



Mechanism of Emulsion Formulation and Substances in Maintaining Skin Hydration

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Submitted: 30/03/2025, Revised: 10/4/2025, Accepted: 15/05/2025, Published: 30/05/2025

ABSTRACT

Proper skin hydration is essential for maintaining healthy skin and protecting it from environmental damage. A thorough understanding of the skin's structure can help researchers identify its layers and components, leading to the development of effective skin hydration formulations. Emulsions are commonly used because they combine water and oil phases, along with ingredients that preserve hydration and enhance chemical penetration through the stratum corneum. Consequently, emulsions are prevalent in skincare and cosmetic products, which are often supplemented with humectants, occlusive agents, and emollients to enhance their efficacy. This study explores the mechanisms through which emulsions support skin hydration, focusing on the roles of water and oil in moisturizing and serving as a skin barrier, as well as the functions of humectants, occlusive agents, and emollients. In conclusion, the stratum corneum is critical for maintaining skin hydration by regulating the water and oil content within its cells and the lipid-rich intercellular spaces. Humectants, occlusive agents, and emollients each enhance hydration through unique mechanisms. We hope this article will assist researchers in developing highly effective, hydrating skincare and cosmetic products.

Keywords: Stratum corneum, skin hydration, emulsion, humectant, occlusion, emollient

1. Introduction

Skin is the largest organ of the body, covering the external surface and consisting of three main layers: the epidermis, dermis, and hypodermis (1). It accounts for approximately 15% of total body weight and is composed of layers with specialized functions. The skin fulfills multiple interconnected roles, with the epidermal layer serving as a protective barrier. The structure of the stratum corneum (SC) plays a crucial role in regulating fluid movement within the skin and maintaining moisture (2). Skin moisture primarily depends on two factors: (a) the presence of natural hygroscopic substances within corneocytes and (b) the organization of SC intercellular lipids, which act as a barrier to transepidermal water loss (TEWL). Proper hydration is essential for normal skin function, particularly for the outermost layer, the stratum corneum. Additionally, hyaluronan, typically considered a dermal component, is also present in the epidermis and is vital for maintaining normal SC structure and epidermal barrier function. Glycerol, a well-known cosmetic ingredient, is a natural endogenous humectant found in the SC. Both extrinsic and intrinsic factors influence the synthesis of natural moisturizing factor (NMF) amino acids. For example, low humidity (<10% relative humidity) inhibits the activity of hydrolytic enzymes responsible for filaggrin breakdown into amino acids, leading to skin surface dryness (3).

Dry skin is a common contributor to various skin issues. Related conditions include atopic dermatitis, discoid dermatitis, and psoriasis vulgaris. The use of moisturizers has been shown to improve these conditions. Skin moisture content varies with factors such as age,

body type, location, temperature, and season. Accurately measuring epidermal water content is essential for maintaining optimal skin hydration. Several skin analyzers typically classify moisture levels as follows: less than 33% indicates very dry skin; 34–37% is dry skin; 38–42% is normal skin; and 43–46% is considered ideally hydrated. Even normal skin without dermatoses can exhibit low moisture levels. Further research is required to better understand the underlying causes (2).

Therefore, the type and formulation of emulsion applied to the skin should be carefully considered, as it can significantly impact skin health. The aqueous and oil phases included in emulsion formulas penetrate the skin and influence hydration levels. Thus, selecting the appropriate emulsion type and optimizing the composition of both phases and their excipients is crucial for effective skin hydration.

An emulsion is a mixture of two or more immiscible liquids, where one liquid is dispersed within another, typically comprising aqueous and oil phases. The characteristics of these phases influence the formation, stability, and properties of the emulsion (4,5). Emulsion stability depends on factors such as pH and surfactant concentration, which help prevent the coalescence of droplets (6,7). Common emulsion types include oil-in-water (O/W), water-in-oil (W/O), and more complex structures like oil-in-water-in-oil (O/W/O) and water-in-oil-in-water (W/O/W) (5). Emulsions, often found in lotions and creams, are widely used in skincare and cosmetic products due to their ability to retain skin moisture. They prevent skin dryness through several mechanisms, including the formation of a protective barrier,

increased water retention, and delivery of hydrating ingredients deep into the skin. Enhanced skin hydration helps maintain moisture and reduces the appearance of fine lines and wrinkles, making emulsions particularly beneficial for individuals with dry or mature skin (8). fine lines and wrinkles, making emulsions particularly beneficial for individuals

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2. Method

This review is compiled based on international journals. The search keywords are “skin hydration” and “emulsion”. The flowchart of methodology can be seen in Figure 1.

