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Natural Food Colorant Stability: Factors, Challenges, and Enhancement

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Introduction

The exploration of natural food colorants has gained significant momentum, driven by consumer demand for healthier and more sustainable alternatives to synthetic dyes. These natural pigments, derived from diverse botanical and microbial sources, offer vibrant hues while often providing beneficial bioactive properties. However, their application in food products is frequently challenged by their inherent instability, which can lead to undesirable color loss and shifts during processing and storage. This review synthesizes current research into the stability of various natural colorants, highlighting the factors that influence their degradation and the strategies employed to enhance their longevity and functional performance. The stability of anthocyanins from beetroot and their susceptibility to pH and temperature variations are extensively studied, revealing significant degradation under certain conditions [1].

Anthocyanins, found in a wide array of fruits and vegetables, are particularly recognized for their broad spectrum of colors, ranging from red to blue. Research has focused on specific sources like black rice and butterfly pea flower, comparing their stability profiles and potential applications. While both offer attractive colors, differences in their sensitivity to pH changes necessitate careful formulation for different food matrices [2].

Carotenoids, another major class of natural colorants, are responsible for yellow, orange, and red colors in many foods. Annatto seeds, a rich source of carotenoids, have been investigated for their stability under thermal processing and light exposure. Findings indicate that while heat resistance is moderate, photodegradation is a significant concern, prompting research into protective measures [3].

Betalains, found in plants like red pitaya, present a unique set of stability challenges. Betacyanins, the red pigments, are notably sensitive to pH fluctuations and elevated temperatures, impacting their suitability for certain food applications. Understanding their degradation pathways is crucial for effective utilization [4].

Purple sweet potato is a valuable source of anthocyanins, and studies have examined their stability and bioaccessibility following various food processing techniques. Methods such as spray drying and microencapsulation have shown promise in improving pigment retention against enzymatic and chemical degradation [5].

Lycopene, a prominent carotenoid found in tomatoes, is widely used as a natural red colorant. Its stability in different food systems under various processing and storage conditions is a critical area of research. While relatively heat-stable, lycopene is susceptible to oxidation and photodegradation, necessitating stabilization strategies [6].

Phycocyanin, a vibrant blue pigment derived from Spirulina algae, offers excellent color and antioxidant properties. However, its stability is highly dependent on pH, temperature, and light exposure, with optimal performance observed within a specific pH range and significant degradation occurring under adverse conditions [7].

Red cabbage is a rich source of anthocyanins, and research has investigated the impact of processing methods on pigment stability. Thermal processing and drying techniques significantly influence color retention, with pH playing a crucial role in preserving the integrity of these compounds [8].

Turmeric and paprika are well-known for their natural colorants, curcuminoids and capsanthin, respectively. Studies on their stability during processing and storage reveal varying degrees of susceptibility to factors like pH, heat, and oxidation, underscoring the need for formulation strategies to enhance their shelf-life [9].

Lutein, a yellow carotenoid extracted from marigold flowers, is another important natural colorant. Its stability in food matrices is influenced by processing, pH, and the presence of oxygen and light. Stabilization through co-formulation with antioxidants and modified atmosphere packaging is actively explored to maintain its color and efficacy [10].

Description

The stability and degradation kinetics of natural food colorants derived from sources such as beetroot and curcumin have been thoroughly investigated. These studies highlight that anthocyanins, particularly those from beetroot, undergo significant degradation when exposed to increasing pH levels and higher temperatures. Conversely, curcuminoids demonstrate better stability under acidic conditions but are prone to photodegradation. The findings propose optimal processing parameters and packaging strategies to enhance the shelf-life and color intensity of these natural colorants [1].

The evaluation of antioxidant activity and color stability of anthocyanins extracted from black rice and butterfly pea flower reveals distinct characteristics. While both sources yield vibrant colors, anthocyanins from butterfly pea flowers are more sensitive to pH variations, leading to observable color shifts. Anthocyanins from black rice exhibit greater stability in neutral to slightly acidic environments, making them versatile for a wider range of food applications. The research also touches upon the protective benefits of encapsulation in maintaining pigment stability [2].

