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A review on betacyanins and anthocyanins as water-soluble pigments in nanotechnology-based natural cosmeceutical formulations

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ABSTRACT

Many cosmetic products, such as lipsticks, often use synthetic dyes that have raised safety concerns. As a result, natural pigments with antioxidant properties are preferred in cosmeceutical formulations as safer alternatives. Betacyanins and anthocyanins are both two water-soluble natural pigments known for their potent antioxidant activity. However, these pigments are sensitive and can degrade quickly when exposed to heat, pH changes, or light during formulation processes. Natural pigments often show limited stability in cosmetic formulations. To address this issue, advanced technologies, such as nanocarrier-based delivery systems (e.g., liposomes, nanoemulsions, and polymeric nanocapsules), have been investigated to improve pigment retention and functionality. These have been combined with betacyanin and anthocyanin pigments to evaluate improvements in stability and antioxidant activity. Studies show that integrating these pigments with nanoparticles significantly reduces degradation and preserves their antioxidant effects. Nanotechnology presents a promising approach for enhancing their robustness in cosmeceutical formulations. Nevertheless, variability in pigment source, formulation scalability, and regulatory evaluation remains a challenge for clinical translation. In conclusion, this review highlights the potential of betacyanins and anthocyanins as natural pigments and the role of nanotechnology in enhancing their use in safer, more stable cosmetic formulations.

Keywords: *Betacyanins; anthocyanins; natural pigments; nanotechnologies and cosmeceutical formulations*

INTRODUCTION

Cosmetic products are designed for application on the human body to enhance appearance and attractiveness (Alnuqaydan, 2024; Nduka et al., 2019). Colouring agents are commonly incorporated into cosmetic formulations to improve visual appeal and attract consumers, contributing to the successful marketing of these products (Monisha et al., 2023). Traditionally, most colourants used in cosmetics are synthetic dyes such as xanthone, quinoline, and azo dyes (Mohana Priya et al., 2020). However, concerns about their safety and the environmental impact have increased in recent decades. Some studies have reported that certain dyes used in cosmetic products may cause adverse reactions, such as skin irritation, allergies, and dermatitis, in sensitive individuals (Chahine et al., 2023; Kumari et al., 2023). In particular, some azo compounds have been associated with toxicological risks because they may degrade into aromatic amines that can be allergenic or carcinogenic, leading to regulatory restrictions in several countries (Barciela et al., 2023; Guerra et al., 2018; International Agency for Research on Cancer, 2010). Additionally, the non-biodegradable nature and potentially harmful degradation products of some dyes have raised environmental concerns.

In response to these issues, natural pigments have gained increasing attention as potential alternatives to synthetic dyes. These pigments are derived from biological sources such as plants, microorganisms, and animals. Natural pigments are generally regarded as safer and more biocompatible than many synthetic dyes, although their safety still depends

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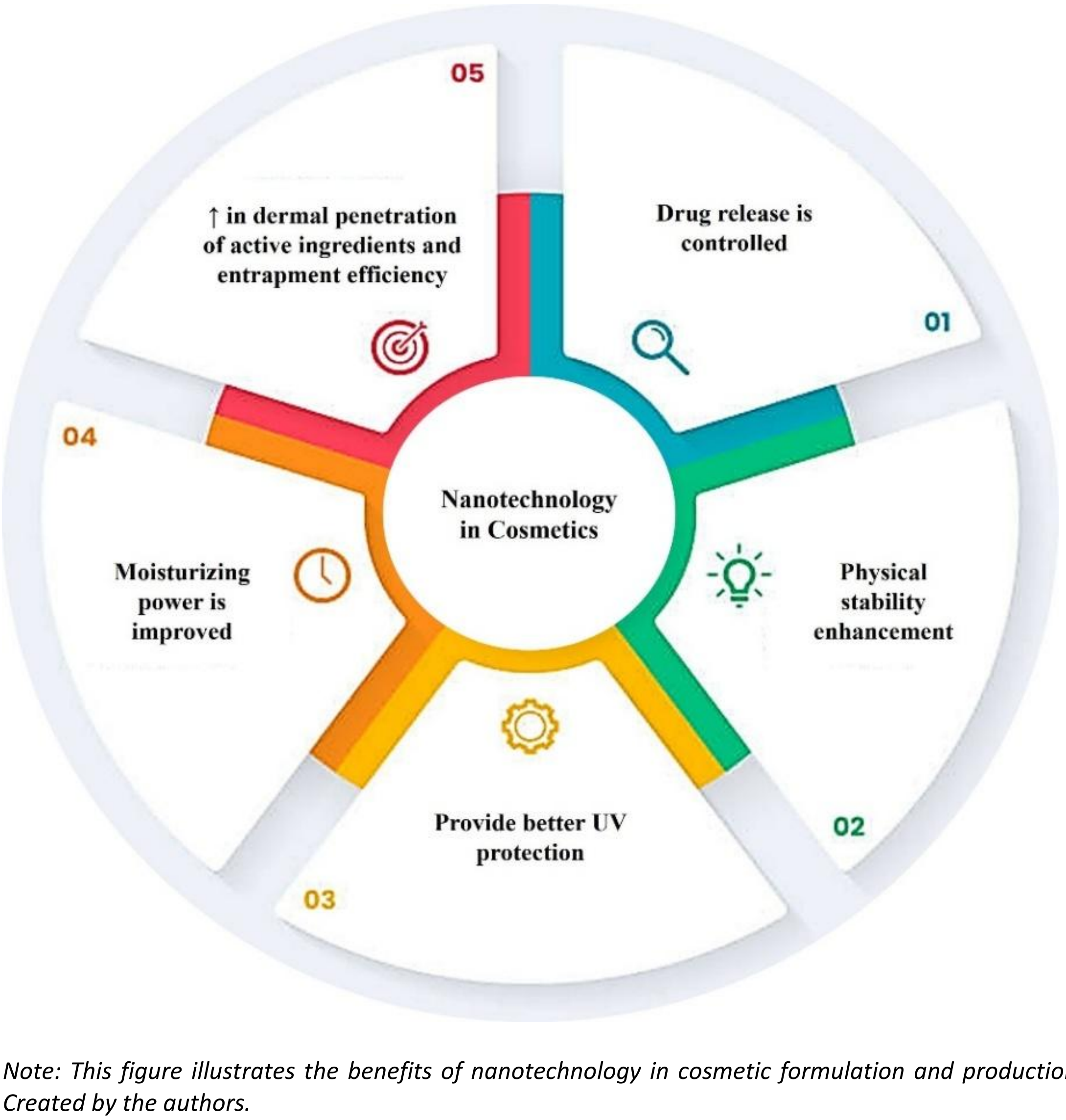
on sources, dose, and processing (Guerra et al., 2018). Consequently, they have been explored for applications in food, pharmaceutical, textile, and cosmetic industries (Brudzyńska et al., 2021). However, natural pigments such as betacyanins and anthocyanins face several challenges, including low colour yield, limited availability, poor robustness, and complex processing and formulation (Klavins et al., 2026). These limitations hinder their wider use in cosmetic formulations, as their susceptibility to degradation and high-water solubility can result in colour fading, shortened shelf life, and poor compatibility with oil-based products such as lipsticks and skincare formulations (Negi, 2025).

Betacyanins and anthocyanins are important water-soluble pigments responsible for red, purple, and blue colouration in many plants. Betacyanins are commonly found in plants such as beetroot, while anthocyanins are widely distributed in fruits and flowers. Interestingly, these two pigment classes are mutually exclusive and have not been found together in the same plant species (Gandía-Herrero et al., 2016). Despite their promising potential as natural colourants in cosmeceutical products, these pigments are sensitive to environmental factors, including light, temperature, oxygen, and pH, which may cause degradation and colour loss during processing and storage.

To overcome these limitations, nanotechnology-based delivery systems have been explored to improve the durability and functionality of natural pigments in cosmetic formulations. Technologies such as nanocarriers (e.g., liposomes, nanoemulsions, and polymeric nanocapsules) can enhance pigment retention, protect them from environmental degradation, and improve their performance in cosmeceutical products (Zhao et al., 2021; Salvioni et al., 2021). Figure 1 illustrates the role of nanotechnology in cosmetic formulation and production, while Figure 2 shows four categories of plant pigments and their respective sources. Therefore, this review aims to summarise the properties and limitations of natural pigments, particularly betacyanins and anthocyanins, and discuss the potential role of nanotechnology-based delivery systems in improving their stability and application in cosmeceutical formulations.

Figure 1

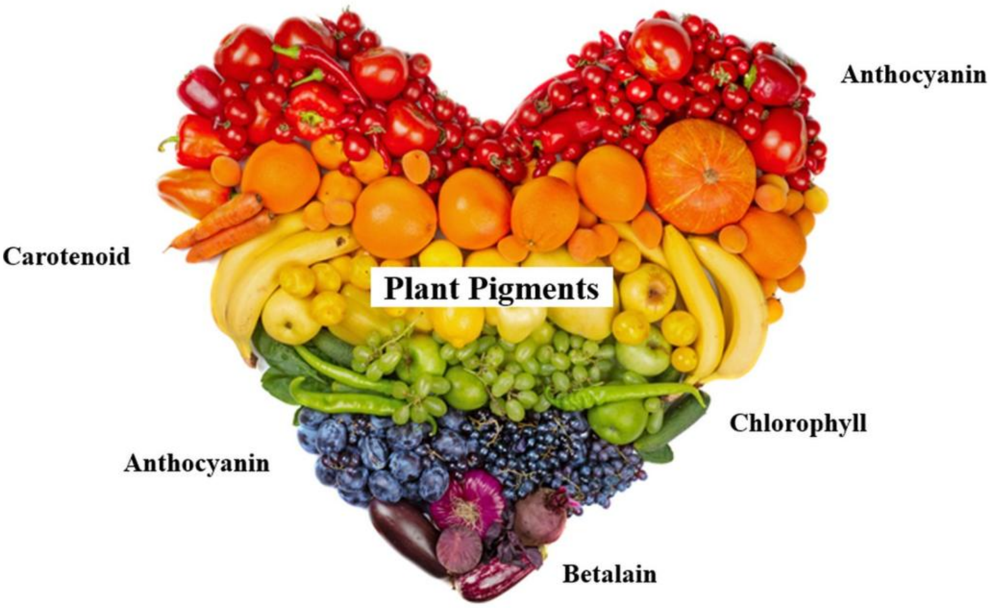
Beneficial role of nanotechnology in cosmetics formulation and production.



Note: This figure illustrates the benefits of nanotechnology in cosmetic formulation and production. UV: ultraviolet. Created by the authors.

Figure 2

Four categories of plant pigments and their respective sources.



Note: This figure depicts four plant pigment groups, such as anthocyanins, carotenoids, betalains, and chlorophylls, and their sources (NsDesing, 2024).

OVERVIEW OF NATURAL PIGMENTS

Natural pigments are colour-producing compounds widely distributed in plants and other biological sources. In plants, these pigments play important roles in physiological processes such as photosynthesis, photoprotection, and attraction of pollinators and seed dispersers (Lu et al., 2021; Muhammad et al., 2025). Based on their chemical structure, plant-derived pigments are generally classified into several major groups, including anthocyanins, carotenoids, betalains, and chlorophylls, which are responsible for a wide range of colours observed in plants (Muhammad et al., 2025). Anthocyanins typically produce red to blue hues, carotenoids contribute yellow to orange colours, betalains generate red to violet tones, and chlorophylls impart green pigmentation (Ghosh et al., 2022).

Natural pigments can also be categorised into lipid-soluble and water-soluble pigments (Yin et al., 2023). Lipid-soluble pigments include carotenoids and chlorophylls, which are commonly associated with lipid-containing cellular structures. In contrast, anthocyanins and betalains are water-soluble pigments that are typically stored in plant vacuoles (Magalhães et al., 2024). The way these pigments dissolve affects their consistency, extraction efficiency, and suitability for various product formulations.

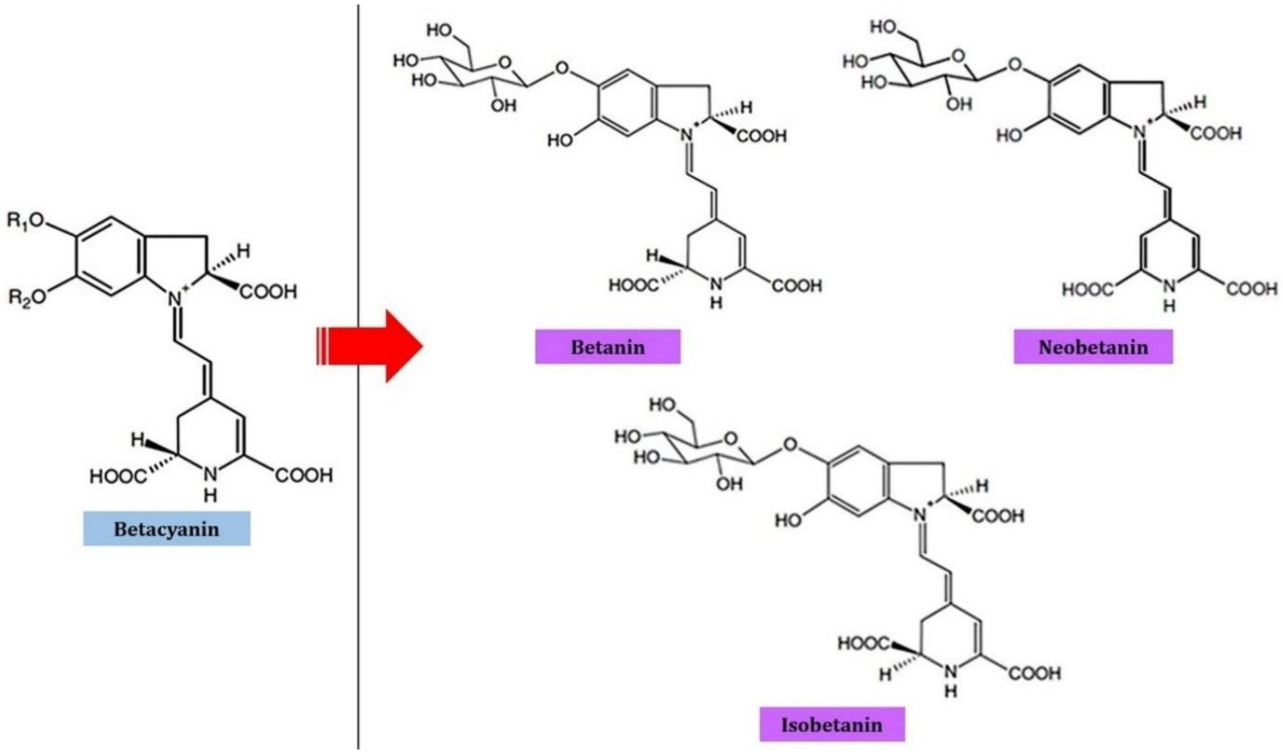
Beyond their colouring properties, many natural pigments exhibit additional functional benefits, such as antioxidant, antimicrobial, and photoprotective activities, which have increased interest in their use in food, pharmaceutical, and cosmetic applications (Klavins et al., 2026; Sharma et al., 2022). Among these pigments, anthocyanins and betacyanins are of particular interest due to their vibrant colouration, water solubility, and potential multifunctional properties. Consequently, these pigments have been increasingly explored as natural alternatives to synthetic colourants in cosmeceutical formulations.

