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Study on Hyaluronic Acid and Its Applications in Cosmetics

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Abstract. This paper examines the role of hyaluronic acid (HA) in cosmetics, focusing on the challenges of rapid degradation and limited penetration that reduce its effectiveness. The purpose of the paper is to evaluate how molecular weight and formulation design influence the stability of HA and their performance. Specifically, it investigates how adjusting the range of molecular weight could affect HA's ability to act on different skin layers, meanwhile focus on optimized formulations address its inherent instability issues. Recent research was included to compare conventional HA with modified approaches such as nano-carriers and cross-linked hydrogels. Evidence shows that these modified systems prolong hydration time, enhance skin barrier recovery, and improve the stability of HA structure. For example, employment of nano-carriers promotes deeper epidermal penetration, whereas cross-linked hydrogels form robust polymeric networks that resist enzymatic degradation. Collectively, these findings suggest that HA is transitioning from a short-term moisturizer to a multifunctional ingredient with a wide range of potential uses in cosmetics.

Keywords: Hyaluronic acid, nano-carrier, cosmetics formulations, Skin hydration, Cross-linked hydrogels.

1. Introduction

In recent years, cosmetics are often designed to do more than give basic coverage. Companies add ingredients in their formulations that can alter skin properties, like keeping it hydrated or making it more elastic. One of the most common of these ingredients is hyaluronic acid (HA). HA is a glycosaminoglycan found in the extracellular matrix, and it is well known for binding large amounts of water. Because of that, it's frequently showing up in moisturizers and serums to smooth and hydrating the skin. HA has also widely been used for it's good safety record and is well tolerated [1].

Even with these advantages, HA in its natural form does not last very long on the skin. Enzymes, oxidative stress, and UV light can all break it down quickly, so the effect is usually short-lasting. Researchers have looked for ways to improve its stability and functionality when applying in formulations. For example, by changing the molecular weight, cross-linking between chains, and using nanocarriers to encapsulate HA [2]. These modifications can slow down degradation, keep hydration time longer, and lower irritation that sometimes comes with higher concentrations.

Current studies also show that the role of HA depends strongly on its molecular weight. Larger molecules usually remain on the surface of the skin, forming a film that helps reduce trans epidermal water loss. In contrast, smaller HA fragments can penetrate epidermis and contribute to elasticity and hydration at a deeper level. Anti-aging effects, such as wrinkle reduction, are often linked to blends that combine both high- and low-molecular-weight HA. In addition, more advanced systems, including nanocarriers and cross-linked hydrogels, have demonstrated improved stability and longer activity compared to unmodified HA [1,3]. Altogether, these findings suggest that HA is no longer only a short-term moisturizer but is developing into a multifunctional cosmetic ingredient with broader applications

2. Properties of Hyaluronic Acid

HA is an important member of glycosaminoglycan (GAGs) family, a highly polymerized macromolecular chemical structure, that naturally occurred in all living organisms. It is widely distributed in human body, especially the extracellular matrix of the tissue [4]. Noticeably, HA is synthesized by hyaluronan synthase enzymes on the cytoplasmic surface of the plasma membrane rather than by rough endoplasmic reticulum and Golgi apparatus like other GAGs. HA is built from repeating disaccharides of N-acetyl-D-glucosamine and D-glucuronic acid, which are linked alternately through β-1,3 and β-1,4 bonds [2]. Because of this repeating structure, HA forms long, unbranched chains that can reach molecular weights from a few kilodaltons up to several million Daltons, depending on how it is sourced and processed [5]. Functional groups along the backbone, such as hydroxyl and carboxyl groups, allow HA to interact strongly with water molecules through hydrogen bonding, which is the basis of its strong water-binding capacity.

In solution, HA is highly hydrophilic and produces viscous, gel-like systems even at relatively low concentrations [5]. Its physical behavior is closely tied to molecular weight. High-molecular-weight (HMW) HA, often above 1,000 kDa, tends to form dense, viscoelastic films on the skin surface, which help reduce transepidermal water loss (TEWL). Smaller HA molecules, usually under 200 kDa, are able to pass into the upper layers of the epidermis more easily than larger forms. This allows them to contribute to skin elasticity and provide hydration from within the tissue, rather than only on the surface [5]. In practice, many cosmetic formulations now use blends of HA with different molecular weights. This approach gives a "layered" benefit, where high-molecular-weight HA forms a film to limit water loss at the surface, while lower-molecular-weight HA penetrates further to support longer-lasting moisture [4].

