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CYCLODEXTRINS IN COSMETIC FORMULATIONS: EMERGING ROLE AS SOLUBILITY ENHANCERS, STABILIZERS AND FUNCTIONAL CARRIERS

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ABSTRACT

Cyclodextrins (CDs) have been known for over a century, yet their relevance in formulation science continues to expand. In both pharmaceutical and cosmetic applications, these molecules are valued for their ability to interact with hydrophobic compounds and form inclusion complexes. In the context of cosmetic formulations, this property becomes particularly useful when dealing with ingredients that show limited solubility in water. Over time, cyclodextrins have been increasingly explored not only for improving solubility, but also for enhancing the stability and availability of active ingredients on the skin. This review discusses their structural features, the mechanism of inclusion complex formation, and their practical role in cosmetic systems. Particular attention is given to their use as solubility enhancers for compounds such as vitamins, essential oils, and UV filters, which are otherwise difficult to formulate. In addition, their contribution to fragrance stabilization, controlled release behavior, and overall skin compatibility is considered. Safety aspects, regulatory considerations, and emerging trends in cosmeceutical applications are also briefly addressed to provide a more complete perspective.

KEYWORDS: Cyclodextrins, inclusion complex, solubility enhancement, cosmetic formulation, controlled release, cosmeceuticals.

INTRODUCTION

In recent years, the cosmetic and personal care industry has gradually moved toward formulations that are not only aesthetically appealing but also scientifically validated. Consumers today tend to expect more than just visible results—they look for products that are stable, safe to use over time, and capable of delivering consistent performance. This shift has naturally encouraged formulators to explore more efficient excipients and delivery approaches.

One of the persistent challenges in formulation development is the incorporation of active ingredients that do not dissolve easily in water. A large number of cosmetic actives, including retinoids, fat-soluble vitamins, essential oils, and several antioxidants, are inherently lipophilic. Because of this, they often show poor dispersion in aqueous bases and may degrade when exposed to light or oxygen (Loftsson & Brewster, 2011; Del Valle, 2004). In practical terms, this can lead to reduced effectiveness as well as stability concerns during storage.

To overcome such limitations, cyclodextrins have gained attention as functional excipients that offer a relatively simple yet effective solution. These molecules are cyclic oligosaccharides with a distinct structural arrangement—a hydrophilic exterior and a comparatively hydrophobic internal cavity. This configuration allows them to interact with lipophilic molecules and accommodate them within the cavity through non-covalent interactions, forming inclusion complexes (Brewster & Loftsson, 2007).

This encapsulation process brings several formulation advantages. It can increase the apparent solubility of poorly soluble compounds, protect sensitive actives from degradation, and in some cases, modify how the active is released from the formulation. Another practical benefit is the potential reduction in skin irritation, as the direct exposure of potent ingredients may be limited (Loftsson et al., 2005). Because of these combined effects, cyclodextrins are now being explored across a range of cosmetic products, including skincare, hair care, and fragrance formulations.

RESEARCH GAP AND SCOPE OF THE REVIEW

While cyclodextrins have been extensively investigated in pharmaceutical research, their role in cosmetic formulations has not been examined in equal depth from a formulation-oriented perspective. Much of the available literature tends to focus on drug delivery applications,

whereas cosmetic-specific considerations—such as sensory characteristics, long-term stability in multiphase systems, and compatibility with common cosmetic excipients—are discussed less frequently.

There is also limited consolidated information that clearly presents cyclodextrins as both solubility enhancers and multifunctional carriers within cosmetic systems. In addition, practical aspects such as selecting the appropriate type of cyclodextrin, optimizing concentration, and addressing cost implications during scale-up are not always covered in detail.

Emerging areas, including their use in herbal formulations, nano-enabled delivery systems, and sustainable cosmetic products, are still developing and remain underrepresented in current reviews. These gaps highlight the need for a more focused discussion tailored to cosmetic applications.

The present review therefore attempts to bring together these aspects by examining the role of cyclodextrins specifically in cosmetic formulations. Emphasis is placed on their function as solubility enhancers, while also considering their broader impact on stability, delivery, and formulation performance. The aim is to provide a clearer and more application-oriented understanding that may be useful for both researchers and formulation scientists.