Betacyanins and anthocyanins

Betalains are nitrogen-containing pigments that are divided into two main categories: betacyanins, which produce red to violet colours, and betaxanthins, which generate yellow to orange tones (Negi, 2025). Betacyanins are particularly valued for their intense colour and antioxidant properties. These pigments are commonly found in plants such as red beetroot (*Beta vulgaris* L.) and dragon fruit, especially *Hylocereus polyrhizus* (Martinez et al., 2024). Chemically, betalains are derived from betalamic acid, which serves as the central structural component of these compounds. Betacyanins are formed through the condensation of betalamic acid with cyclo-3,4-dihydroxyphenylalanine (cyclo-DOPA), while betaxanthins result from the interaction between betalamic acid and amino acids or amine groups (Sadowska-Bartosz & Bartosz, 2021). The extensive conjugated structure of betalains enables them to absorb visible light, producing their characteristic bright colours (Sadowska-Bartosz & Bartosz, 2021) (Figure 3).

Figure 3

Chemical structures of betacyanins



Note: This figure illustrates the chemical structures of the main betalain subclasses. Betalamic acid, the common precursor of betalains, gives rise to betacyanins (red/purple), formed by conjugation with cyclo-DOPA groups. Examples of betacyanins include betanin, isobetanin, and neobetanin. COOH: carboxyl group; HOOC: carboxylic acid group; cyclo-DOPA: cyclo-3,4-dihydroxyphenylalanine (Khan et al., 2016).

Anthocyanins belong to the flavonoid class of phenolic compounds and are generally present as glycosylated molecules. They are responsible for the red, purple, and blue pigmentation observed in many fruits and vegetables, including berries, grapes, currants, and several tropical fruits (Farheen et al., 2025). These pigments are widely distributed across plant tissues, including flowers, leaves, stems, and fruits. The colour displayed by anthocyanins varies with pH, appearing red under acidic conditions and shifting toward purple or blue at higher pH (Li et al., 2023). Structurally, anthocyanins possess a flavonoid backbone containing a positively charged oxygen atom within the *C*-ring. In purple sweet potato (*Ipomoea batatas* L.), for example, they can be categorised into monoacetylated derivatives, such as cyanidin-based compounds, and diacetylated derivatives, including peonidin-based compounds (Li et al., 2019) (Figure 4). Pomegranates (*Punica granatum*) are also well known for their high anthocyanin levels, primarily due to compounds such as delphinidin-3,5-diglucoside, cyanidin-3,5-diglucoside, and pelargonidin-3,5-diglucoside, which are responsible for their strong antioxidant activity (Gardeli et al., 2019). Notably, malvidin, peonidin, and petunidin occur less frequently than cyanidin-based glycosides, possibly due to their lower biosynthetic prevalence or greater susceptibility to degradation within berries (Khoo et al., 2017).

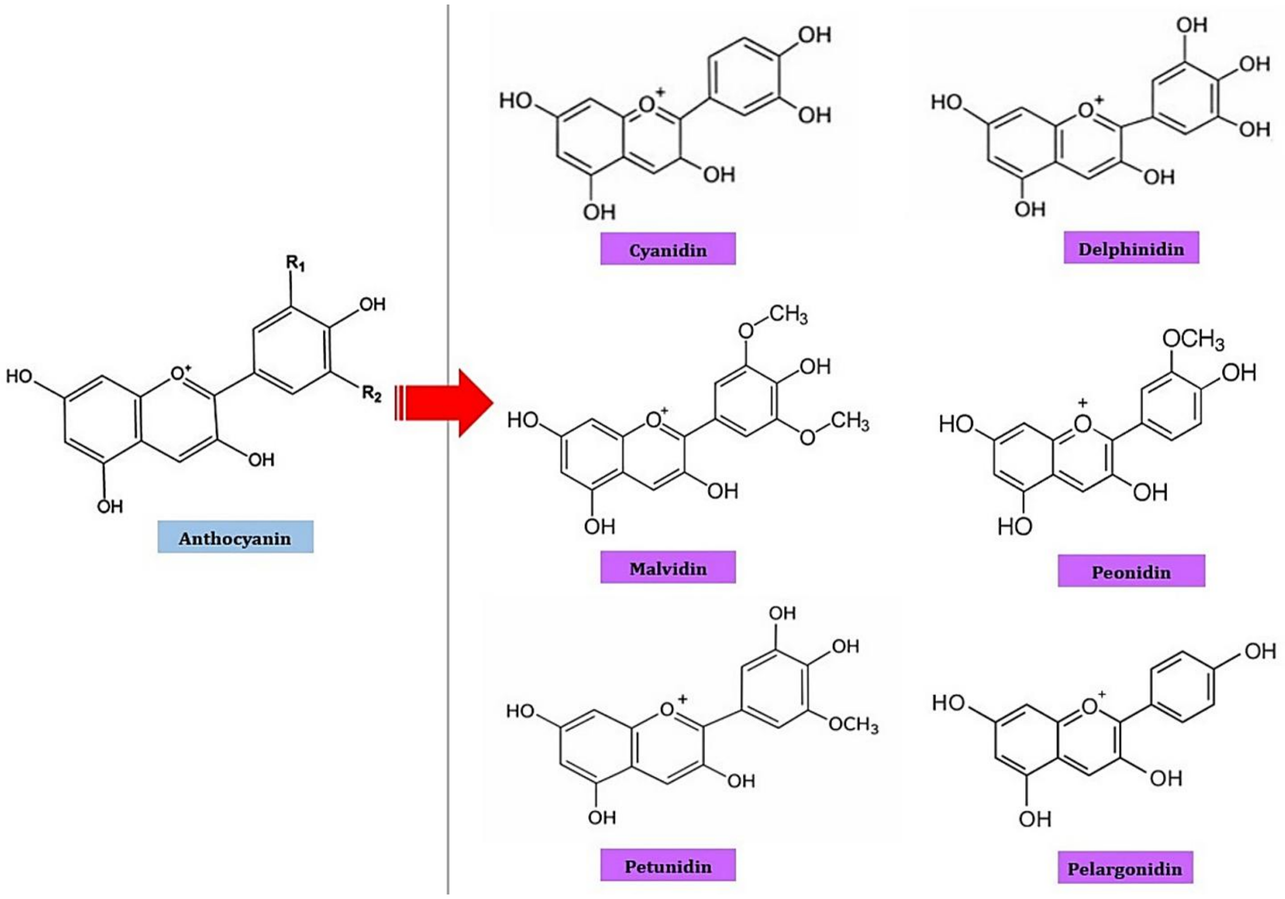
Due to their vivid colouration, water solubility, and diverse biological activities, betacyanins and anthocyanins have attracted considerable interest as natural alternatives to synthetic colourants in cosmetic and cosmeceutical formulations. However, both pigment groups are highly sensitive to environmental conditions. Exposure to factors such as temperature, oxygen, light, pH changes, and moisture can accelerate pigment breakdown, leading to colour fading and reduced integrity during processing and storage (Masyita et al., 2025). Understanding how these pigments respond under different conditions is therefore crucial for their effective use in cosmetic formulations.

Key factors affecting the physicochemical stability of natural pigments

Although natural pigments possess numerous beneficial properties, their wider application in cosmeceutical formulations is often constrained by limitations such as poor robustness and low bioavailability, which may reduce their effectiveness in cosmetic products (Nabi et al., 2023). The stability of pigments such as betacyanins and anthocyanins is influenced by several environmental factors, including pH, storage temperature, light exposure, oxygen, solvents, and metal ions (Khoo et al., 2017). Under unfavourable conditions, particularly in systems with high water activity, interactions among variables such as temperature, moisture, oxygen, and sulphur dioxide can accelerate pigment discolouration and degradation (Dhiman et al., 2021; Enaru et al., 2021). Numerous studies have investigated how these parameters affect pigment behaviour. For instance, Perez et al. (2022) evaluated the physicochemical properties and antioxidant capacity of purple carrot extracts across a pH range of 2.5-7.0 and temperatures between 4-40°C, reporting reduced anthocyanin degradation at lower temperatures and under acidic conditions. These findings highlight the importance of understanding the environmental conditions that influence pigment integrity during formulation and storage, as variations in these factors may lead to colour fading, reduced antioxidant activity, and diminished functional performance in cosmetic products. The following subsections discuss the key environmental factors, such as temperature, pH, and light exposure, that influence the physicochemical integrity of natural pigments.

Figure 4

Chemical structures of anthocyanins



Note: This figure illustrates the structure of naturally occurring anthocyanins. OCH_3: methoxy group; OH: hydroxyl group; O: oxygen (Lakshmikanthan et al., 2024).

Temperature

Temperature plays a key role in affecting the integrity and breakdown of natural pigments. Sadowska-Bartosz and Bartosz (2021) reported that pigment samples degraded in a thermostat at 75°C under aerobic conditions without light exposure exhibited notable changes in betacyanin properties. During thermal degradation, the red colour of betacyanins gradually fades to yellowish-brown at around 100°C as a result of heat-induced reactions such as hydrolysis, decarboxylation, and auto-oxidation (Cai et al., 1998; Lombardelli et al., 2021). The impact of heat treatment may also vary depending on the heating method and exposure time. For example, Ravichandran et al. (2013) observed that microwave heating at 900 W for 30 seconds increased the antioxidant activity of beetroot betacyanins, whereas boiling at 100°C reduced betacyanin content. Similarly, Bassama et al. (2021) reported that heating at 90°C reduced total phenolic content and antioxidant activity by up to 50%, although a slight increase in betaxanthin content was detected. Moreover, betacyanin concentration has been shown to decrease progressively with heating time, particularly at elevated temperatures. Rapid degradation was observed at 70°C and 80°C, where pigment retention dropped below 30% within the first 20 minutes. At 80°C, the remaining pigment concentration declined to approximately 20% after 20 minutes and remained low throughout a 120-minute heating period, highlighting the high thermal sensitivity of betacyanins (Sari et al., 2026). Lower temperature conditions have been widely reported to be more favourable for pigment retention. This phenomenon may occur because betalain degradation can yield phenolic compounds that enhance antioxidant activity.

In addition to betacyanins, anthocyanins are also highly susceptible to thermal degradation. Because anthocyanin degradation is an endothermic process that is strongly influenced by temperature, elevated temperatures can accelerate several degradation reactions, including glycosylation, nucleophilic attack by water, cleavage, and polymerisation, ultimately resulting in pigment loss (Rodriguez-Amaya, 2019; Sendri et al., 2023). For example, Luna-Vital et al. (2017) reported that anthocyanin content in grape extracts decreased by more than half when heated at 35°C compared with samples stored at 25°C, accompanied by a colour shift from red to orange at approximately 40°C. Marangoni Júnior et al. (2020) further demonstrated that increasing temperatures between 60 and 90°C significantly accelerated anthocyanin degradation in açaí pulp. Consistent with these findings, high-temperature processing such as frying has been reported to reduce anthocyanin content in eggplant by up to 84%, highlighting the strong thermal sensitivity of these pigments (Wang et al., 2024). Overall, previous studies have established that increasing temperature accelerates pigment degradation, resulting in reduced pigment concentration and noticeable colour changes.

pH

The integrity of betacyanins is strongly affected by pH levels and storage conditions. Unlike anthocyanins, betacyanins exhibit relatively good colour retention within a wide pH range in food matrices (Guneser, 2021). For example, Vieira Teixeira da Silva et al. (2019) reported that betacyanins remained stable for approximately 20 days at pH 7 when stored at 4°C and could be preserved for more than 275 days under frozen conditions at -30°C. Other studies have also indicated that betacyanin retention is slightly higher at pH 5 compared with pH 3 or pH 7 (Woo et al., 2011). Although betalains are generally stable across a broad pH range of approximately 3-7, betacyanin pigments are generally more resilient in mildly acidic environments, particularly between pH 4 and 6, with optimal pigment retention often observed around pH 4-5 (Carreón-Hidalgo et al., 2022; Fu et al., 2020). Under these conditions, proton dissociation from intermediate molecules occurs more gradually than in neutral or alkaline environments, thereby slowing pigment degradation. In contrast, strongly acidic conditions (pH <4) may accelerate betacyanin degradation due to changes in the underlying reaction mechanism (Havlíková et al., 1985).

The colour behaviour and structural integrity of anthocyanins are also highly influenced by pH, as they exist in ionic forms (Xue et al., 2024). Anthocyanins typically appear red in acidic media, shift toward purple at near-neutral pH, and develop darker or bluish tones as the pH increases (Zhao et al., 2019). In general, these pigments are more stable under acidic conditions, whereas alkaline environments promote pigment degradation. At very low pH values (pH 1-2), anthocyanins often exhibit higher pigment concentrations and more intense colouration (Jiang et al., 2019; Zhao et al., 2019). Similarly, Chua et al. (2024) reported that strongly acidic conditions (pH 1.5) significantly enhanced anthocyanin extraction from jaboticaba berries using ultrasound-assisted extraction, indicating that acidic environments promote pigment retention and colour intensity (Chua et al., 2024). Overall, maintaining appropriate pH conditions is essential for preserving pigment and colour quality. Betacyanins typically maintain their colour more consistently across a wider pH range, whereas anthocyanins are more susceptible to pH changes, leading to notable structural shifts and colour variations. Besides pH, environmental conditions such as light exposure can further affect pigment integrity and contribute to their degradation.

Light exposure

Light exposure is another important environmental factor affecting the integrity of natural pigments. Both betacyanins and anthocyanins pigments are susceptible to light-induced degradation, particularly under ultraviolet (UV) and visible radiation, which can accelerate pigment breakdown through photooxidative reactions (Carreón-Hidalgo et al., 2022; Enaru et al., 2021). Lombardelli et al. (2021) conducted an experimental study on beetroot extracts and reported that betacyanin pigments were more susceptible to degradation under UV-light exposure than under dark storage conditions. Previous studies have shown that betacyanin-containing extracts from red dragon fruit pulp and peel stored in the dark retain higher pigment content than those stored in the light (Abdul Razak et al., 2017). This behaviour is attributed to the sensitivity of the double bonds in the betacyanin molecular structure, which can be disrupted by light, leading to pigment degradation (Reshmi et al., 2012). A study on betacyanins extracted from red dragon fruit (*Hylocereus polyrhizus*) also demonstrated that pigment retention was significantly higher when samples were stored in the dark, whereas exposure to light accelerated pigment degradation through photooxidative reactions (Madzuki et al., 2024). Similarly, betacyanins extracted from red dragon fruit and stored in the dark retained about 70% of their pigment during the first week at 25°C. However, increasing pigment concentration did not significantly affect the degradation rate, suggesting that light exposure plays a more important role in betacyanin degradation (Ling et al., 2020; Wong & Siow, 2015).

For anthocyanins, light plays a dual role by influencing both pigment biosynthesis and degradation. Although light is necessary for anthocyanin production in plants, it can also accelerate pigment breakdown during storage (Guo et al., 2022). For instance, Amogne et al. (2020) observed that only about 30% of anthocyanins degraded when samples were stored in darkness at 20°C, whereas nearly half of the pigment content was lost when the samples were exposed to light under the same temperature conditions. Similarly, Modesto Junior et al. (2023) reported that anthocyanins extracted from Grumixama berries degraded more rapidly under light exposure than in dark storage, highlighting the role of light in accelerating pigment degradation. Besides, exposure to light can reduce the antioxidant capacity of anthocyanin pigments. A significant reduction in both anthocyanin content and antioxidant activity was observed in mulberry fruit stored at room temperature and exposed to fluorescent light for 10 hours (Aramwit et al., 2010). Likewise, Di Stefano et al. (2020) demonstrated that sunlight exposure significantly reduced anthocyanin levels in pomegranate juice due to photochemical degradation. Taken together, these findings suggest that light exposure can accelerate pigment degradation and reduce antioxidant capacity, emphasising the need to minimise light exposure during storage and processing.