Even though HA is generally safe for skin use, its natural form doesn't last long in real-world conditions. Enzymes like hyaluronidases, UV exposure, oxidative stress, and fluctuations in pH can all lead to the breakdown of HA, which in turn harm the moisturizing, smoothing, or firmness effects and those effects wear off quickly [2]. To make HA last longer, researchers have developed a number of chemical modification methods. Natural HA does not remain stable for long once it is applied to skin. Enzymes such as hyaluronidases, along with oxidative stress, can rapidly degrade the polymer and shorten its effect [2]. Because of this limitation, many studies have looked at ways to modify HA so it lasts longer in cosmetic use. One approach is crosslinking the chains, which makes the network more resistant to enzymatic attack [6]. Another strategy is incorporating HA into hydrogel systems or combining it with stabilizing agents that reduce breakdown, which helps it retain water for extended periods [7]. These changes are important because they shift HA from a simple short-term moisturizer to an ingredient that can provide more durable benefits, including skin hydration, repair, and anti-aging support.

3. Mechanism

The reason why HA is so widely used in skin care is mainly tied to its strong water-binding properties and its role in skin biology. HA is built from repeating disaccharides that contain hydroxyl and carboxyl groups, and these functional groups give the polymer its hydrophilic character. Because of this, HA can attract and hold a large number of water molecules. In the skin, this helps keep the stratum corneum hydrated and lowers trans epidermal water loss (TEWL), which is why products containing HA often improve surface moisture right after application [2].

The molecular weight of HA changes how it behaves once applied [8]. Larger chains, usually called high-molecular-weight (HMW) HA, tend to stay on the outer surface of the skin and form a thin, gel-like layer that slows water evaporation. In contrast, smaller chains, or low-molecular-weight (LMW) HA, can move more easily into the upper layers of the epidermis. Smaller HA chains can move past the surface film and reach into the upper epidermis. In that region, they contribute to hydration but also seem to play a role in keeping the barrier flexible and intact [8]. Because HMW HA mainly works at the surface while LMW HA can reach deeper, many modern cosmetic products use both forms in the same formula. This approach allows for a fast surface effect together with longer-lasting activity below the stratum corneum.

HA does more than hold water. Shorter fragments are able to interact with receptors such as CD44 and RHAMM on skin cells. When this happens, fibroblasts can become more active, extracellular matrix components are produced, and in some cases inflammatory responses are adjusted [2]. These receptor interactions explain why HA is also connected to wound healing and anti-aging effects, not just surface moisture. In general, HA works through three overlapping routes: it binds water at the surface, smaller fragments can move into epidermal layers, and receptor binding leads to biological responses. This combined activity is the reason HA is treated as more than a simple humectant in cosmetic science.

4. Applications in Skin Care

HA is one of the most widely used ingredients in modern cosmetic formulations due to its excellent hydrating and anti-aging effects. Its strong water-binding ability makes it highly effective in maintaining skin hydration, reducing transepidermal water loss (TEWL), thus maintaining skin hydration. Moreover, recent studies have demonstrated that the performance of haluoronic acid depends not only on its inherent chemcial properties but also on how it is processed, modified and delivered in formulations [1].

4.1. Nano-Delivery of Hyaluronic Acid

One problem with regular HA in creams or serums is that large HA molecules often don't penetrate well, so most of their effect is just surface-moisture. To improve this, nano-HA (or smaller molecular weight HA in nanoformulations) has been developed for topical use. The goal: better penetration, stronger hydration, and longer lasting effects [9].

A recent paper by Mehmood et al. (2024) studied a solid lipid nanoparticle (SLN) formulation that contains HA + tretinoin for skin application [3]. They made a nano-carrier system so that HA is more stable and can deliver its hydrating function more deeply. In tests on skin model systems and some human skin safety assessments, the SLN-HA formulation improved hydration and reduced skin roughness more than some control creams after repeated application. The nano-form helped protect HA from degradation (from environment or enzymes) and improved its retention in the stratum corneum. That means the product offers better hydration over a longer period than standard HA creams without nano-carriers.