STRUCTURE AND TYPES OF CYCLODEXTRINS

Cyclodextrins are cyclic oligosaccharides formed by glucose units linked through α-1,4 glycosidic bonds. The three commonly used types—α-, β-, and γ-cyclodextrins—differ primarily in the number of glucose units they contain, which in turn influences their cavity size and inclusion capacity (Szejtli, 1998; Jansook et al., 2018).

- α-cyclodextrin (6 glucose units)
- β-cyclodextrin (7 glucose units)
- γ-cyclodextrin (8 glucose units)

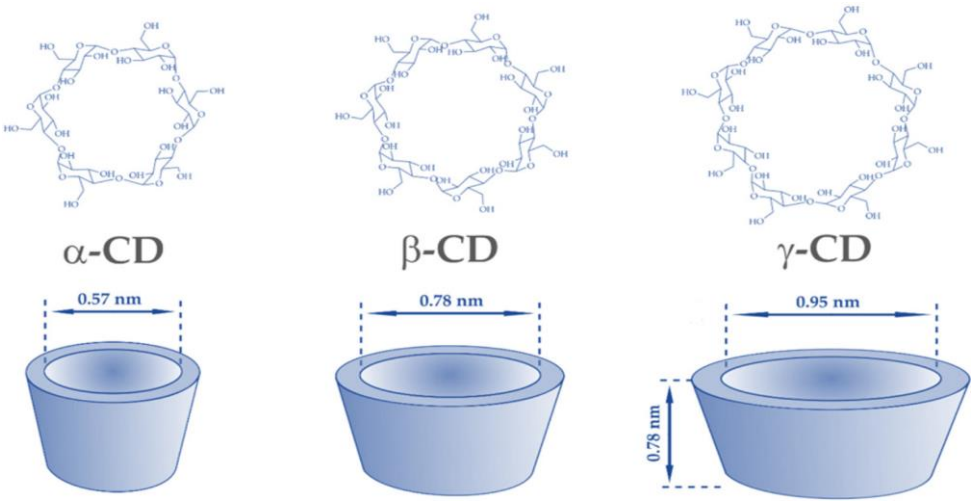

Figure 1: Structure of Cyclodextrins (α, β, γ types showing cavity differences).

Structurally, these molecules resemble a truncated cone. The outer surface is hydrophilic due to the presence of hydroxyl groups, whereas the inner cavity is relatively hydrophobic. This dual character enables them to interact simultaneously with aqueous environments and lipophilic guest molecules (Del Valle, 2004).

Because of this unique arrangement, these molecules are capable of hosting hydrophobic compounds within their cavity, forming inclusion complexes without altering the chemical structure of the guest molecule. Over time, several modified derivatives—such as hydroxypropyl-β- cyclodextrin—have been developed to address limitations of native cyclodextrins. These derivatives typically show improved water solubility and better safety profiles, making them more suitable for cosmetic and pharmaceutical use (Stella & He, 2008).

Mechanism of Inclusion Complex Formation

The formation of inclusion complexes between cyclodextrins and guest molecules is primarily driven by relatively weak, non-covalent interactions. These include van der Waals forces, hydrophobic interactions, and, in some cases, hydrogen bonding. Since these interactions are reversible and do not involve the formation of new chemical bonds, the original structure of the guest molecule remains intact (Carrier et al., 2007).

When a hydrophobic molecule comes into proximity with a cyclodextrin, it tends to enter the inner cavity, where the environment is more favorable for non-polar compounds. At the same time, the hydrophilic exterior of the cyclodextrin allows the overall complex to remain compatible with aqueous surroundings (Brewster & Loftsson, 2007).