Potential cosmetic applications and limitations of natural pigments

Given their vibrant colours and natural origin, betacyanins and anthocyanins have attracted considerable interest for incorporation into cosmetic formulations. In recent years, natural pigments have gained increasing attention in cosmetic products due to growing awareness of the potential adverse effects of synthetic ingredients and the rising demand for cleaner, more environmentally friendly formulations (Pailliè-Jiménez et al., 2020). These pigments have been explored in a variety of cosmetic products, including lipsticks, lip balms, creams, serums, and other skincare formulations, where they may function not only as colourants but also as bioactive ingredients. Betacyanins and anthocyanins are particularly promising because they provide vibrant red to purple hues and exhibit biological activities, including antioxidant and antimicrobial effects (Di Salvo et al., 2023). These properties may contribute to improved skin protection and enhanced formulation performance in cosmetic applications. Despite these advantages, incorporating natural pigments into cosmetic formulations remains challenging. Issues such as colour inconsistency, pigment degradation, and their sensitivity to environmental factors, including light, temperature, and pH, can negatively affect product quality and shelf life (Enaru et al., 2021). Consequently, understanding both the potential applications and the associated limitations of these pigments is essential for their effective utilisation in cosmetic products. Beyond colour cosmetic products, natural pigments have also been explored in topical skincare formulations, such as creams and serum-based products, where their antioxidant properties may enhance skin protection and overall product performance (Mohd Nasir & Mohd-Setapar, 2018).

Several studies have investigated the incorporation of natural pigments such as betacyanins and anthocyanins into lipstick formulations. For example, Lwin et al. (2020) demonstrated that lipstick formulated with betacyanins extracted from red dragon fruit (*Hylocereus polyrhizus)* exhibited strong antioxidant activity (IC_{50} = 22.23 µg/mL), showed no detectable microbial growth, contained 2.9 ppm of lead within the allowable safety limit, and caused negligible skin irritation. Similarly, Ling et al. (2020) evaluated betacyanin-based lipstick derived from red dragon fruit under light and dark storage conditions over a one-month period. The results indicated that products stored in dark conditions retained colour more effectively, while freeze-dried pigments showed better preservation compared with spray-dried pigments, although spray-dried formulations produced colour characteristics closer to those of commercial lipsticks. In another investigation, Sabu et al. (2022) developed herbal lipstick using beetroot pigments and evaluated four formulations (F) with melting points ranging from 56-62°C, pH values between 6.0-6.5, and breaking strengths of 23-30 g. Among these, F4 demonstrated the most favourable performance without causing skin irritation. This optimal formula featured a specific composition of 13 g beeswax, 1 ml castor oil, 5 g beetroot extract, 1 ml coconut oil, 1.0 ml olive oil, and 1 vitamin E. Evaluation of F4 also revealed a melting point of 60-62°C, a pH 6.3, and a breaking strength of 30 g, providing a balance of structural integrity and smooth texture while remaining safe for topical use.

Similarly, Balaguru et al. (2023) developed a vegan lipstick using beetroot-derived pigments that exhibited strong antioxidant activity in the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay and antimicrobial activity against *Escherichia coli* and *Staphylococcus aureus*. Among the samples evaluated, Sample A (the beetroot formulation) was identified as the most effective, featuring a composition of 5 ml beetroot extract, 1.5 g candelilla wax as a vegan binder, 5 ml olive oil, 2.5 ml lime juice, and 2.5 g each of shea and cocoa butter. Phytochemical analysis of this optimal formulation further confirmed the presence of bioactive compounds, including betacyanins, which contributed to its functional performance without the use of synthetic chemicals. In another study, Anilkumar et al. (2020) prepared herbal lipstick formulations containing beetroot pigments and reported that F3 displayed the most desirable cosmetic properties, including good shine, smooth texture, and favourable spreadability, with no observable side effects. This optimal formulation featured a specific composition of 10 g beeswax, 20 g castor oil, 10 g lanolin, 15 ml beetroot extract, 8.5 g shikakai, 6.5 ml eugenol, lemon juice, rose oil, and a few drops of vanilla essence. Evaluation of F3 yielded a melting point of 60-62°C and a pH of 6.5-6.6, passing all stability tests and demonstrating that natural ingredients can achieve a balance of structural integrity and consumer-preferred application characteristics.

In addition to betacyanin-based formulations, anthocyanin pigments have also been investigated in lip cosmetic products. For instance, Łusiak et al. (2025) incorporated grape pomace, a by-product rich in anthocyanins, into lip balm formulations at concentrations of 1%, 3%, and 5%, and found that higher pomace concentrations enhanced both antioxidant activity and colour intensity. Likewise, Aprilia et al. (2025) developed lip cream formulations containing anthocyanin extract from *Clitoria ternatea* at concentrations of 0%, 2%, 4%, and 6%. Among these, the formulation containing 2% extract demonstrated the most favourable performance over 28 days of storage, with viscosity values ranging from 5500 to 13,000 cP, adhesion times of 7.10-26.8 s, and spreadability of 5-7.5 cm. The 2% formulation was chosen as the best because higher concentrations (4% and 6%) made the lip cream too thick (viscosity >40,000 cP) and difficult to apply. The formulations contained butterfly pea extract (2%), candelilla and carnauba waxes, castor oil, cocoa oleum, kaolin, dimethicone, tocopherol, titanium dioxide, phenoxyethanol, and essence. Sai Datri et al. (2022) prepared herbal lipstick using anthocyanins extracted from *Rosa* 'Mister Lincoln', where the formulations exhibited melting points above 50°C and breaking points of 105-110 g, exceeding the commercial standard of 95 g. Among the samples, F9 was identified as optimal, featuring a specific blend of 4.5 g beeswax, 3 g shreeji wax, 6 ml castor oil, 1 ml olive oil, 2 ml rose, and a few drops of lemon juice and fragrance. A short skin-irritation test indicated no adverse reactions, and F9 met all commercial requirements, including pH 6.5 and excellent spreadability, confirming its suitability for lip cosmetic applications. Setyawaty et al. (2020), on the other hand, evaluated lipstick formulations containing anthocyanins from purple sweet potato *(Ipomoea batatas*) and reported a breaking point of 330 g, melting points above 50°C, and pH values between 4 and 6. The formulations maintained their odour and physical shape after 30 days of storage; however, samples containing 2.4-14.6% extract exhibited relatively low colour deposition, which was attributed to pigment degradation associated with the high sugar content in the raw extract.

Beyond lip cosmetic products, natural pigments such as anthocyanins and betacyanins have also been explored in other cosmetic formulations, including topical creams and serum-based skincare products. For instance, bilberry-derived anthocyanins have been incorporated into cream formulations and demonstrated considerable antioxidant activity, suggesting their potential role in skin-protective cosmetic applications (Ștefănescu & Marian, 2023). Likewise, anthocyanin-rich extracts from butterfly pea (*Clitoria ternatea*) have been formulated into facial serum products, which have exhibited promising antioxidant properties that may improve skin condition (Bangar et al., 2025). Recent studies have highlighted the increasing interest in anthocyanins as multifunctional cosmetic ingredients due to their antioxidant and photoprotective effects (Li et al., 2023). Betacyanin-containing plant extracts have also been investigated for use in topical skincare products such as creams and gels. For example, beetroot (*Beta vulgaris*) extract, rich in betacyanin pigments including betanin, has been incorporated into topical gel formulations for cosmetic purposes, such as skin brightening and antioxidant support (Sukmawati et al., 2024). These formulations exhibited favourable physicochemical properties while maintaining the pigment's functional characteristics during storage. Overall, this evidence suggests that anthocyanins and betacyanin-rich plant extracts may serve not only as natural colourants but also as bioactive components in topical cosmetic formulations, including creams and gel-based skincare products.

Collectively, these studies highlight the considerable potential of betacyanins and anthocyanins as natural colourants in cosmetic formulations. Most reported products exhibited acceptable physicochemical characteristics, including suitable melting points, pH values, breaking strength, and spreadability. Many formulations demonstrated beneficial biological activities, including antioxidant and antimicrobial effects, as well as favourable skin compatibility with minimal irritation. Nevertheless, some limitations remain, including colour fading, pigment degradation during storage, and reduced colour deposition in certain formulations. A summary of studies investigating lipstick formulations incorporating betacyanin and anthocyanin as natural pigments is presented in Table 1.

To address these challenges, various formulation strategies have been explored to improve pigment preservation and overall formulation performance. Among these approaches, nanocarrier-based delivery systems such as liposomes, nanoemulsions, and polymeric nanocapsules have shown promising potential for protecting sensitive compounds and improving colour retention in cosmetic products (Gao et al., 2025; Leyva-Gómez et al., 2026). These systems can encapsulate natural pigments and enable controlled release, thereby extending product shelf life and maintaining colour quality. Furthermore, nanocarriers may enhance pigment dispersion and bioavailability, thereby improving formulation performance and product functionality (Dubey et al., 2022). Consequently, integrating nanotechnology into cosmetic formulations represents a promising strategy for expanding the practical applications of natural pigments in lipstick and other cosmetic products. This advancement also supports the development of more sustainable and consumer-friendly cosmetic products derived from natural sources.

Nanotechnology approaches in cosmetic formulations

Cosmeceuticals are formulations containing biologically active ingredients that provide therapeutic benefits upon topical application, distinguishing them from conventional cosmetics. These products offer measurable improvements to the skin and hair and are widely used to address conditions such as wrinkles, photoaging, dryness, pigmentation disorders, and hair damage (Fatima et al., 2020). Positioned between pharmaceuticals and traditional cosmetics, cosmeceuticals aim to enhance appearance while delivering functional benefits. To further improve cosmeceutical performance, recent advances in cosmetic science have increasingly focused on integrating nanotechnology. Nanotechnology-based systems utilise nanoscale materials to improve the effectiveness, robustness, and skin absorption of active ingredients, thereby enhancing overall formulation performance (Gupta et al., 2022). In addition, these systems enable controlled and targeted delivery of active compounds, reducing degradation and prolonging their effectiveness. Nanocarriers also contribute to improved texture and sensory properties, which are critical for consumer acceptance. Furthermore, nanotechnology facilitates the incorporation of poorly soluble compounds, thereby broadening formulation potential. Consequently, it plays a pivotal role in developing innovative, high-performance cosmetic products (Gupta et al., 2022).

Table 1

Studies regarding lipstick formulations using betacyanins and anthocyanins as natural pigments

Authors	Extract	Pigments	Key findings
Sabu et al., 2022	Beetroot	Betacyanins	• Four formulations evaluated; melting point 56-62°C, pH 6.0-6.5, breaking point 23-30 g, softening point 54-57°C, and no skin irritation. • F4 showed the best overall performance. This optimal formula featured a specific composition of 13 g beeswax, 1 ml castor oil, 5 g beetroot extract, 1 ml coconut oil, 1.0 ml olive oil, and 1 vitamin E. • Evaluation of F4 also revealed a melting point of 60-62°C, a pH of 6.3, and a breaking strength of 30 g.
Lwin et al., 2020	Red dragon fruit	Betacyanins	• Exhibited antioxidant activity (IC_{50} = 22.23 μg/mL), met microbial safety standards, contained 2.9 ppm lead within allowable limits, and caused negligible skin irritation.
Ling et al., 2020	Red dragon fruit	Betacyanins	• Lipsticks stored in dark conditions maintained colour better, while greater colour loss occurred under light exposure. Freeze-dried pigments showed better colour retention than spray-dried pigments, although spray-dried formulations produced colours more similar to commercial lipsticks. Due to low pigmentation, the pigments were suggested for lip balm formulations.
Balaguru et al., 2023	Beetroot	Betacyanins	• Vegan lipstick using beetroot-derived pigments exhibited strong antioxidant activity in the DPPH assay and antimicrobial activity against *Escherichia coli* and *Staphylococcus aureus*. • Among the samples evaluated, Sample A (the beetroot formulation) was identified as the most effective, featuring a composition of 5 ml beetroot extract, 1.5 g candelilla wax as a vegan binder, 5 ml olive oil, 2.5 ml lime juice, and 2.5 g each of shea and cocoa butter. • Phytochemical analysis of this optimal formulation (Sample A) further confirmed the presence of bioactive compounds such as betacyanins, which contributed to its functional performance without the use of synthetic chemicals.
Anilkumar et al., 2020	Beetroot	Betacyanins	• Several formulations were evaluated, and F3 passed all evaluations tests, showed no side effects, maximum local effects, and exhibited good spreadability and smooth application. • This optimal F3 featured a specific composition of 10 g beeswax, 20 g castor oil, 10 g lanolin, 15 ml beetroot extract, 8.5 g shikakai, 6.5 ml eugenol, lemon juice, rose oil, and a few drops of vanilla essence. • Evaluation of F3 yielded a melting point of 60-62°C and a pH of 6.5-6.6

Notes: This table summarizes research findings on lipstick formulations using natural pigments, specifically betacyanins and anthocyanins. DPPH: 2,2-diphenyl-1-picrylhydrazyl; F: formulation; ppm: parts per million; VCO: virgin coconut oil.

Table 1 (continued)

Studies regarding lipstick formulations using betacyanins and anthocyanins as natural pigments

Authors	Extract	Pigments	Key findings
Łusiak et al., 2025	Grape pomace	Anthocyanins	• Formulations prepared with 1%, 3%, and 5% pomace, antioxidant activity (DPPH) and phenolic content increased with pomace concentration, particle size ~200 µm, colour intensity increased with pomace level. • This formulation (5%) achieved the highest antiradical activity (64.44% inhibition in the DPPH assay) and the highest total phenolic content (0.103 mg).
Aprilia et al., 2025	Butterfly pea	Anthocyanins	• During 28 days of evaluation, the 2% extract formulation demonstrated optimal performance, with viscosity 5500-13,000 cP, adhesion 7.10-26.8 s, and spreadability 5-7.5 cm. • The 2% formulation was chosen as the best because higher concentrations (4% and 6%) made the lip cream too thick (viscosity >40,000 cP) and difficult to apply. The base typically included stearic acid, cetyl alcohol, cera alba, and VCO.
Sai Datri et al., 2022	*Rosa* 'Mister Lincoln' (tea rose)	Anthocyanins	• Melting point >50 °C for F7-12, breaking point 105-110 g (higher than commercial lipstick 95 g), no skin irritation after 5 min test. • Among the samples, F9 was identified as optimal, featuring a specific blend of 4.5 g beeswax, 3 g shreeji wax, 6 ml castor oil, 1 ml olive oil, 2 ml rose, and a few drops of lemon juice and fragrance. • A short skin-irritation test indicated no adverse reactions. • F9 met all commercial requirements, including pH 6.5 and excellent spreadability, confirming its suitability for lip cosmetic applications.
Setyawaty et al., 2020	Purple sweet potato	Anthocyanins	• Breaking point 330 g, melting point >50°C, pH 4-6, formulation remained stable with no change in odour or shape after 30 days of storage. • Formulations containing 2.4%, 4.5%, and 14.6% extract showed low colour deposition, indicating pigment instability due to sugar content.

