making them the right choice in other applications [14].

8.2. Nanoencapsulation

Nanoencapsulation implies the inclusion of anthocyanins into the following types of nanoparticles: liposomes, nano emulsions, or polymeric nanoparticles. The small size and high surface area contributes to the increase in bioavailability, absorption and stability of anthocyanins by this method. Nanoencapsulation is also promising as it can be targeted as well as controlled at release and thus is very promising in advanced functional foods and nutraceuticals [8].

8.3. Improvement of shelf life and colour retention

The encapsulation methods are also important in improving the shelf life and colour stability of anthocyanins in food products. These ways protect the pigments against unfavourable environmental conditions, e.g., pH, temperature, and light exposures all of which would result in the rapid breakdown of anthocyanins by enclosing them in protective carriers. Besides aiding the preservation of the colourful qualities that the anthocyanins provide to foods, this protective barrier also allows the maintenance of the valuable antioxidant qualities of foods during storage. This is more crucial in processed food products, where otherwise it is the anthocyanins that receive huge losses as a result of poor processing and storage environments. Consequently, food manufacturers have begun to embrace encapsulation as the hardest approach in maximizing the visual appeal and

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functional value of the anthocyanin-enriched products to ensure that the consumer experience the aesthetic and health promoting value of the natural pigments on the shelf life of the product [11].

IX. CHALLENGES AND LIMITATIONS OF ANTHOCYANINS IN FOOD APPLICATIONS

9.1. Stability issues

Anthocyanins are naturally found pigments, which are characterised by their colourful nature and possible health values, although inherently unstable and very sensitive to any environmental conditions. PH, light exposure, oxygen presence, temperature, and change may severely affect the stability of such compounds. The chemical structure of anthocyanins are likely to be degraded when they are exposed to such conditions as food processing or storage. The loss of the intensity of the colour and loss of their biological activity caused by this breakdown make them less effective. The anthocyanins are not very stable, which is the greatest limitation of using them in food industry especially as natural colorants and functional ingredients. Although they have the desirable properties, they are sensitive to environmental conditions and are therefore limited in the use in products that need long shelf life or subjected to different processing conditions hence presenting a challenge to manufacturers who want to find a natural substitute to synthetic additives[18].

9.2. Sensitivity to Processing Conditions

The anthocyanins are particularly susceptible to the common food processing characteristics such as exposure to heat, variation in pH, as well as exposure to oxygen. Thermal treatments, e.g. pasteurization, baking, can significantly reduce the amount of anthocyanin as well as alter their characteristic colour. Such reactions may cause disruption of anthocyanin complex, and loss of visual appeal and possible health benefits could be achieved. In addition to that, the anthocyanins are capable of interacting with other food matrix constituents including proteins, enzymes and metal ions and may also weaken them further reducing their stability and functionality. Such reactions can also proceed to further degrade or undergo chemical reactivity leading to an alteration in the functional properties of the pigment. Therefore, preservation of anthocyanins in food processing and storage has been a major obstacle and constraint to the use of anthocyanins as natural colour additives and health-promoting constituents in most food products[11].

9.3. Regulatory Challenges

The inclusion of anthocyanins in food products is governed differently in different countries and regions and this provides a complicated approval environment. The regulatory agencies might have their specific requests in terms of standardization, safety tests, and labelling that might make the commercialization process challenging. Compliance of anthocyanin-containing products with these varied standards often requires a lot of testing and documentation which makes them more expensive to manufacturers. Furthermore, the lack of uniformity in the regulation of natural colorants worldwide is another source of complication, since manufacturers need to adjust their formula and labelling to comply with certain local standards. This disharmonization can restrict the possibility of companies promoting anthocyanin products on the foreign market and can also deter investments towards developing this type of products. Consequently, the challenge of manoeuvring through the different regulatory regimes poses a great challenge towards the popularisation and acceptance of anthocyanins as natural food colourants in the international market [4].

X. FUTURE PERSPECTIVES OF ANTHOCYANINS IN FOOD SYSTEMS

Future innovations in the anthocyanin uses are aimed at creating new food stuffs that have better functionality and appearance. These comprise smart drinks, functional foods and interactive food that takes advantage of colour changing capabilities of anthocyanins. This is likely to enhance their stability and increase their application in various food matrices with the advancements in encapsulation and formulation techniques[10]. To fulfill the ambitions of anthocyanins to be transferred to industrial-level processes, it has to be more efficient in extraction, stable and economical. One of the issues is to scale up production processes without compromising quality and consistency. Advanced processing and encapsulation technologies are likely to be developed further, and they will be useful in industrial-wide food and packaging applications [18].Regardless of the research conducted, there are still some gaps in the knowledge of the stability, bioavailability, and interaction of anthocyanins in

complex food systems. Further optimization of conditions of processing and enhancement of long-term stability as well as testing their health benefits via clinical trials are required. Moreover, the extraction and application procedures should be standardized in order to achieve the same results in all studies [8].

XI. CONCLUSION

Plant and flower derived anthocyanin has also become a promising natural colorant in the food industry with much potential. They have been useful ingredients in many types of food products due to their capacity to offer colourful hues and other useful functions like antioxidant and anti-inflammatory properties as well as health-promoting functionality. Use of anthocyanins has been found in the beverage industry, dairy, bakery, confectionery as well as staple foods, with all indicating the versatility of anthocyanins and increased acceptance among consumers as natural substitutes to artificial preservatives. Besides food systems, anthocyanins have been of tremendous potential in smart and active packaging technology because of their colour change capacities of pH-sensitivity, which allow real-time monitoring of food freshness and quality. Their stability, bioavailability, and shelf life have been further enhanced with the advancement of encapsulation methods, such as microencapsulation and nanoencapsulation, in order to overcome some of the biggest challenges that are linked to their usage. Nevertheless, the instability during processing conditions, high production costs and regulatory restrictions remain as an impediment to their large-scale application in the industry. These restrictions notwithstanding, current research and technological advances are opening the doors to sustainable production processes, better methods of processing and increased use. Although the evidence presented above is not exhaustive, anthocyanins are a flexible and efficient solution to the creation of safer, healthier and more innovative food systems. Their role in the food industry and the functional food development will be enhanced further in future by stability enhancement studies and large scale production and clinical validation of health benefits.

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