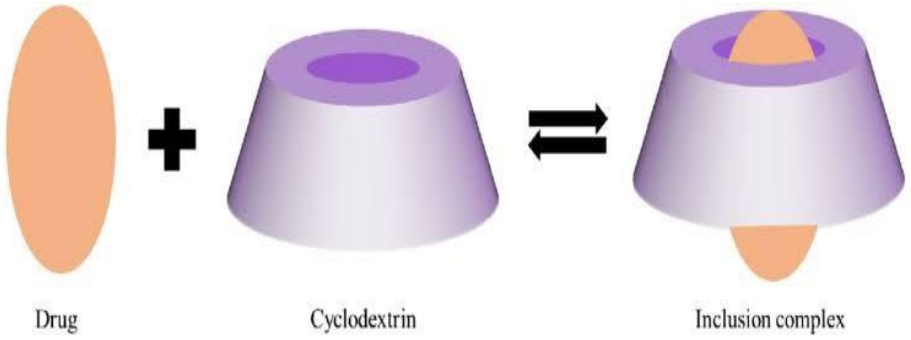

Figure 2: Mechanism of Inclusion Complex Formation between cyclodextrin and guest molecule.

This inclusion process leads to several practical benefits. The apparent solubility of the guest molecule increases, and its exposure to environmental stressors—such as light, heat, and oxygen— is reduced. As a result, the stability of sensitive ingredients improves. In the case of volatile substances like essential oils, partial encapsulation can also help minimize evaporation (Loftsson & Duchêne, 2007). Another important aspect of this system is its dynamic nature. The complex can dissociate under suitable conditions, allowing the guest molecule to be released when required. This reversible behavior makes cyclodextrins particularly useful in formulations where a controlled or sustained release of active ingredients is desirable (Matencio et al., 2021).

Cyclodextrins as Solubility Enhancers

Among the various functional roles of cyclodextrins in cosmetic science, their ability to improve the solubility of poorly water-soluble actives stands out as one of the most practically useful. Many ingredients commonly used in cosmetics—particularly vitamins, essential oils, and plant-derived compounds—are predominantly lipophilic. Because of this, incorporating them into water-based systems such as gels, lotions, or serums often becomes a formulation challenge.

When such actives are not adequately solubilized, a number of issues may arise, including uneven distribution within the formulation, reduced bioavailability on application, and instability during storage. In some cases, these limitations can even affect the visual appearance of the product, leading to turbidity or phase separation (Challa et al., 2005).

Cyclodextrins offer a relatively straightforward way to address these concerns. By acting as molecular hosts, they can accommodate hydrophobic molecules within their internal cavity, thereby improving their apparent solubility in aqueous environments. An important advantage

here is that this can be achieved without relying on aggressive solvents or overly complex formulation strategies. As a result, cyclodextrins are increasingly considered valuable tools in the design of stable and efficient cosmetic systems (Kurkov & Loftsson, 2013).

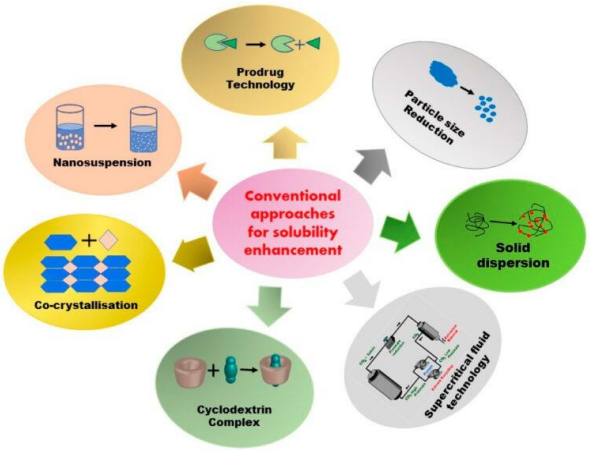

Figure 3: Conventional vs Cyclodextrin-Based Solubility Enhancement.

4.1 Mechanism of Solubility Enhancement

The solubility-enhancing effect of cyclodextrins is closely linked to their ability to form inclusion complexes with hydrophobic molecules. When a poorly soluble compound comes into contact with cyclodextrins, it may partially or completely enter the inner cavity. This cavity provides a more favorable microenvironment for non-polar substances, allowing them to interact more effectively with the surrounding aqueous phase. Consequently, the apparent solubility of the compound increases (Brewster & Loftsson, 2007; Loftsson & Brewster, 2011).

Another factor that contributes to improved solubility is the alteration of the physical state of the active ingredient. Many lipophilic compounds exist in a highly ordered crystalline form, which limits their dissolution rate. Upon complexation, this crystalline structure may be disrupted, resulting in a more amorphous form that dissolves more readily (Higuchi & Connors, 1965).