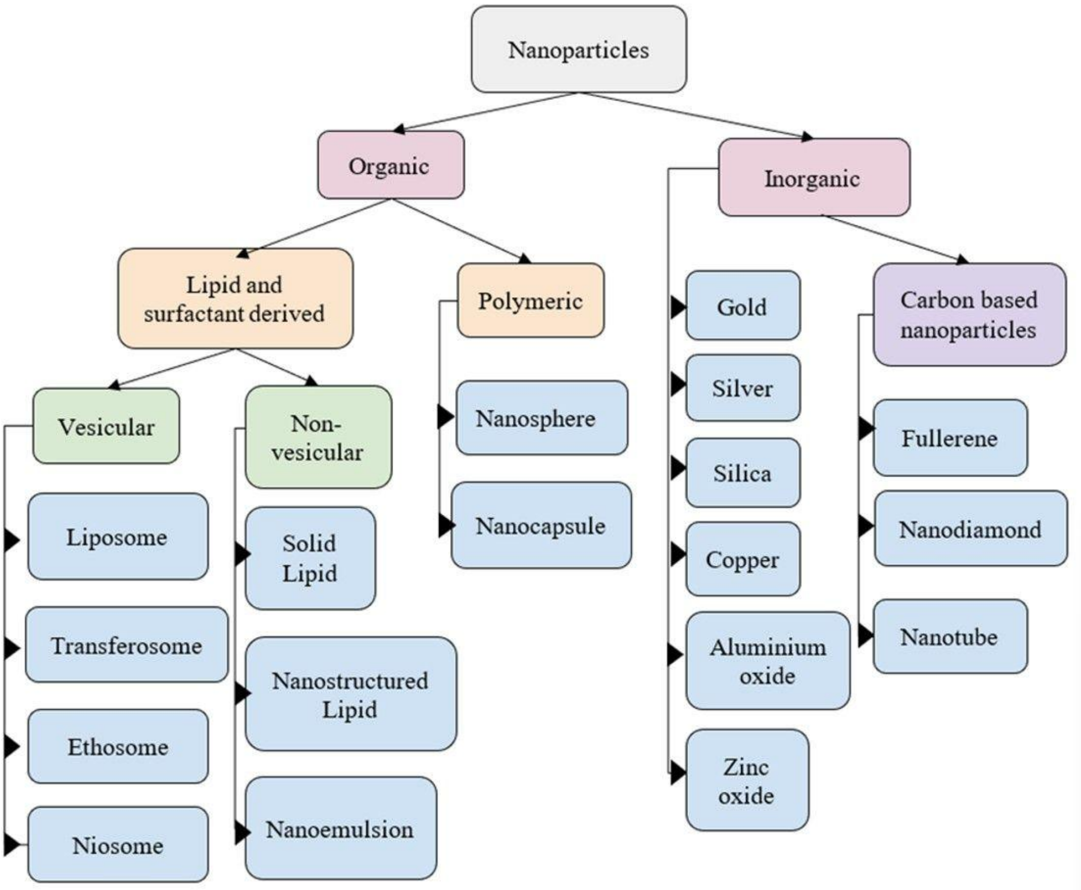
Notes: This table summarizes research findings on lipstick formulations using natural pigments, specifically betacyanins and anthocyanins. DPPH: 2,2-diphenyl-1-picrylhydrazyl; F: formulation; ppm: parts per million; VCO: virgin coconut oil.

In cosmeceutical applications, nanoscale components can enhance UV protection, improve colour intensity, and promote deeper skin penetration, resulting in longer-lasting effects (Aziz et al., 2019). Nanoparticles used in cosmetic formulations are generally classified into two main categories: organic and inorganic nanoparticles. Organic nanoparticles include lipid-based carriers, surfactant-based systems, and polymeric nanoparticles, whereas inorganic nanoparticles comprise metal- and carbon-based nanomaterials (Eker et al., 2024). Lipid- and surfactant-based nanocarriers can be further categorised into vesicular systems (e.g., liposomes) and non-vesicular systems (e.g., nanoemulsions and nanocapsules) (Eker et al., 2024).

Beyond cosmetic applications, nanotechnology has been extensively applied in fields such as pharmaceutical drug delivery and food safety. These systems are valued for their ability to enhance bioavailability, protect sensitive compounds from degradation, and enable controlled release (Petrovic et al., 2024; Singh et al., 2017). In particular, nanotechnology-based delivery systems have been explored for natural pigments such as anthocyanins and betacyanins to improve retention, enhance bioavailability, and reduce environmental degradation (Harimurti et al., 2021; Yin et al., 2023). An overview of nanoparticle classification commonly used in cosmeceutical formulations is presented in Figure 5.

Figure 5

Type of nanoparticles used in cosmeceutical formulations



Notes: This figure shows different nanoparticles applied in cosmeceutical formulations. Created by the authors.

Liposome (lipid-derived)

Among various nanotechnology-based delivery systems, lipid-derived nanocarriers, such as liposomes, have attracted considerable attention for enhancing the delivery of bioactive compounds in cosmetic formulations. Liposomes are spherical vesicular structures composed of phospholipid bilayers that can encapsulate both hydrophilic and lipophilic substances. Hydrophilic compounds are typically entrapped within the internal aqueous core, whereas lipophilic molecules are incorporated within the lipid bilayer membrane (Honda et al., 2013). Owing to their closed bilayer structure, liposomes can shield encapsulated compounds from external degradation. Furthermore, their structural resemblance to biological membranes enables efficient interaction with cells, facilitating the transport of active molecules into cellular or subcellular compartments (Gao et al., 2013).

Liposomes have been extensively employed as delivery carriers in both cosmetic and pharmaceutical applications. Their physicochemical properties may vary depending on several factors, including lipid composition, particle size, surface charge, and preparation techniques. A major advantage of liposomal systems is their biodegradability and biocompatibility, which make them suitable for cosmetic and biomedical applications (Akbarzadeh et al., 2013). Apart from cosmetics and pharmaceuticals, liposome technology has been explored in the food and agricultural sectors, where it is used to encapsulate unstable compounds, such as antimicrobial agents, antioxidants, flavour compounds, and other bioactive molecules, to improve their delivery and functional performance (Mankan et al., 2025).

Several studies have explored the use of liposomal delivery systems for encapsulating natural pigments. For example, Lee and Na (2019) developed anthocyanin-loaded liposomes using a remote pH-gradient loading method, achieving 71.2% loading efficiency and 85.4% stability. The liposomal formulation enhanced antioxidant activity by 2.1-fold and increased skin permeability by 2.9-fold compared with free anthocyanins, while maintaining integrity for 14 days, indicating potential for pharmaco-cosmetic applications. In another study, Wang et al. (2021) showed that incorporating chitosan enhanced the protection of anthocyanins. Chitosan-coated anthocyanin liposomes demonstrated enhanced antioxidant activity compared to unmodified liposomes, along with sustained release properties and physicochemical integrity of blueberry-derived anthocyanins. Liposomal systems demonstrate clear advantages in enhancing pigment preservation and functional performance compared with free pigments. For instance, Lin et al. (2022) reported that approximately 80% of the betacyanins content were retained after 21 days of storage at pH 4.3-7.0 when encapsulated in liposomes, demonstrating improved pigment retention and bioavailability.

Moreover, Chi et al. (2019) revealed that anthocyanin nanoliposomes with an average particle size of 53.01 nm retained 85.60% of anthocyanins after 16 days at 25°C, while improving resistance to temperature, pH, and light exposure and enabling sustained release. Hwang et al. (2013) demonstrated that liposome-encapsulated anthocyanins from *Hibiscus sabdariffa* significantly enhanced antioxidant activity and inhibited melanogenesis in human melanocytes. The liposomal formulation showed 64-76% DPPH scavenging activity and 23-60% inhibition of melanin synthesis, compared with 11-24% and 8-30%, respectively, for free anthocyanins, suggesting potential applications in skin photoprotection and cosmetic formulations. Similarly, Amjadi et al. (2018) reported that betanin-loaded liposomal nanocarriers achieved an encapsulation efficiency of 80.35 ± 1% and significantly improved pigment retention and antioxidant activity. The betanin content and antioxidant activity of samples containing nanoliposomal betanin were at least 2-fold higher than those containing free betanin, demonstrating the effectiveness of liposomal encapsulation for stabilising betacyanin pigments. Martínez-Rodríguez et al. (2023) encapsulated betalain pigments in liposomes and demonstrated that the encapsulated compounds reduced oxidative stress and lipid accumulation in *Caenorhabditis elegans*, increasing lifespan by up to 21.8%, indicating that nanoencapsulation can preserve the bioactive properties of betalain pigments.

Across seven liposome-based studies (2013-2023), encapsulation consistently improved pigment retention and functional performance compared with non-encapsulated anthocyanins or betacyanins. Liposomal systems typically achieved high encapsulation efficiencies of approximately 71-93%, preserved up to 80% of betacyanins after 21 days of storage, and maintained anthocyanins integrity for up to 14 days under physiological conditions. Furthermore, several formulations enhanced antioxidant activity and skin permeability by about 1.7-2.9-fold, with some systems demonstrating nearly 2-fold higher antioxidant activity than free pigments. Overall, the findings were largely consistent across studies, indicating that liposome nanocarriers effectively improve pigment preservation, antioxidant functionality, and controlled release, highlighting their potential for delivering natural pigments in cosmetic formulations. A summary of previous studies on the role of liposome-based on the stability and functional enhancement of betacyanins and anthocyanins in cosmeceutical formulations is presented in Table 2.

Table 2

Role of liposome-based on the stability and functional enhancement of betacyanins and anthocyanins in cosmeceutical formulations.

Authors	Pigments	Nanotechnology Type	Key Findings
Lee & Na, 2019	Anthocyanins	Liposome	• RAH liposomal encapsulation improved anthocyanins' integrity, antioxidant activity, and skin permeability compared with free anthocyanins. • The formulation achieved a loading efficiency of 71.2% and retained 85.4% of anthocyanins, maintaining their integrity for up to 14 days. • Antioxidant activity and skin permeability were enhanced by 2.1-fold and 2.9-fold, respectively, compared with non-encapsulated anthocyanins.
Wang et al., 2021	Anthocyanins	Liposome	• The results showed that the particle size (210.7 ± 1.8 nm), zeta potential (-20.0 ± 1.0 mV), and entrapment efficiency (82.13%) for blueberry anthocyanin liposomes. The addition of chitosan has increased the integrity of anthocyanins compared to these values. • The antioxidant capacity of chitosan-modified anthocyanins liposome is higher compared to anthocyanins liposome. • Exhibited controlled release behaviour and improved physicochemical properties of the pigment.

Notes: Liposome-based stability and functional enhancement of betacyanins and anthocyanins in cosmeceutical formulations. DPPH: 2,2-diphenyl-1-picrylhydrazyl; MITF: microphthalmia-associated transcription factor; RAH: remote-loaded anthocyanin.

Table 2 (continued)

Role of liposome-based on the stability and functional enhancement of betacyanins and anthocyanins in cosmeceutical formulations.

Authors	Pigments	Nanotechnology Type	Key Findings
Lin et al., 2022	Betacyanins	Liposome	• The retention of betacyanins during storage at varying temperatures was significantly improved. • Liposomal betacyanins showed a high encapsulation efficiency of 93.43 ± 0.11%. • Approximately 80% of the pigment of *Hylocereus polyrhizus* was retained after 21 days of storage at pH 4.3-7.0, indicating improved storage conditions. • Liposomal encapsulation also increased betacyanins' bioavailability by 14% during gastric digestion and 40% during intestinal digestion.
Chi et al., 2019	Anthocyanins	Liposome	• Anthocyanin nanoliposomes had an average particle size of 53.01 nm. • Approximately 85.60% of anthocyanins were retained after 16 days at 25°C, indicating enhanced pigment preservation. • Nanoliposomal encapsulation enhanced anthocyanins' resilience under varying temperature, pH, and light conditions and showed sustained release during in vitro digestion.
Hwang et al., 2013	Anthocyanins	Liposome	• Liposomal anthocyanins showed enhanced antioxidant activity with DPPH scavenging of 64-76%, compared with 11-24% for free anthocyanins. • Melanin production was inhibited by 23-60% with liposomal anthocyanins, compared with 8-30% for free anthocyanins. • The formulation suppressed tyrosinase activity and MITF expression, indicating potential for skin photoprotection and cosmetic applications.
Amjadi et al., 2018	Betanins	Liposome	• Betanin was successfully encapsulated in liposomal nanocarriers with an encapsulation efficiency of 80.35 ± 1%. • Samples containing betanin-loaded nanoliposomes showed at least 2-fold higher betanin content and antioxidant activity compared with free betanin. • Liposomal encapsulation improved pigment retention.
Martínez-Rodríguez et al., 2023	Betalains	Liposome	• Encapsulated betalains (25-500 µM) reduced oxidative stress and lipid accumulation in *Caenorhabditis elegans* • Increasing lifespan of *Caenorhabditis elegans* by 21.8%, indicating that liposomal encapsulation preserves pigment bioactivity.

Notes: Liposome-based stability and functional enhancement of betacyanins and anthocyanins in cosmeceutical formulations. DPPH: 2,2-diphenyl-1-picrylhydrazyl; MITF: microphthalmia-associated transcription factor; RAH: remote-loaded anthocyanin.

Nanoemulsion (surfactant-derived)

Alongside lipid-based vesicular carriers such as liposomes, surfactant-derived systems, including nanoemulsions, have also been widely investigated for improving the delivery of natural pigments. Nanoemulsions are colloidal dispersions composed of two immiscible liquids, typically oil and water, stabilised by surfactants and co-surfactants (Shaker et al., 2019). Depending on the phase arrangement, three main types of nanoemulsions can be formed: oil-in-water (O/W), water-in-oil (W/O), and bi-continuous systems. In O/W nanoemulsions, oil droplets are dispersed in a continuous aqueous phase, whereas W/O nanoemulsions consist of water droplets dispersed in a continuous oil phase (Nikolaev et al., 2023). Nanoemulsions can be produced using either low-energy or high-energy preparation techniques (Preeti et al., 2023). Low-energy methods rely on spontaneous emulsification via phase inversion by adjusting surfactant-oil-water composition or temperature, whereas high-energy methods employ mechanical devices such as microfluidisers, ultrasonic homogenisers, or high-pressure homogenisers to generate intense disruptive forces that reduce droplet size. Compared with high-energy techniques, low-energy methods are generally simpler, faster, and more cost-effective, while high-energy processes often require lower surfactant concentrations (Preeti et al., 2023).

Nanoemulsions have also been widely investigated as effective carriers for natural pigments such as anthocyanins and betacyanins. Several studies have demonstrated that nanoemulsion systems can enhance pigment preservation, antioxidant activity, and physicochemical performance. For instance, Yin et al. (2023) evaluated blueberry anthocyanin nanoemulsions formulated as both O/W and W/O systems. The formulations produced droplets of 10-600 nm and remained physically stable for up to 2 weeks at room temperature and 1 week at 4-25°C, as well as during high-speed centrifugation tests. Furthermore, skin irritation and sensitisation assessments showed no adverse reactions, indicating their potential suitability for cosmetic applications. Research on anthocyanin nanoemulsions has also demonstrated improved pigment preservation during storage.

Rabelo et al. (2017) developed W/O anthocyanin nanoemulsions that improved pigment retention during 30 days of storage, increasing polyphenol retention from 56% in the free extract to 74-85% in the nanoemulsions containing 2% and 5% anthocyanins extract while maintaining antioxidant activity. In a subsequent study, Rabelo et al. (2018) demonstrated that anthocyanin nanoemulsions maintained favourable antioxidant properties and reduced pigment degradation during storage. They formulated W/O nanoemulsions containing açaí anthocyanins with droplet sizes ranging from 146.8 to 814.8 nm, which remained stable without phase separation for 30 days. The nanoemulsion system also slowed pigment degradation, with formulations containing 2% extract exhibiting an estimated half-life of 385 days for anthocyanins. Similar observations were reported by Nazareth et al. (2021), who reported that anthocyanins extracted from *Carissa spinarum* exhibited improved antioxidant activity when encapsulated in nanoemulsion systems, particularly under refrigerated conditions (-4°C). That nanoemulsions containing anthocyanins also increase the degradation half-life from 6 to 40 days at 28°C while producing very small droplets (5-25 nm) and demonstrating strong anti-quorum-sensing activity.