From a cosmetic product perspective, this shows nano formulations can shift HA from being just a quick fixer to something with more lasting effect. For example, if you're using nano-HA in an SLN or similar nanocarrier, you could expect more "all-day" hydration, reduced tightness, smoother texture, and possibly less frequent reapplication. This is useful in moisturizers and serums where customers want visible results (moisture, plumpness, texture) but also convenience.

Also, molecular weight still matters. In the same paper and other newer studies, low- or medium molecular weight HA in nanoform seems to reduce wrinkles and improve elasticity more strongly than high molecular weight HA when used topically. That's probably because smaller HA + nano-carrier can move into upper epidermal layers better.

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4.2. Cross-Linked Hyaluronic Acid in Anti-Wrinkle Applications

HA is a popular ingredient in skincare because it can hold large amounts of water, but in its natural form it does not last long once applied to skin. Enzymes break it down quickly, and most of the effect is limited to surface hydration. To make HA more durable, chemists have developed cross-linked forms. Cross-linking connects the polymer chains and creates a tighter network, which slows degradation and allows the skin to stay hydrated for longer [9]. This type of modification is especially useful for topical products, where people want hydration and firmness that continue throughout the day.

A recent study by Ha et al. (2023) tested a hydrogel moisturizer made with cross-linked HA that was prepared without using harsh cross-linking chemicals [10]. The product was compared against a common moisturizer (Physiogel) in people with xerosis, a condition where skin becomes very dry and uncomfortable. Over the treatment period, the hydrogel with cross-linked HA gave clear improvements. Skin hydration increased, dryness scores decreased, and participants reported that their skin felt smoother and more comfortable. Instrument measurements also showed an improvement in barrier function, with reduced transepidermal water loss.

What stands out from this study is how cross-linked HA changes the role of a moisturizer. Instead of providing only short-term moisture, the modified HA extended the effect, giving the skin more lasting improvements in hydration and barrier support. For people with dry or photoaged skin, this means that creams or gels with cross-linked HA can help restore elasticity and visible smoothness when used consistently. The fact that the cross-linking was achieved through a safe method also shows that these modifications can be made suitable for cosmetic use without adding unnecessary irritation risk [10].

5. Outlook

Hyaluronic acid will likely continue to play a central role in cosmetics, but its use is no longer limited to surface hydration. Recent studies have tested HA nanogels and hybrid carriers to stabilize active ingredients and help them pass through the skin barrier more effectively [12] These systems also slow down enzymatic degradation, which normally shortens the lifetime of HA in the skin. Crosslinking has been used for the same reason, but the drawback is that chemical modifications can raise concerns about irritation and regulation [9].

The effect of molecular weight is another area that is not well understood. Smaller HA fragments are thought to reach deeper into the skin, while larger chains mainly stay on the surface. Even though this difference is often mentioned, direct comparisons are limited. Without those comparisons, it is still unclear which size range is best for different cosmetic purposes [10]

On the production side, there has been progress toward more sustainable methods. Instead of older extraction approaches, most HA is now produced by microbial fermentation. Using safer bacterial strains has become common, and recent work is focusing on cleaner purification to lower waste and improve yields [11,13]. These improvements are not only about efficiency but also reflect consumer demand for products made under environmentally responsible conditions.

6. Conclusion

HA is widely used in cosmetics because it holds water and helps skin stay elastic. The effect changes with molecular weight. Large molecules stay on the skin and reduce water loss. Small ones move into the epidermis and give deeper hydration. Native HA does not last long because light, oxidation, and enzymes break it down fast. Researchers have made modified forms to fix this problem. Cross-linked hydrogels and nanocarrier systems make HA more stable, keep hydration longer, and lower irritation. Studies show that products using these systems improve skin texture and comfort.

HA is also being tested together with other active ingredients, such as peptides and antioxidants. The idea is that they can hydrate the skin and repair or protect it. Many of the results are still from lab work or short trials, so more in vivo research is needed to check safety and lasting effects. Work on sustainable production, like microbial fermentation, is also growing as people want safer and more eco-friendly products.

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