In addition to this, cyclodextrins promote better dispersion of active ingredients within the formulation. Rather than aggregating or separating over time, the encapsulated molecules tend to remain more uniformly distributed. This not only improves solubility but also contributes to overall formulation stability and consistency (Kurkov & Loftsson, 2013).

4.2 Examples in Cosmetic Applications

Cyclodextrins have been successfully applied to a variety of cosmetic ingredients, particularly those that are sensitive or difficult to formulate.

For instance, vitamins such as vitamin A and vitamin E are known to be unstable when exposed to environmental factors like light and oxygen. When incorporated into cyclodextrin complexes, these molecules exhibit improved stability and become easier to incorporate into aqueous formulations (Loftsson et al., 2005).

Essential oils present another interesting example. While they are widely valued for their functional and sensory benefits, their volatility often limits their long-term effectiveness. Encapsulation within cyclodextrins can help reduce their evaporation rate and preserve their activity over time (Fenyvesi & Szente, 2008).

In sunscreen formulations, certain UV filters show limited water solubility, which can lead to uneven application on the skin. Cyclodextrins assist in improving their dispersion, thereby supporting more uniform and reliable sun protection (Davis & Brewster, 2004).

Similarly, plant extracts used in herbal cosmetics often contain bioactive compounds with low solubility and poor bioavailability. Complexation with cyclodextrins can enhance their dissolution and improve their functional performance in topical applications (Astray et al., 2009).

4.3 Advantages in Cosmetic Formulations

The use of cyclodextrins as solubility enhancers brings several advantages from both a formulation and performance perspective. One of the most immediate benefits is improved efficacy. When active ingredients are present in a more soluble form, they are more readily available to interact with the skin, which can enhance their overall effectiveness (Challa et al., 2005).

Cyclodextrins may also support better penetration of certain actives by maintaining them in a dissolved and bioavailable state. At the same time, they can help reduce irritation by moderating how quickly potent ingredients are released onto the skin (Loftsson et al., 2005).

From a formulation standpoint, their inclusion often leads to improved product aesthetics. Issues such as precipitation, turbidity, or phase separation are less likely to occur, resulting in

products that are not only more stable but also visually appealing (Loftsson, 1998).

Applications in Cosmetic Formulations

Cyclodextrins are now used across a wide range of cosmetic products, largely due to their multifunctional nature. While their role as solubility enhancers is well recognized, they also contribute to improved stability, controlled release, and overall formulation performance (Del Valle, 2004; Brewster & Loftsson, 2007).

They are particularly useful in products containing sensitive or poorly soluble ingredients such as retinoids, antioxidants, and fragrance components. The increasing presence of cyclodextrins in commercial formulations reflects their practical value and growing acceptance within the cosmetic industry (Astray et al., 2009).

Table 1: Marketed Cosmetic Products Containing Cyclodextrins.

Sr. No.	Product Name	Brand	Product Type	Key Function of Cyclodextrin	Applicatio n Area
1	Retinol Intelligent Repair Serum	skinChemist s London	Serum	Stabilization of retinol, solubility enhancement	Anti-aging skincare
2	Crystal Retinal 20	Medik8	Serum	Controlled release of retinal	Advanced
3	Phytoestrogen Elasticity Renewal Serum	Paulaâ€™s Choice	Serum	Improved bioavailability of actives	Anti-aging
4	Vitamin C Anti-Ox Serum	Radiance Cosmetics	Serum	Protection from oxidation	Antioxidant skincare
5	Anti-Acne Gel	Fixderma	Gel	Enhanced delivery of actives	Acne
6	Green Tea Alcohol-Free	Plum	Toner	Stabilization of plant extracts	Daily
7	Daily Hydrating	Olay	Cleanser	Improved dispersion of	Cleansing
8	Underarm Roll-On	Chemist at	Deodoran	Odor trapping and controlled	Personal
9	Deo Pure Antiperspirant Cream	Biotherm	Deodoran t cream	Encapsulation of odor molecules	Sweat/odor control
10	Sensitive Gel-CrÃ¨me SPF 50+	Cetaphil Daylong	Sunscree n	Improved solubility & photostability of UV filters	Sun protection

5.1 Skin Care Products

In skincare formulations such as creams, lotions, and gels, cyclodextrins are often used to improve the delivery of active ingredients. Many skincare actives require a controlled release profile to remain effective while minimizing irritation. Cyclodextrins help achieve this by

forming inclusion complexes that allow the active to be released gradually over time (Loftsson et al., 2005).