Alongside anthocyanins, nanoemulsion systems have also been explored for delivering betacyanin pigments. Harimurti et al. (2020) formulated a water-in-oil-in-water (W/O/W) nanoemulsion incorporating betacyanins derived from red dragon fruit (*Hylocereus polyrhizus*), achieving a droplet size of 199 nm with a polydispersity index (PDI) of 0.18 and a zeta potential of -37.1 mV. The formulation retained its antioxidant activity, as demonstrated by a DPPH value of 9.15 ppm. In a later study, Harimurti et al. (2021) further explored betacyanin-loaded nanoemulsions and identified an optimal water-in-oil (W/O) system composed of a 5% oil phase, 15% (w/w) emulsifier, and 1.5% (w/w) Tween 80 as the hydrophilic surfactant. The results showed that the IC_{50} values of both the crude extract and the nanoemulsion were comparable, indicating that encapsulation did not compromise the antioxidant activity of the pigment. Similarly, Mohammed et al. (2021) observed that beetroot betacyanin nanoemulsions, with droplet sizes of 701.53 ± 27.2 nm, demonstrated enhanced resistance to heat and pH changes compared with microemulsions, maintaining their integrity over 15 days of storage at temperatures ranging from 4°C to 100°C. Collectively, these findings highlight the potential of nanoemulsion-based systems to enhance pigment preservation, antioxidant functionality, and overall formulation performance in cosmetic and related applications.

Across seven nanoemulsion studies (2017-2023), as shown in Table 3, encapsulation consistently improved the physicochemical stability and antioxidant activity of anthocyanins and betacyanins compared with free extracts. Most systems produced droplets ranging from approximately 5 to 814 nm and extended pigment retention for 30-40 days, while significantly reducing degradation and maintaining antioxidant functionality. Betacyanin nanoemulsions, with droplet sizes ranging from approximately 199 to 701 nm, showed enhanced physicochemical and thermal robustness compared with non-encapsulated pigments. These systems retained antioxidant activity and demonstrated improved preservation over up to 15 days of storage, highlighting the effectiveness of nanoemulsion carriers in maintaining betacyanin pigments. Taken together, these findings suggest that nanoemulsion-based delivery systems provide an effective strategy for improving pigment preservation, antioxidant functionality, and formulation performance in cosmetic products.

Table 3

Role of nanoemulsion-based on the enhancement of pigment retention and antioxidant performance of betacyanins and anthocyanins in cosmeceutical formulations

Authors	Pigments	Nanotechnology type	Findings
Yin et al., 2023	Anthocyanins	Nanoemulsion W/O & O/W	• Anthocyanin nanoemulsions were tested at normal and high temperatures, and high centrifugal tests showed that the blueberry anthocyanins have good stability. • Optimised blueberry anthocyanin nanoemulsions (anthocyanin: EL-35: IPM: glycerine: water = 2: 16:5:4:40) produced droplets of 10-600 nm with anthocyanins content of 608.89 µg/mL. • The nanoemulsion remained stable for up to 2 weeks at room temperature and 1 week at 4-25 °C, with no phase separation after centrifugation (3000 rpm, 20 min). • Skin irritation tests showed no irritation and only weak sensitisation, indicating suitability for topical cosmetic applications.
Rabelo et al., 2017	Anthocyanins	Nanoemulsion W/O	• W/O nanoemulsions improved anthocyanin retention during 30 days of storage compared with the free extract. • Polyphenol retention increased from 56% in free extract to 74% and 85% in nanoemulsions containing 2% and 5% anthocyanin extract, respectively. • Encapsulated samples-maintained antioxidant activity after 30 days of storage.
Rabelo et al., 2018	Anthocyanins	Nanoemulsion W/O	• W/O nanoemulsions containing açaí berry anthocyanins showed droplet sizes ranging from 146.8-814.8 nm with no phase separation during 30 days of storage. • Encapsulation significantly reduced anthocyanin degradation and maintained antioxidant activity after 30 days. • A formulation with 2% açaí extract in a 30% W/O nanoemulsion exhibited an estimated anthocyanin half-life of 385 days.
Nazareth et al., 2021	Anthocyanins	Microemulsion & nanoemulsion	• Nanoemulsion formulation prepared from *Carissa spinarum* fruit reduced particle size from 1154 nm to 70-300 nm, and to 5-25 nm with Tween 80. • Anthocyanin integrity improved significantly, with degradation half-life increasing from 6 days (control) to 40 days in nanoemulsions at 28°C. • Nanoemulsions also exhibited strong anti-quorum-sensing activity (73.7%) and inhibited biofilm formation by 70.1% and 64.4% *Pseudomonas aeruginosa* and *Yersinia enterocolitica*, respectively.

Notes: This table summarises studies on nanoemulsion-based enhancement of pigment retention and antioxidant performance of betacyanins and anthocyanins in cosmeceutical formulations. EL-35: castor oil polyoxymethylene ether; IPM: isopropyl myristate; PDI: polydispersity index; W/O: water/oil; IC: inhibitory concentration; W/O/W: water/oil/water.

Table 3 (continued)

Role of nanoemulsion-based on the enhancement of pigment retention and antioxidant performance of betacyanins and anthocyanins in cosmeceutical formulations

Authors	Pigments	Nanotechnology type	Findings
Harimurti et al., 2020	Betacyanins	Nanoemulsion W/O/W	• Betacyanins loaded in W/O/W nanoemulsion of red dragon fruit betacyanin produced droplets of 199 nm with PDI 0.18 and zeta potential -37.1 mV, indicating good colloidal integrity. • The nanoemulsion exhibited antioxidant activity with a DPPH value of 9.15 ppm and enhanced antioxidant performance compared with the natural extract.
Harimurti et al., 2021	Betacyanins	Nanoemulsion W/O/W	• The most stable W/O/W formulation has the least oil phase separation of 5% *v*/*v* consisting of W/O emulsion (15% *w*/*w*) and Tween 80 (1.5% *w*/*w*) as hydrophilic emulsifiers. • IC_{50} values of red dragon fruit extracts and nanoemulsions were the same. • The higher the pigment concentration, the lower the IC_{50} value of the extract, and this shows how good the nanoemulsion is.
Mohammed et al., 2021	Betacyanins	Nanoemulsion	• Nanoemulsion showed droplet size of 701.53 ± 27.2 nm with viscosity of 0.089 Pa·s. • Nanoemulsions demonstrated enhanced resistance to temperature and pH changes compared with microemulsions during 15 days of storage at 4°C, 30°C, 40°C, and 100°C. • The nanoemulsion system also demonstrated sustained pigment release and reduced droplet coarsening.

Notes: This table summarises studies on nanoemulsion-based enhancement of pigment retention and antioxidant performance of betacyanins and anthocyanins in cosmeceutical formulations. EL-35: castor oil polyoxymethylene ether; IPM: isopropyl myristate; PDI: polydispersity index; W/O: water/oil; IC: inhibitory concentration; W/O/W: water/oil/water.

Polymeric nanocapsule

Polymeric nanocapsules represent another important type of nanocarrier widely explored for the delivery of bioactive compounds. Structurally, polymeric nanocapsules consist of a liquid or solid core enclosed within a polymeric membrane, forming a core-shell architecture. This structure differentiates them from nanospheres, which generally consist of a homogeneous polymer matrix without a distinct core (Deng et al., 2020). The core-shell configuration offers several advantages in delivery applications. In particular, the internal liquid or solid core enables higher loading of active compounds, while the surrounding polymer layer serves as a protective barrier, isolating the encapsulated molecules from the external environment (Deng et al., 2020). As a result, the degradation of sensitive compounds caused by environmental factors such as pH variation, enzymatic activity, and temperature fluctuations can be minimised (Trindade et al., 2018). Furthermore, the properties of the polymeric shell strongly influence key characteristics of the nanocapsules, including encapsulation efficiency, release behaviour, and biodistribution of the loaded molecules.

Polymeric nanocapsules can be fabricated using either biodegradable or non-biodegradable polymers (Rochín-Wong & Vélaz Rivas, 2022). Among these materials, biodegradable polymers such as chitosan, alginate, and cellulose are widely applied in biomedical and pharmaceutical fields because of their favourable physicochemical characteristics. These materials possess large surface areas, good mechanical strength, barrier properties, and low toxicity, and exhibit excellent biodegradability and biocompatibility (Strnad & Zemljič, 2023). Chitosan is particularly attractive due to its biodegradable cationic nature. It can be derived from various biological sources, including crustaceans, insects, molluscs, and fungi, although industrial production typically utilises crustacean shells obtained as by-products of the seafood processing industry. The suitability of chitosan for biomedical and delivery applications is strongly influenced by factors such as its molecular weight, degree of deacetylation, solubility, and bioadhesive properties (Murugesan & Scheibel, 2021). Chitosan exhibits antimicrobial activity against a wide range of microorganisms, including bacteria, fungi, and certain viruses (Shoueir et al., 2021). Dextran sulphate has also been frequently combined with chitosan to form multilayer nanocapsules through electrostatic interactions, producing stable nanostructures with desirable physicochemical characteristics (Crecente-Campo et al., 2019).

Several investigations have demonstrated that polymer-based nanocarriers can enhance the preservation and functional performance of anthocyanin pigments. For example, Doronio et al. (2022) reported that anthocyanins from fermented black garlic encapsulated using a chitosan-alginate complex produced nanoparticles with sizes of 50.7-92.0 nm and encapsulation efficiencies of 65.77-78.82%, while maintaining DPPH radical scavenging activity of 14.02 mg AAE/g despite a low total phenolic content of 0.11 mg GAE/g. The chitosan-alginate complex has successfully encapsulated the anthocyanins from fermented black garlic. Ge et al. (2018) also observed that anthocyanin-loaded chitosan nanoparticles degraded more slowly compared with free anthocyanin molecules. Furthermore, He et al. (2017) developed nanocomplexes using chitosan hydrochloride (CHC) and carboxymethyl chitosan (CMC) that showed average particle sizes of 219.53 nm and 63.15% encapsulation efficiency, respectively, and significantly delayed pigment degradation and enhanced overall integrity compared with free anthocyanins.

In another study, Wang et al. (2020) developed chitosan-based nanocapsules encapsulating anthocyanins extracted from black chokeberry (*Aronia melanocarpa*) and reported improved pigment protection compared with non-encapsulated anthocyanins. The nanocapsules exhibited favourable encapsulation efficiency and enhanced resistance to environmental stress conditions, suggesting that polymeric nanocarriers may improve the preservation and delivery of anthocyanin pigments in potential cosmetic and cosmeceutical formulations. Silva Nieto et al. (2023) found that betanin-rich beetroot extract was incorporated into chitosan nanogels, forming particles of approximately 166 ± 6 nm with an encapsulation efficiency of 45 ± 3%. The system improved pigment resistance against pH and light exposure and showed a controlled release for about 12 hours while retaining antioxidant activity. Ghoorchi et al. (2025) prepared polymeric nanocapsules of beetroot extract rich in betanin (a major betacyanin pigment) using gelatine and cress seed gum via coacervation. Increasing gum concentration from 0.2% to 0.6% led to smaller particle sizes and lower zeta potential, while enhancing nanocapsule structure and emulsion robustness over 20 days, with the 0.6% formulation demonstrating the best performance. Therefore, polymeric nanocapsules represent a promising strategy to improve the preservation and delivery of betacyanin pigments for cosmetic applications. Shafqat et al. (2023) synthesised betanin-encapsulated chitosan nanoparticles via ionic gelation, yielding particles of 270.3 ± 8.50 nm with an encapsulation efficiency of 87.5%, thereby significantly enhancing betanin's antioxidant and anti-inflammatory activities. Similarly, polymer-based matrices have also been explored to improve the functional properties of natural pigments. Although not specifically focused on cosmetic applications, Nadi et al. (2023) incorporated anthocyanins from red cabbage extract as a colourimetric indicator into a basil seed gum-chitosan matrix for monitoring fish freshness, resulting in improved solubility, water vapour permeability, and mechanical flexibility of the material.

Across seven polymeric nanocapsule studies published between 2017 and 2025, encapsulation consistently improved pigment retention and antioxidant performance compared with free anthocyanins or betacyanins/betanin. For the anthocyanin system, particles typically ranged from 50-219 nm with encapsulation efficiencies of 63-79%, resulting in slower degradation and enhanced antioxidant activity. In contrast, betacyanins/betanin nanocapsules exhibited particle sizes of approximately 166-270 nm and encapsulation efficiencies of 45-88%, likewise demonstrating enhanced pigment preservation, controlled release behaviour, and antioxidant functionality. A summary of previous studies on preservation and antioxidant enhancement of anthocyanins and betacyanins in cosmeceutical formulations is provided in Table 4.

DISCUSSION

Liposomes are phospholipid-based vesicles capable of encapsulating both hydrophilic and lipophilic compounds. They are particularly effective in enhancing dermal delivery, as their bilayer structure improves skin permeability and bioavailability of bioactive compounds. Several studies reviewed in this work demonstrate that liposomal encapsulation significantly improves pigment stability and antioxidant performance (Table 2). For instance, liposomal anthocyanin formulations have been shown to enhance antioxidant activity and skin permeability compared with free pigments (Lee & Na, 2019). Similarly, liposomal encapsulation of betacyanins preserved approximately 80% of pigment retention during storage while maintaining antioxidant functionality (Lin et al., 2022). In some cases, liposomal systems achieved up to a 2-fold increase in antioxidant activity. These properties make liposomes highly suitable for advanced cosmetic applications such as anti-ageing creams, dermal serums, and photoprotective (sunscreen) products. However, their integrity may be limited by potential oxidation and phospholipid bilayer leakage.

In contrast, nanoemulsions consist of nanoscale droplets that enhance pigment dispersion and solubility due to their high surface area. Studies summarised in this review indicate that anthocyanin- and betacyanin-loaded nanoemulsions significantly enhance pigment retention during storage (Table 3). For example, anthocyanin nanoemulsions were reported to maintain antioxidant activity while reducing pigment degradation for up to 30-40 days under controlled storage conditions (Rabelo et al., 2018; Nazareth et al., 2021). Notably, blueberry anthocyanin nanoemulsions

Table 4

Role of polymeric nanocapsule-based on preservation and antioxidant enhancement of anthocyanins and betacyanins in cosmeceutical formulations.