Research focusing on the impact of thermal processing and light exposure on carotenoids from annatto seeds indicates their relative stability under heat. However, prolonged exposure to UV and visible light significantly diminishes their color intensity. The study explores the potential use of co-pigments and antioxidants to mitigate light-induced degradation, offering pathways for improved color preservation in food systems [3].

The color stability of betalains, specifically betacyanins from red pitaya fruit, under different pH and temperature conditions relevant to food processing has been assessed. Betacyanins are found to be more susceptible to elevated pH and high temperatures compared to betaxanthins. The research further elucidates degradation pathways and the influence of metal ions on betalain stability, providing valuable insights for their incorporation into acidic beverages and dairy products [4].

Studies examining the color and bioactivity retention of anthocyanin-rich extracts from purple sweet potato after simulated digestion and within model food systems highlight the substantial effect of processing methods. Techniques like spray drying and microencapsulation have proven effective in enhancing the stability of these pigments against enzymatic and chemical degradation. Encapsulation using maltodextrin and gum arabic demonstrates considerable success in preserving both color intensity and antioxidant capacity [5].

The stability of lycopene from tomato paste under various processing and storage conditions has been explored. Lycopene exhibits reasonable stability to heat; however, oxidation and light exposure are significant contributors to its degradation, resulting in color loss and a shift towards yellow hues. The research investigates strategies for its stabilization, including its inclusion in oil-based systems and the addition of antioxidants [6].

The color stability and bioactivity of phycocyanin extracted from Spirulina platensis in response to pH, temperature, and light have been investigated. Phycocyanin shows optimal stability within a pH range of 5.0-6.0 and is highly prone to degradation at low pH and elevated temperatures. Light exposure, particularly at longer wavelengths, also leads to considerable color loss. The study emphasizes the importance of encapsulation and formulation adjustments for its successful application in food products [7].

The influence of processing methods, including blanching, drying, and milling, on the stability of pigments in red cabbage has been examined. Anthocyanins, the primary colorants, are significantly affected by processing temperature and duration, with degradation observed during extensive heat treatment. Drying methods like freeze-drying and air-drying demonstrate varying impacts on color retention, and pH plays a critical role, with best retention observed in acidic conditions [8].

An evaluation of the color stability of natural colorants from turmeric (curcuminoids) and paprika (capsanthin) during thermal processing and storage reveals their behavior. Curcuminoids are stable at low pH but susceptible to photodegradation, while capsanthin is relatively heat stable but can be affected by oxidation. The research explores the use of co-pigmentation and encapsulation to improve the stability of these colorants [9].

Research on the stability of lutein from marigold flowers in various food matrices considers the impact of processing temperatures, pH, and the presence of other food components. Lutein's stability is notably influenced by oxygen and light, leading to isomerization and degradation. The study investigates methods to enhance its shelf-life and maintain its yellow color, such as co-formulation with antioxidants and storage under modified atmosphere packaging [10].

Conclusion

This collection of studies examines the stability of various natural food colorants, including anthocyanins (from beetroot, black rice, butterfly pea flower, red cabbage, purple sweet potato), carotenoids (curcuminoids from turmeric, capsanthin from paprika, lycopene from tomato, lutein from marigold), betalains (from red pitaya), and phycocyanin (from Spirulina). Key factors affecting their stability are identified as pH, temperature, light exposure, and oxidation. Many pigments exhibit sensitivity to high temperatures and alkaline pH, while others degrade under UV light or oxidative conditions. Strategies such as microencapsulation, co-pigmentation, the use of antioxidants, and modified atmosphere packaging are frequently proposed to enhance their shelf-life and color intensity in food applications.

Acknowledgement

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Conflict of Interest

None.

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