This gradual release can improve skin compatibility, particularly for potent ingredients. By reducing direct and immediate exposure, the likelihood of irritation or sensitivity may be minimized. At the same time, sustained release ensures that the active remains available over a longer duration, enhancing overall product performance.

5.2 Fragrance and Deodorant Systems

In fragrance-based formulations, cyclodextrins play a key role in improving scent longevity. Volatile aromatic compounds tend to evaporate quickly, which limits their lasting effect. When encapsulated within cyclodextrins, their release becomes more gradual, resulting in prolonged fragrance perception (Fenyvesi & Szente, 2008).

In deodorant systems, cyclodextrins can also act as odor-trapping agents. By binding to odor-causing molecules, they help reduce their perception and contribute to improved product effectiveness.

5.3 Hair Care Products

Cyclodextrins are also useful in hair care formulations, where they help stabilize oils and conditioning agents that may otherwise degrade or separate. In addition, they can improve the deposition of these ingredients onto the hair surface, leading to better conditioning effects (Pinho et al., 2014).

This often translates into improved texture, shine, and manageability of hair, making them valuable components in shampoos, conditioners, and serums.

5.4 Sunscreen Formulations

In sunscreen products, cyclodextrins assist in improving the solubility and distribution of UV filters. This helps ensure more uniform coverage on the skin, which is essential for effective sun protection (Davis & Brewster, 2004).

They may also enhance photostability by providing a degree of protection against degradation caused by sunlight exposure.

Advantages of Cyclodextrins in Cosmetics

Cyclodextrins are generally considered safe and compatible with the skin, which supports their use in a wide range of cosmetic applications (Stella & He, 2008). One of their key advantages is their ability to stabilize sensitive ingredients by shielding them from environmental factors such as light, heat, and oxidation.

They can also reduce irritation by controlling the release of active compounds, preventing sudden exposure to high concentrations. In addition, their role in sustained release helps improve product performance and prolong the duration of action.

Another practical benefit is improved shelf-life. By minimizing issues such as precipitation, phase separation, and loss of volatile components, cyclodextrins contribute to maintaining product quality over time (Hedges, 1998).

Limitations of Cyclodextrins

Despite their many advantages, cyclodextrins are not without limitations. Modified derivatives, although more effective, can be relatively costly, which may increase formulation expenses, particularly in large-scale production (Jansook et al., 2018).

Their effectiveness also depends on the compatibility between the size of the guest molecule and the cavity of the cyclodextrin. Not all compounds can form stable inclusion complexes, which limits their universal applicability.

Additionally, formulation parameters such as concentration, pH, and temperature need to be carefully optimized, as they can influence the efficiency and stability of complex formation.

FUTURE PERSPECTIVES

Looking ahead, cyclodextrins are expected to play an increasingly important role in advanced cosmetic formulations. Their combination with nanotechnology-based systems offers promising opportunities for improving skin penetration and enabling more precise control over the release of active ingredients (Ribeiro et al., 2020).

They are also likely to find broader use in herbal and natural formulations, where challenges related to solubility and stability are particularly common (Astray et al., 2009).

In targeted skincare applications, especially in anti-aging products, cyclodextrins may help

enhance the delivery of actives while reducing irritation. Continued research into modified and polymer- based systems is expected to further expand their potential in this area.

CONCLUSION

Cyclodextrins have established themselves as highly useful components in cosmetic formulations, particularly due to their ability to improve solubility, stability, and delivery of active ingredients. Their multifunctional nature allows them to be applied across a wide range of product types, from skincare to fragrance systems.

As formulation technologies continue to evolve, the importance of cyclodextrins is likely to grow, especially when combined with emerging delivery approaches. With appropriate selection and optimization, they offer significant potential for developing more effective, stable, and user-friendly cosmetic products (Loftsson & Brewster, 2011)

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