Authors	Pigments	Nanotechnology Type	Key Findings
Doronio et al., 2022	Anthocyanins	Polymeric nanocapsule	• The obtained anthocyanin-loaded nanocapsules have small particle sizes (50.7-92.0 nm) with high encapsulation efficiency (T3: 78.82%, T2: 68.18%, T1: 65.77%). • Results showed that a higher initial concentration of anthocyanin extract from fermented black garlic promotes higher encapsulation efficiency. • Antioxidant activity of the nanocapsules showed low phenolic content (0.11 mg GAE/g) but high DPPH scavenging activity (14.02 mg AAE/g).
Ge et al., 2018	Anthocyanins	Polymeric nanocapsule	• Anthocyanin-loaded chitosan nanoparticles showed a slower degradation compared to free anthocyanin.
He et al., 2017	Anthocyanins	Polymeric nanocapsule	• Anthocyanin-loaded CHC and CMC nanocomplexes exhibited a particle size of 219.53 nm with a high encapsulation efficiency of 63.15%. • The nanocomplexes also showed improved integrity compared with free anthocyanin.
Wang et al., 2020	Anthocyanins	Polymeric nanocapsule	• Improved pigment protection, particle size (197 nm) with good surface morphology, high encapsulation efficiency (65.7%), suitable zeta potential (+42.7 mV), and low polydispersity index (0.032). • The nanoencapsulated anthocyanins exhibited significantly slower degradation and stronger antioxidant activity compared with free anthocyanins.
Silva Nieto et al., 2023	Betanins	Polymeric nanocapsule	• Chitosan-based nanogels for the encapsulation of betanin-rich beetroot extract, producing nanoparticles with a mean size of 166 ± 6 nm and encapsulation efficiency of 45 ± 3%. • The nanogel system provided pH and light protection and sustained release for approximately 12 h, while maintaining antioxidant activity • Demonstrating the potential of chitosan-based polymeric carriers for delivering betalain pigments.
Ghoorchi et al., 2025	Betanins	Polymeric nanocapsule	• Increasing cress seed gum concentration from 0.2% to 0.6% reduced particle size and zeta potential. • The emulsion remained stable for up to 20 days. • 0.6% cress seed gum produced the most stable nanocapsules with smoother morphology.
Shafqat et al., 2023	Betanins	Polymeric nanocapsule	• Betanin-loaded chitosan nanoparticles showed a particle size of 270.3 ± 8.50 nm with an encapsulation efficiency of 87.5%. • Demonstrating enhanced antioxidant and anti-inflammatory activities and improved stability compared with free betanin.

Notes: This table summarises studies on polymeric nanocapsules focusing on the preservation and antioxidant enhancement of anthocyanins and betacyanins in cosmeceutical formulations. Abbreviations: CHC: chitosan hydrochloride; CMC: carboxymethyl chitosan; DPPH: 2,2-diphenyl-1-picrylhydrazyl.

Table 5

Comparative overview of nanotechnology-based delivery systems used to enhance the stability and functionality of anthocyanins and betacyanins for cosmeceutical formulations.

Nanotechnology type	Typical particle size range (nm)	Stability improvements	Antioxidant retention/pigment protection	Limitations	Potential cosmetic application
Liposomes	50-200	Enhance skin permeability and bioavailability through phospholipid bilayer systems.	Can preserve up to 80% pigment stability in storage and increase antioxidant activity.	Possible leakage or oxidation if the lipid bilayer is unstable	• Anti-ageing creams • Dermal serum • Sunscreen
Nanoemulsions	5-814	Improve dispersion, enhance thermal stability, and reduce pigment degradation during storage.	Maintain antioxidant activity and extend pigment stability up to 30-40 days in several studies.	Possible droplet coalescence or Ostwald ripening during long storage if not stabilised	• Lotions • Creams • Sprays • Hydrating • serum
Polymeric nanocapsules	50-270	Strong protection against environmental factors such as pH and oxidation due to the polymeric shell.	High encapsulation efficiency (45-88%) with controlled release and prolonged pigment protection.	More complex preparation and higher production cost	• Lipsticks • Tinted balms • Long-wear makeup

Notes: This table provides a comparative overview of nanotechnology-based delivery systems used to enhance the stability and functionality of anthocyanins and betacyanins for cosmetic formulations.

demonstrated good physicochemical stability and showed no skin irritation in safety assessments, supporting their suitability for cosmetic applications (Yin et al., 2023). Nanoemulsions also demonstrate strong resistance to heat and phase separation, attributed to their small droplet size and well-optimized surfactant systems. These characteristics make them ideal for formulations such as lotions, creams, sprays, and hydrating serums. Nevertheless, nanoemulsions may become unstable, leading to droplet coalescence or Ostwald ripening, if not properly stabilized during prolonged storage.

Polymeric nanocapsules offer an alternative stabilization strategy by encapsulating pigments within a polymeric shell that protects them from environmental stressors. The studies reviewed here report particle sizes ranging from approximately 50 to 270 nm, with encapsulation efficiencies between 45% and 88% (Table 4). These systems significantly reduce pigment degradation while preserving antioxidant activity. For instance, anthocyanin-loaded chitosan nanoparticles improved pigment retention and antioxidant activity by encapsulating the anthocyanins within a polymeric matrix (He et al., 2017). Similarly, betanin-loaded chitosan nanoparticles exhibited strong antioxidant and anti-inflammatory activities, along with high encapsulation efficiency (Shafqat et al., 2023). Polymeric nanocapsules enable controlled release behaviour, allowing pigments to be gradually released over time. Compared with nanoemulsions, nanoemulsions provide stronger protection against environmental degradation, particularly pH variation and oxidation, due to their polymeric shell. This makes them especially suitable for long-lasting cosmetic applications such as lipsticks, tinted balms, and long-wear makeup products. However, their preparation is generally more complex and costly compared with nanoemulsion systems.

Overall, each nanotechnology-based delivery system offers distinct functional advantages depending on the formulation requirements. Nanoemulsions are particularly effective in improving thermal resistance and dispersion, polymeric nanocapsules offer superior protection against environmental degradation and controlled release, while liposomes provide enhanced dermal delivery and bioavailability. Therefore, the selection of an appropriate nano-system should be guided by the intended cosmetic application, formulation conditions, and desired performance outcomes. Despite the promising results reported for each nanocarrier system, the current literature reveals a limited number of studies directly comparing multiple nanotechnology-based delivery systems under identical experimental conditions. Most investigations focus on a single encapsulation strategy, making it difficult to determine which nanotechnology platform offers the best overall performance. Future research should therefore emphasise systematic comparative studies involving liposomes, nanoemulsions, and polymeric nanocapsules, using standardised experimental protocols. Such studies could offer clearer insight into variations in pigment retention, antioxidant preservation, and dermal delivery efficiency among different nanocarrier systems. Another important observation from the reviewed literature is that most studies focus primarily on anthocyanins, whereas fewer examine encapsulation of betacyanins in these systems. Given the intense colouration and strong antioxidant properties of betacyanins, further research is needed to assess their long-term stability and compatibility with cosmetic formulations. Future work should also address issues related to formulation scalability, safety evaluation, and regulatory considerations associated with incorporating nanoencapsulated pigments into commercial cosmetic products. Overall, nanotechnology offers a promising approach for overcoming the inherent instability of natural pigments and expanding their potential in cosmeceutical formulations.

CONCLUSION

Nanoencapsulation has shown significant potential to enhance the stability, bioavailability, and functional performance of natural pigments, such as anthocyanins and betacyanins. The studies reviewed indicate that different nanotechnology-based delivery systems provide distinct advantages depending on the formulation requirements. Nanoemulsions primarily improve pigment dispersion and short-term physicochemical integrity, whereas polymeric nanocapsules offer stronger protection and controlled release due to their polymeric shell structure. Liposomes, on the other hand, are particularly effective in enhancing skin permeability and antioxidant activity, making them suitable for advanced dermal delivery systems. These characteristics highlight the versatility of nanocarrier technologies for incorporating natural pigments into cosmetic formulations such as creams, serums, and colour cosmetics. Further research focusing on comparative performance, long-term integrity, and safety evaluation will be important for supporting the large-scale application of nanoencapsulated pigments in cosmetic products.

AUTHOR CONTRIBUTIONS

Nur Afizah Yusoff and Aswini Kumareswaran made substantial contributions to the conception and design of the work, as well as to the acquisition, analysis, and interpretation of data. Nur Afizah Yusoff also responsible for drafting the manuscript and revising it critically for important intellectual content. Zariyantey Abd Hamid, Izatus Shima Taib, and Hemabarathy Bharatham contributed to the conception and design of the work through project supervision, research management, and critical revision of the manuscript for important intellectual content. All authors participated in the development of the manuscript, provided final approval of the version to be published, and agreed to be accountable for all aspects of the work, ensuring that any questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest associated with this work.

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REFERENCES

Abdul Razak, U. N. A., Taha, R., Che Musa, S. A. N., & Mohamed, N. (2017). Detection of betacyanins pigment stability from *Hylocereus polyrhizus* (Weber) Britton & Rose fruit pulp and peel for possible use as natural coating. *Pigment and Resin Technology*, *46*(4):303–308. https://doi.org/10.1108/PRT-11-2016-0104

Akbarzadeh, A., Rezaei-Sadabady, R., Davaran, S., Joo, S. W., Zarghami, N., Hanifehpour, Y., Samiei, M., Kouhi, M., & Nejati-Koshki, K. (2013). Liposome: classification, preparation, and applications. *Nanoscale Research Letters*, *8*(1):1–9. https://doi.org/10.1186/1556-276X-8-102

Alnuqaydan, A. M. (2024). The dark side of beauty: an in-depth analysis of the health hazards and toxicological impact of synthetic cosmetics and personal care products. *Frontiers in Public Health*, *12*:1439027. https://doi.org/10.3389/fpubh.2024.1439027

Amjadi, S., Ghorbani, M., Hamishehkar, H., & Roufegarinejad, L. (2018). Improvement in the stability of betanin by liposomal nanocarriers: its application in gummy candy as a food model. *Food Chemistry*, *256*:156–162. https://doi.org/10.1016/j.foodchem.2018.02.114

Amogne, N. Y., Ayele, D. W., & Tsigie, Y. A. (2020). Recent advances in anthocyanin dyes extracted from plants for dye-sensitised solar cells. *Materials for Renewable and Sustainable Energy, 9*(23):1–16. https://doi.org/10.1007/s40243-020-00183-5

Anilkumar, V., Kalyani, R., Sangeeta Kumari, L., Lavanya, A. (2020). Design, development and evaluation of herbal lipstick from natural color pigment. *International Journal of Pharmacognosy and Phytochemical Research*, *18*(2):276–289. https://ijppr.humanjournals.com/design-development-and-evaluation-of-herbal-lipstick-from-natural-color-pigment/

Aprilia, J., Rahmalia, W., & Budi, F. S. (2025). Formulation of lip cream with anthocyanin extract from butterfly pea flowers (*Clitoria ternatea*) as a natural dye. *Jurnal Ilmiah Farmasi*, *21*(2):170–184. https://journal.uii.ac.id/JIF/article/view/42831

Aramwit, P., Bang, N., & Srichana, T. (2010). The properties and stability of anthocyanins in mulberry fruits. *International Food Research Journal*, *43*(4):1093–1097. https://doi.org/10.1016/j.foodres.2010.01.022

Aziz, Z. A., Mohd Nasir, H., Mohd Setapar, S., Peng, W. L., Chuo, S. C., Khatoon, A., Mohamad Ibrahim, M., Umar, K., & Ahmad A. (2019). Role of nanotechnology for design and development of cosmeceutical: application in makeup and skin care. *Frontier in Chemistry*, *7*:1–15. https://doi.org/10.3389/fchem.2019.00739

Balaguru, R., Bhowmick, S., & Iyer, P. (2023). Formulation of chemical and cruelty-free vegan lipstick and analysing its components. *International Journal of Engineering Science Technologies*, *7*(5):37–53. https://doi.org/10.29121/ijoest.v7.i5.2023.507

Bangar, S. B., Lad, S. S., Gaikwad, S. S., Masal, A. S., Bayaskar, P. G., Misal, D. B., & Patil, S. (2025). Formulation and evaluation of an anthocyanin-rich herbal face serum for antioxidant activity. *International Journal of Pharmaceutical Sciences and Drug Analysis*, *5*(1):143–151. https://www.pharmacyjournal.info/archives/2025.v5.i1.B.116

Barciela, P., Pérez-Vázquez, A., & Prieto, M. A. (2023). Azo dyes in the food industry: Features, classification, toxicity, alternatives, and regulation. *Food and Chemical Toxicology*, *178*:1–12. https://doi.org/10.1016/j.fct.2023.113935

Bassama, J., Tamba, A., Ndong, M., Sarr, K. D. D., & Cissé, M. (2021). Degradation kinetics of betacyanins during the pasteurisation and storage of cactus pear (*Opuntia Dillenii* Haw.) juice using the arrhenius, eyring, and ball models. *Beverages*, *7*(1):1–12. https://doi.org/10.3390/beverages7010002

Brudzyńska, P., Sionkowska, A., & Grisel, M. (2021). Plant-derived colorants for food, cosmetic and textile industries: a review. *Materials*, *14*(13):1–18. https://doi.org/10.3390/ma14133484

Cai, Y., Sun, M., Wu, H., Huang, R., & Corke, H. (1998). Characterization and quantification of betacyanin pigments from diverse *Amaranthus* species. *Journal of Agricultural and Food Chemistry*, *46*(6):2063–2070. https://doi.org/10.1021/jf9709966

Carreón-Hidalgo, J. P., Franco-Vásquez, D. C., Gómez-Linton, D. R., & Pérez-Flores, L. J. (2022). Betalain plant sources, biosynthesis, extraction, stability enhancement methods, bioactivity, and applications. *Food Research International*, *151*:110821. https://doi.org/10.1016/j.foodres.2021.110821

Chahine, B., Hanna, V., Ghandour, I., Haydar, S., & Faddoul, L. (2023). Knowledge and attitude of Lebanese women about cosmetics: a cross-sectional survey. *International Journal of Women's Dermatology*, *9*(3):1–6. https://doi.org/10.1097/JW9.0000000000000091

Chi, J., Ge, J., Yue, X., Liang, J., Sun, Y., Gao, X., & Yue, P. (2019). Preparation of nanoliposomal carriers to improve the stability of anthocyanins. *Food Science and Technology*, *109*(1):101–107. https://doi.org/10.1016/j.lwt.2019.03.070

Chua, L. S., Thong, H. Y., & Soo, J. (2024). Effect of pH on the extraction and stability of anthocyanins from jaboticaba berries. *Food Chemistry Advances*, *5*:1–8. https://doi.org/10.1016/j.focha.2024.100835

Crecente-Campo, J., Virgilio, T., Morone, D., Calviño-Sampedro, C., Fernández-Mariño, I., Olivera, A., Varela-Calvino, R., González, S. F., & Alonso, M. J. (2019). Design of polymeric nanocapsules to improve their lympho-targeting capacity. *Nanomedicine*, *14*(23):3013–3033. https://doi.org/10.2217/nnm-2019-0206

Deng, S., Gigliobianco, M. R., Censi, R., & Di Martino, P. (2020). Polymeric nanocapsules as a nanotechnological alternative for drug delivery systems: current status, challenges, and opportunities. *Nanomaterials*, *10*(5):1–36. https://doi.org/10.3390/nano10050847

Dhiman, A., Suhag, R., Chauhan, D. S., Thakur, D., Chhikara, S., & Prabhakar, P. K. (2021). Status of beetroot processing and processed products: thermal and emerging technologies intervention. *Trends in Food Science and Technology*, *114*:443–458. https://doi.org/10.1016/j.tifs.2021.05.042

Di Salvo, E., Lo Vecchio, G., De Pasquale, R., De Maria, L., Tardugno, R., Vadalà, R., & Cicero, N. (2023). Natural pigments production and their application in food, health and other industries. *Nutrients*, *15*(8):1–27. https://doi.org/10.3390/nu15081923

Di Stefano, V., Scandurra, S., Pagliaro, A., Di Martino, V., & Melilli, M. G. (2020). Effect of sunlight exposure on anthocyanin and non-anthocyanin phenolic levels in pomegranate juices by high-resolution mass spectrometry approach. *Foods*, *9*(9):1–11. https://doi.org/10.3390/foods9091161

Doronio, J. P., Salazar, J. R., Monserate, J. J., Arevalo, B. J. A., Eugenio, P. J. G., Sarong, M. M. (2022). Nanoencapsulation of anthocyanin extract from fermented black garlic (FBG) based on biocompatible polymeric materials. *Annales de Chimie - Science des Matériaux*, *46*(1):37–43. https://doi.org/10.18280/acsm.460105

Dubey, S. K., Dey, A., Singhvi, G., Pandey, M. M., Singh, V., & Kesharwani, P. (2022). Emerging trends of nanotechnology in advanced cosmetics. *Colloids and surfaces. B, Biointerfaces*, *214*(35):112440. https://doi.org/10.1016/j.colsurfb.2022.112440

Eker, F., Duman, H., Akdaşçi, E., Bolat, E., Sarıtaş, S., Karav, S., & Witkowska, A. M. (2024). A comprehensive review of nanoparticles: from classification to application and toxicity. *Molecules*, *29*(15):3482. https://doi.org/10.3390/molecules29153482

Enaru, B., Drețcanu, G., Pop, T. D., Stănilă, A., & Diaconeasa, Z. (2021). Anthocyanins: factors affecting their stability and degradation. *Antioxidants*, *10*(12):1–24. https://doi.org/10.3390/antiox10121967

Farheen, H., Kumar, A., Kumar, D., Parmar, S., Pathak, D., Sharma, P., & Chahar, S. S. (2025). Anthocyanins: natural pigments with multifaceted health benefits for humans. *Journal of Science Innovations and Nature of Earth*, *5*(3):1–3. https://doi.org/10.59436/jsiane.407.2583-2093

Fatima, S., Braunberger, T., Mohammad, T. F., Kohli, I., & Hamzavi, I. H. (2020). The role of sunscreen in melasma and postinflammatory hyperpigmentation. *Indian Journal of Dermatology*, *65*(1):5–10. https://doi.org/10.4103/ijd.IJD_295_18

Fu, Y., Shi, J., Xie, S. Y., Zhang, T. Y., Soladoye, O. P., & Aluko, R. E. (2020). Red beetroot betalains: perspectives on extraction, processing, and potential health benefits. *Journal of Agricultural and Food Chemistry*, *68*(42):11595–11611. https://doi.org/10.1021/acs.jafc.0c04241

Gandía-Herrero, F., Escribano, J., & García-Carmona, F. (2016). Biological activities of plant pigments betalains. *Critical Reviews in Food Science and Nutrition, 56*(6):937–945. https://doi.org/10.1080/10408398.2012.740103

Gao, L., Wang, J., & Bi, Y. (2025). Nanotechnology for neurodegenerative diseases: recent progress in brain-targeted delivery, stimuli-responsive platforms, and organelle-specific therapeutics. *International Journal of Nanomedicine*, *20*:11015–11044. https://doi.org/10.2147/IJN.S549893

Gao, W., Hu, C. M. J., Fang, R. H., & Zhang, L. (2013). Liposome-like nanostructures for drug delivery. *Journal of Materials Chemistry*, *1*(48):6569–6585. https://doi.org/10.1039/C3TB21238F

Gardeli, C., Varela, K., Krokida, E., & Mallouchos, A. (2019). Investigation of anthocyanins stability from pomegranate juice (*Punica Granatum* L. *Cv Ermioni*) under a simulated digestion process. *Medicines*, *6*(3):90. https://doi.org/10.3390/medicines6030090

Ge, J., Yue, P., Chi, J., Liang, J., & Gao, X. (2018). Formation and stability of anthocyanins-loaded nano complexes prepared with chitosan hydrochloride and carboxymethyl chitosan. *Food Hydrocolloids*, *74*:23–31. https://doi.org/10.1016/j.foodhyd.2017.07.029

Ghoorchi, A., Arianfar, A., Hakimzadeh, V., & Naji-Tabasi, S. (2025). Nano-encapsulation of red beetroot extract based on betanin with gelatin and cress seed gum by coacervation technique. *Food Science and Nutrition*, *13*(11):1–11. https://doi.org/10.1002/fsn3.71068

Ghosh, S., Sarkar, T., Das, A., & Chakraborty, R. (2022). Natural colourants from plant pigments and their encapsulation: an emerging window for the food industry. *Lebensmittel-Wissenschaft und Technologie*, *153*:1–12. https://doi.org/10.1016/j.lwt.2021.112527

Guerra, E., Llompart, M., & Garcia-Jares, C. (2018). Analysis of dyes in cosmetics: challenges and recent developments. *Cosmetics*, *5*(3):1–15. https://doi.org/10.3390/cosmetics5030047

Guneser, O. (2021). Kinetic modelling of betalain stability and color changes in yogurt during storage. *Polish Journal of Food and Nutrition Sciences*, *71*:135–145. https://doi.org/10.31883/pjfns/134393

Guo, Y., Zhang, H., Shao, S., Sun, S., Yang, D., Lv, S. (2022). Anthocyanin: a review of plant sources, extraction, stability, content determination and modifications. *International Journal of Food Science and Technology*, *57*(12):7573–7591. https://doi.org/10.1111/ijfs.16132

Gupta, V., Mohapatra, S., Mishra, H., Farooq, U., Kumar, K., Ansari, M. J., Aldawsari, M. F., Alalaiwe, A. S., Mirza, M. A., & Iqbal, Z. (2022). Nanotechnology in cosmetics and cosmeceuticals-a review of latest advancements. *Gels*, *8*(3):5–31. https://doi.org/10.3390/gels8030173

Harimurti, N., Mulia, K., & Nasikin, M. (2020). Preparation of W/O/W double nanoemulsions loaded with red dragon fruit extract. *AIP Conference Proceedings*, *2255*:1–7. https://doi.org/10.1063/5.0013757

Harimurti, N., Nasikin, M., & Mulia, K. (2021). Water-in-oil-in-water nanoemulsions containing temulawak (*Curcuma Xanthorriza Roxb*) and red dragon fruit (*Hylocereus Polyrhizus*) extracts. *Molecules*, *26*(1):1–11. https://doi.org/10.3390/molecules26010196

Havlíková, L., Míková, K., & Kyzlink, V. (1985). Red beet pigments as soft drink colorants. *Food/Nahrung*, *29*:723–730. https://doi.org/10.1002/food.19850290802

He, B., Ge, J., Yue, P., Yue, X., Fu, R., Liang, J., & Gao, X. (2017). Loading of anthocyanins on chitosan nanoparticles influences anthocyanin degradation in gastrointestinal fluids and stability in a beverage. *Food Chemistry*, *221*:1671–1677. https://doi.org/10.1016/j.foodchem.2016.10.120

Honda, M., Asai, T., Oku, N., Araki, Y., Tanaka, M., & Ebihara, N. (2013). Liposomes and nanotechnology in drug development: focus on ocular targets. *International Journal of Nanomedicine*, *8*:495–503. https://doi.org/10.2147/IJN.S30725

Hwang, J. M., Kuo, H. C., Lin, C. T., & Kao, E. S. (2013). Inhibitory effect of liposome-encapsulated anthocyanin on melanogenesis in human melanocytes. *Pharmaceutical Biology*, *51*(8):941–947. https://doi.org/10.3109/13880209.2013.771376

International Agency for Research on Cancer. (2010). Some aromatic amines, organic dyes, and related exposures. *IARC Monograph on the Evaluation of Carcinogenic Risks to Humans*. https://monographs.iarc.fr/ENG/Monographs/vol99/mono99.pdf

Jiang, X., Li, X., Zhu, C., Sun, J., Tian, L., Chen, W., & Bai, W. (2019). The target cells of anthocyanins in metabolic syndrome. *Critical Reviews in Food Science and Nutrition*, *59*(6):921–946. https://doi.org/10.1080/10408398.2018.1491022

Khan, M. I. (2016). Plant betalains: safety, antioxidant activity, clinical efficacy, and bioavailability. *Comprehensive Reviews in Food Science and Food Safety*, *15*(2):316–330. https://doi.org/10.1111/1541-4337.12185

Khoo, H. E., Azlan, A., Tang, S. T., & Lim, S. M. (2017). Anthocyanidins and anthocyanins: colored pigments as food, pharmaceutical ingredients, and the potential health benefits. *Food and Nutrition Research*, *61*(1):1–21. https://doi.org/10.1080/16546628.2017.1361779

Klavins, L., Zommere, A., Gricenko, T., & Klavins, M. (2026). The multifunctionality of plant pigments: roles, recovery from by-products and stability challenges. *Journal of Agriculture and Food Research*, *26*(2026):1–21. https://doi.org/10.1016/j.jafr.2026.102748

Kumari, S., Pal, B., Tewari, D., & Sahu, S. K. (2023). Cosmetics utilization and associated adverse events: a community based cross-sectional study. *Clinical Epidemiology and Global Health*, *23*(2023):1–6. https://doi.org/10.1016/j.cegh.2023.101382

Lakshmikanthan, M., Muthu, S., Krishnan, K., Altemimi, A. B., Haider, N. N., Govindan, L., Selvakumari, J., Alkanan, Z. T., Cacciola, F., & Francis, Y. M. (2024). A comprehensive review on anthocyanin-rich foods: insights into extraction, medicinal potential, and sustainable applications. *Journal of Agriculture and Food Research*, *17*:1–15. https://doi.org/10.1016/j.jafr.2024.101245

Lee, C., & Na, K. (2019). Anthocyanin-loaded liposomes prepared by the pH-gradient loading method to enhance the anthocyanin stability, antioxidation effect and skin permeability. *Macromolecule Research*, *28*(3):289–297. https://doi.org/10.1007/s13233-020-8039-7

Leyva-Gómez, G., Piñón-Segundo, E., Urban-Morlan, Z., Magaña-Vergara, N. E., Quintanar-Guerrero, D., Jaime-Escalante, B., & Mendoza-Muñoz, N. (2026). Quality by design for the nanoformulation of cosmeceuticals. *Pharmaceutics*, *18*(1):1–25. https://doi.org/10.3390/pharmaceutics18010062

Li, J., Li, Z., Ma, Q., & Zhou, Y. (2023). Enhancement of anthocyanins extraction from haskap by cold plasma pretreatment. *Innovative Food Science and Emerging Technologies*, *84*:103294. https://doi.org/10.1016/j.ifset.2023.103294

Li, Y., Huang, J., Wang, Z., & Wang, X. (2019). Anthocyanin content in mature/immature blueberry fruits under different storage temperature. *Earth and Environmental Science*, *310*:1–5. https://doi.org/10.1088/1755-1315/310/5/052084

Lin, X., Li, B., Wen, J., Wu, J., Tang, D., Yu, Y., Xu, Y., & Xu, B. (2022). Storage stability and in vitro bioaccessibility of liposomal betacyanins from red pitaya (*Hylocereus Polyrhizus*). *Molecules*, *27*(4):1–17. https://doi.org/10.3390/molecules27041193

Ling, T. Y., Tunku, U., & Rahman, A. (2020). Preparation of lipstick with red dragon fruit (*Hylocereus Polyrhizus*) pigment and storage stability study. http://eprints.utar.edu.my/3739/1/1601859_FYP_report_-_YONG_LING_TAN.pdf

Lombardelli, C., Benucci, I., Mazzocchi, C., & Esti, M. (2021). Betalain extracts from beetroot as food colorants: effect of temperature and UV-light on storability. *Plant Foods for Human Nutrition*, *76*(3):347–353. https://doi.org/10.1007/s11130-021-00915-6

Lu, W., Shi, Y., Wang, R., Su, D., Tang, M., Liu, Y., & Li, Z. (2021). Antioxidant activity and healthy benefits of natural pigments in fruits: a review. *International Journal of Molecular Sciences*, *22*(9):1–18. https://doi.org/10.3390/ijms22094945

Luna-Vital, D., Li, Q., West, L., West, M., & Gonzalez de Mejia, E. (2017). Anthocyanin condensed forms do not affect color or chemical stability of purple corn pericarp extracts stored under different pHs. *Food Chemistry*, *232*:639–647. https://doi.org/10.1016/j.foodchem.2017.03.169

Łusiak, P., Kęska, P., Mazur, J., Wójcik, M., & Sobczak, P. (2025). The quality of lip balm produced with grape pomace addition. *Sustainability*, *17*(13):1–12. https://doi.org/10.3390/su17136146

Lwin, T., Myint, C. Y., Win, H. H., Oo, W. W., & Chit, K. (2020). Formulation and evaluation of lipstick with betacyanin pigment of *Hylocereus polyrhizus* (red dragon fruit). *Journal of Cosmetics, Dermatological Sciences and Applications*, *10*(4):212–224. https://doi.org/10.4236/jcdsa.2020.104022

Madzuki, I. N., Samsudin, N. J., Nordin, R., Mohamed Rasheed, Z. B., & Mohsin, A. Z. (2024). Thermal and photostability of betacyanin from dragon fruit (*Hylocereus polyrhizus*). *Journal of Agrobiotechnology*, *15*(1):88-97. https://doi.org/10.37231/jab.2024.15.S1.377

Magalhães, D., Gonçalves, R., Rodrigues, C. V., Rocha, H. R., Pintado, M., & Coelho, M. C. (2024). Natural pigments recovery from food by-products: health benefits towards the food industry. *Foods*, *13*(14):1–29. https://doi.org/10.3390/foods13142276

Mankan, E., Karakas, C. Y., Saroglu, O., Mzoughi, M., Sagdic, O., & Karadag, A. (2025). Food-grade liposome-loaded delivery systems: current trends and future perspectives. *Foods*, *14*(17):1–28. https://doi.org/10.3390/foods14172978

Marangoni Júnior, L., De Bastiani, G., Vieira, R. P., & Anjos, C. R. (2020). Thermal degradation kinetics of total anthocyanins in açaí pulp and transient processing simulations. *SN Applied Sciences*, *2*:523. https://doi.org/10.1007/s42452-020-2340-0

Martinez, R. M., Melo, C. P. B., Pinto, I. C., Mendes-Pierotti, S., Vignoli, J. A., Verri, W. A., & Casagrande, R. (2024). Betalains: a narrative review on pharmacological mechanisms supporting the nutraceutical potential towards health benefits. *Foods*, *13*(23):1–27. https://doi.org/10.3390/foods13233909

Martínez-Rodríguez, P., Guerrero-Rubio, M. A., Hernández-García, S., Henarejos-Escudero, P., García-Carmona, F., & Gandía-Herrero, F. (2023). Characterisation of betalain-loaded liposomes and their bioactive potential in vivo after ingestion. *Food Chemistry*, 407:1–12. https://doi.org/10.1016/j.foodchem.2022.135180

Masyita, A., Hardinasinta, G., Astuti, A. D., Firdayani, F., Mayasari, D., Hori, A., Nisha, I. N. A., Nainu, F., & Kuraishi, T. (2025). Natural pigments: innovative extraction technologies and their potential application in health and food industries. *Frontiers in Pharmacology*, *15*:1–28. https://doi.org/10.3389/fphar.2024.1507108

Modesto Junior, E. N., Martins, M. G., Pereira, G. A., Chisté, R. C., & Pena, R. D. S. (2023). Stability kinetics of anthocyanins of grumixama berries (*Eugenia brasiliensis* Lam.) during thermal and light treatments. *Foods*, *12*(3):1–15. https://doi.org/10.3390/foods12030565

Mohammed, A. N., Ishwarya, S. P., & Nisha, P. (2021). Nanoemulsion versus microemulsion systems for the encapsulation of beetroot extract: comparison of physicochemical characteristics and betalain stability. *Food and Bioprocess Technology*, *14*(12):133–150. https://doi.org/10.1007/s11947-020-02562-2

Mohana Priya, M., Rajan, C., & Lavanya, M. (2020). Use of natural pigments as colorants in cosmetics - a review. *Journal of Emerging Technologies and Innovative Research*, *7*(3):907–917. http://www.jetir.org/papers/JETIR2003135.pdf

Mohd-Nasir, H., & Siti Hamidah Mohd-Setapar, S. H. (2018). Natural ingredients in cosmetics from Malaysian plants: a review. *Sains Malaysiana*, *47*(5):951–959. https://doi.org/10.17576/jsm-2018-4705-10

Monisha, B., Sridharan, R., Kumar, P. S., Rangasamy, G., Krishnaswamy, V. G., & Subhashree, S. (2023). Sensing of azo toxic dyes using nanomaterials and its health effects - a review. *Chemosphere*, *313*:137614. https://doi.org/10.1016/j.chemosphere.2022.137614

Muhammad, N., Yang, Z., Wang, L., Liu, Z., Yanga, M., & Liu, M. (2025). Exploring major fruit coloring pigments: uncovering their biological significance and applications. *Food Science and Human Wellness*, *14*(11):1–17. https://doi.org/10.26599/FSHW.2025.9250654

Murugesan, S., & Scheibel, T. (2021). Chitosan-based nanocomposites for medical applications. *Journal of Polymer Science*, *59*(15):1–33. https://doi.org/10.1002/pol.20210251

Nabi, B. G., Mukhtar, K., Ahmed, W., Manzoor, M. F., Ranjha, M. M. A. N., Kieliszek, M., Bhat, Z. F., & Aadil, R. M. (2023). Natural pigments: anthocyanins, carotenoids, chlorophylls, and betalains as colorants in food products. *Food Bioscience*, *52*:1–13. https://doi.org/10.1016/j.fbio.2023.102403

Nadi, M., Razavi, S. M. A., & Shahrampour, D. (2023). Fabrication of green colourimetric smart packaging based on basil seed gum/chitosan/red cabbage anthocyanin for real-time monitoring of fish freshness. *Food Science and Nutrition*, *11*:6360–6375. https://doi.org/10.1002/fsn3.3574

Nazareth, M. S., Shreelakshmi, S. V., Rao, P. J., & Shetty, N. P. (2021). Micro and nanoemulsions of *Carissa spinarum* fruit polyphenols, enhances anthocyanin stability and anti-quorum sensing activity: comparison of degradation kinetics. *Food Chemistry*, *359*:1–10. https://doi.org/10.1016/j.foodchem.2021.129876

Nduka, K. J., Ijeoma, K. H., & Omoche Odiba, I. (2019). Review of health hazards and toxicological effects of constituents of cosmetics. poisoning in the modern world - new tricks for an old dog? *IntechOpen*, 1–18. https://doi.org/10.5772/intechopen.84590

Negi, A. (2025). Natural dyes and pigments: sustainable applications and future scope. *Sustainable Chemistry*, *6*(3):1–50. https://doi.org/10.3390/suschem6030023

Nikolaev, B., Yakovleva, L., Fedorov, V., Li, H., Gao, H., & Shevtsov, M. (2023). Nano- and microemulsions in biomedicine: from theory to practice. *Pharmaceutics*, *15*(7):1–39. https://doi.org/10.3390/pharmaceutics15071989

NsDesing. (2024). A heart made of fruits and vegetables with a heart that says fresh fruit. https://www.freepik.com/premium-photo/heart-made-fruits-vegetables-with-heart-that-says-fresh-fruit_308470287.htm

Paillié-Jiménez, M. E., Stincone, P., & Brandelli, A. (2020). Natural pigments of microbial origin. *Frontiers in Sustainable Food Systems*, *4*:1–8. https://doi.org/10.3389/fsufs.2020.590439

Perez, M. B., Da Peña Hamparsomian, M. J., Gonzalez, R. E., Denoya, G. I., Dominguez, D. L. E., Barboza, K., Iorizzo, M., Simon, P. W., Vaudagna, S. R., & Cavagnaro, P. F. (2022). Physicochemical properties, degradation kinetics, and antioxidant capacity of aqueous anthocyanin-based extracts from purple carrots compared to synthetic and natural food colourants. *Food Chemistry*, *387*:1–42. https://doi.org/10.1016/j.foodchem.2022.132893

Petrovic, S., Bita, B., & Barbinta-Patrascu, M. E. (2024). Nanoformulations in pharmaceutical and biomedical applications: green perspectives. *International Journal of Molecular Sciences*, *25*(11):1–67. https://doi.org/10.3390/ijms25115842

Preeti, Sambhakar, S., Malik, R., Bhatia, S., Al Harrasi, A., Rani, C., Saharan, R., Kumar, S., Geeta, & Sehrawat, R. (2023). Nanoemulsion: an emerging novel technology for improving the bioavailability of drugs. *Scientifica*, *2023*:1–25. https://doi.org/10.1155/2023/6640103

Rabelo, C. A. S., Taarji, N., Khalid, N., Kobayashi, I., Neves, M. A., & Nakajima, M. (2017). Development and characterization of W/O nanoemulsions loaded with anthocyanins [Paper presentation]. 18th Annual Meeting of the Japan Society of Food Engineering, Osaka, Japan. https://shorturl.at/ol7aQ

Rabelo, C. A. S., Taarji, N., Khalid, N., Kobayashi, I., Nakajima, M., & Neves. M. A. (2018). Formulation and characterisation of water-in-oil nanoemulsions loaded with açaí berry anthocyanins: insights of degradation kinetics and stability evaluation of anthocyanins and nanoemulsions. *International Food Research*, *106*:542–548. https://doi.org/10.1016/j.foodres.2018.01.017

Ravichandran, K., Saw, N. M. M. T., Mohdaly, A. A. A., Gabr, A. M. M., Kastell, A., Riedel, H., Cai, Z., Knorr, D., & Smetanska, I. (2013). Impact of processing of red beet on betalain content and antioxidant activity. *International Food Research Journal*, *50*(2):670–675. https://doi.org/10.1016/j.foodres.2011.07.002

Reshmi, S. K., Aravindhan, K. M., & Suganya Devi, P. (2012). The effect of light, temperature, and pH on the stability of betacyanin pigments in *Basella Alba* fruit. *Asian Journal of Pharmaceutical and Clinical Research*, *5*(1):107–110. https://innovareacademics.in/journal/ajpcr/Vol5Issue4/1275.pdf

Rochín-Wong, S., & Vélaz Rivas, I. (2022). Lipid and polymeric nanocapsules. In L. J. Villarreal-Gómez (Ed.), *Drug carriers*. IntechOpen. https://doi.org/10.5772/intechopen.103906

Rodriguez-Amaya, D. B. (2019). Update on natural food pigments - a mini-review on carotenoids, anthocyanins, and betalains. *International Food Research Journal*, *124*:200–205. https://doi.org/10.1016/j.foodres.2018.05.028

Sabu, S., Vismaya, A., Chithira, C. S., Sasi, S., Murali, V., Bhagyalakshmi, A. S., & Mahesh, A. (2022). Formulation and evaluation of herbal lipsticks by using *Beta vulgaris. International Journal of Pharmaceutical Sciences Review and Research, 75*(1):98–102. http://dx.doi.org/10.47583/ijpsrr.2022.v75i01.017

Sadowska-Bartosz, I., & Bartosz, G. (2021). *Biological properties and applications of betalains. Molecules, 26*(9):1–36. https://doi.org/10.3390/molecules26092520

Sai Datri, A., Lakshmana Rao, A., B. D. VVinayaki, M., Zakir, Md., Sri Snigdhanjani, M., & Pavani, N. (2022). Formulation and evaluation of herbal lipstick using *Rosa* 'Mister Lincoln'. *International Journal of Medical Laboratory Research*, *7*(2):18–23. http://doi.org/10.35503/IJMLR.2022.7204

Salvioni, L., Morelli, L., Ochoa, E., Labra, M., Fiandra, L., Palugan, L., Prosperi, D., & Colombo, M. (2021). The emerging role of nanotechnology on skincare. *Advances in Colloid and Interface Science, 293:*1–35**.** https://doi.org/10.1016/j.cis.2021.102437

Sari, R. A., Pranoto, Y., Setiowati, A. D., Kartini, I. (2026). Ultrasound-assisted extraction of betacyanin from dragon fruit (*Hylocereus polyrhizus*) for sustainable natural colourant production. *Sustainable Food Technology*, *2026*:1–18. https://doi.org/10.1039/d5fb00719d

Sendri, N., Singh, S., Sharma, B., Purohit, R., & Bhandari, P. (2023). Effect of co-pigments on anthocyanins of Rhododendron arboreum and insights into interaction mechanism. *Food Chemistry*, *426*:1–20. https://doi.org/10.1016/j.foodchem.2023.136571

Setyawaty, R., Noviani, D., & Dewanto, D. (2020). The usage of extract of purple fleshed sweet potato (*Ipomoea Batatas* L.) as lipstick colour. *Majalah Obat Tradisional*, *25*(2):126–131. https://doi.org/10.22146/mot.52702

Shafqat, O., Rehman, Z., Shah, M. M., Ali, S. H. B., Jabeen, Z., & Rehman, S. (2023). Synthesis, structural characterization and in vitro pharmacological properties of betanin-encapsulated chitosan nanoparticles. *Chemico-Biological Interactions*, *370*:110291. https://doi.org/10.1016/j.cbi.2022.110291

Shaker, D. S., Ishak, R. A. H., Ghoneim, A., & Elhuoni, M. A. (2019). Nanoemulsion: a review on mechanisms for the transdermal delivery of hydrophobic and hydrophilic drugs. *Scientia Pharmaceutica*, *87*(3):1–34. https://doi.org/10.3390/scipharm87030017

Sharma, M., Hussain, S., Shalima, T., Aav, R., & Bhat, R. (2022). Valorisation of seabuckthorn pomace to obtain bioactive carotenoids: an innovative approach of using green extraction techniques (ultrasonic and microwave-assisted extractions) synergised with green solvents (edible oils). *Industrial Crops and Products*, *175*:1–9. https://doi.org/10.1016/j.indcrop.2021.114257

Shoueir, K. R., El-Desouky, N., Rashad, M. M., Ahmed, M. K., Janowska, I., & El-Kemary, M. (2021). Chitosan based-nanoparticles and nanocapsules: Overview, physicochemical features, applications of a nanofibrous scaffold, and bioprinting. *International Journal of Biological Macromolecules*, *167*:1176–1197. https://doi.org/10.1016/j.ijbiomac.2020.11.072

Silva Nieto, R., Samaniego López, C., Moretton, M. A., Lizarraga, L., Chiappetta, D. A., Alaimo, A., & Pérez, O. E. (2023). Chitosan-based nanogels designed for betanin-rich beetroot extract transport: physicochemical and biological aspects. *Polymers*, *15*(19):1–25.
https://doi.org/10.3390/polym15193875

Singh, T., Shukla, S., Kumar, P., Wahla, V., & Bajpai, V. K. (2017). Application of nanotechnology in food science: perception and overview. *Frontiers in Microbiology*, *8*:1–7.
https://doi.org/10.3389/fmicb.2017.01501

Ștefănescu, R., & Marian, R. (2023). Bilberry anthocyanins - possible applications in skincare products. *Acta Biologica Marisiensis*, *6*(1):54–61.
https://doi.org/10.2478/abmj-2023-0005

Strnad, S., & Zemljič, L. F. (2023). Cellulose-chitosan functional biocomposites. *Polymers*, *15*(2):1–27.
https://doi.org/10.3390/polym15020425

Sukmawati, A., Marthadilla, C. C., Risdiyanti, I. V. (2024). Improving the stability of betanin in beetroot (*Beta vulgaris*, Linn) extract using chitosan microparticle. *International Journal of Applied Pharmaceutics*, *16*(6):1–5.
https://journals.innovareacademics.in/index.php/ijap/article/view/52786

Trindade, I. C., Pound-Lana, G., Pereira, D. G. S., de Oliveira, L. A. M., Andrade, M. S., Vilela, J. M. C., Postacchini, B. B., & Mosqueira, V. C. F. (2018). Mechanisms of interaction of biodegradable polyester nanocapsules with non-phagocytic cells. *European Journal of Pharmaceutical Sciences*, *124*:89–104.
https://doi.org/10.1016/j.ejps.2018.08.024

Vieira Teixeira da Silva, D., dos Santos Baião, D., de Oliveira Silva, F., Alves, G., Perrone, D., Mere Del Aguila, E., & Flosi Paschoalin, V. M. (2019). Betanin, a natural food additive: stability, bioavailability, antioxidant and preservative ability assessments. *Molecules*, *24*(3):1–15.
https://doi.org/10.3390/molecules24030458

Wang, L., Wang, L., Wang, X., Lu, B., & Zhang, J. (2021). Preparation of blueberry anthocyanin liposomes and changes of vesicle properties, physicochemical properties, in vitro release, and antioxidant activity before and after chitosan modification. *Food Science and Nutrition*, *10*(1):75–87.
https://doi.org/10.1002/fsn3.2649

Wang, M., Li, L., Wan, M., Lin, Y., Tong, Y., Cui, Y., Deng, H., Tan, C., Kong, Y., & Meng, X. (2020). Preparing, optimising, and evaluating chitosan nanocapsules to improve the stability of anthocyanins from *Aronia melanocarpa*. *RSC Advances*, *11*(1):210–218.
https://doi.org/10.1039/d0ra08162k

Wang, Z., Zhang, Y., Tu, Z., Yu, C., Liu, R., Deng, Z., & Luo, T. (2024). The degradation and antioxidant capacity of anthocyanins from eggplant peels in the context of complex food system under thermal processing. *Food Bioscience*, *59*:103914.
https://doi.org/10.1016/j.fbio.2024.103914

Wong, Y. M., & Siow, L. F. (2015). Effects of heat, pH, antioxidant, agitation and light on betacyanin stability using red-fleshed dragon fruit (*Hylocereus Polyrhizus*) juice and concentrate as models. *Journal of Food Science and Technology*, *52*(5):1–7.
https://doi.org/10.1007/s13197-014-1362-2

Woo, K. K., Ngou, F. H., Ngo, L. S., Soong, W. K., & Tang, P. Y. (2011). Stability of betalain pigment from red dragon fruit (*Hylocereus Polyrhizus). Journal of Food and Nutrition Research*, *6*(2):140–148.
https://doi.org/10.3923/ajft.2011.140.148

Xue, H., Zhao, J., Wang, Y., Shi, Z., Xie, K., Liao, X., & Tan, J. (2024). Factors affecting the stability of anthocyanins and strategies for improving their stability: a review. *Food chemistry X*, *24*:101883.
https://doi.org/10.1016/j.fochx.2024.101883

Yin, M., Song, J., Zhou, X., Zhang, W., & Wu, A. (2023). Preparation of blueberry anthocyanin nanoemulsion and its stability and skin safety evaluation. *Materials Research and Development*, *2*:1–11.
https://doi.org/10.21203/rs.3.rs-1184938/v1

Zhao, L., Fan, H., Zhang, M., Chitrakar, B., Bhandari, B., & Wang, B. (2019). Edible flowers: review of flower processing and extraction of bioactive compounds by novel technologies. *Food Research International*, *126*:108660.
https://doi.org/10.1016/j.foodres.2019.108660

Zhao, Y., Zhang, Z., Pan, Z., & Liu, Y. (2021). Advanced bioactive nanomaterials for biomedical applications. *Exploration*, *1*(3):1–29. 20210089.
https://doi.org/10.1002/EXP.20210089

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