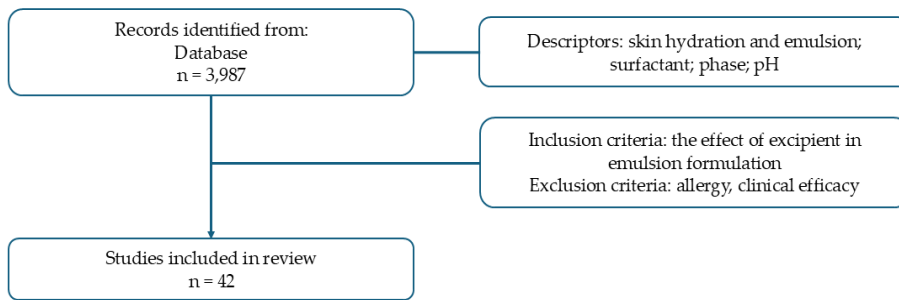


Figure 1. Flowchart of methodology

3. Result

3.1 Skin Structure

The epidermis, the outermost layer of the skin, is subdivided into several sublayers: the stratum corneum (the most superficial), stratum lucidum, stratum granulosum, stratum spinosum, and stratum basale (stratum germinativum), which is the deepest layer (1). The epidermis is a lipid-rich region, with its extracellular space organized into

multiple bilayers dominated by lipids such as various ceramides, cholesterol, cholesterol esters, and non-esterified fatty acids (9). As illustrated in Figure 2, the skin consists of the epidermis and dermis, each with distinct functions. The stratum basale, the innermost layer of the epidermis, comprises a single layer of basal keratinocyte stem cells, melanocytes responsible for melanin production, and Merkel cells that function as touch receptors.

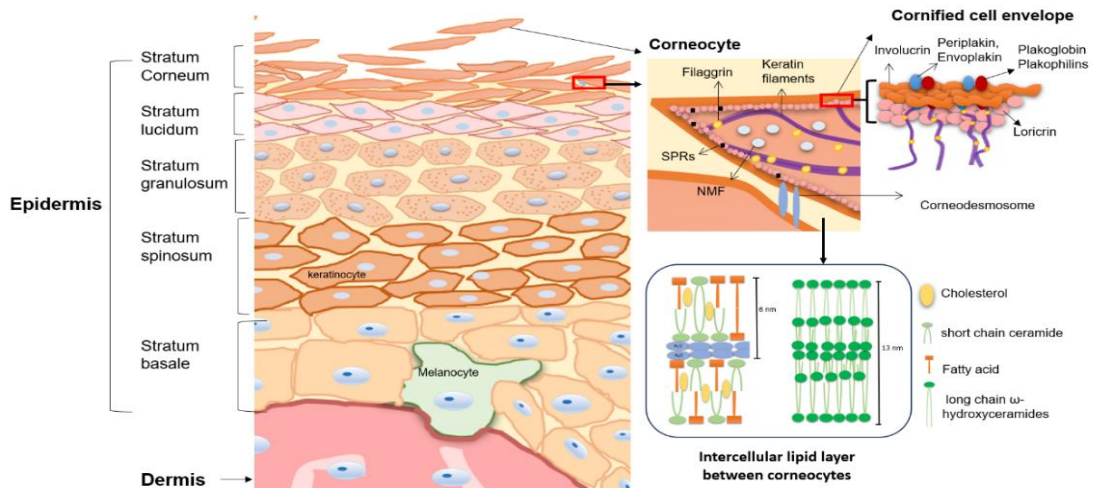


Figure 2. Composition of the skin layer, corneocyte, cornified cell envelope, and intercellular lipid

The stratum spinosum, or spiny cell layer, comprises 8 to 10 layers of cells. The stratum granulosum consists of 3 to 5 layers of diamond-shaped cells containing keratohyalin and flat granules. Keratohyalin granules possess keratin precursors that aggregate, cross-link, and form bundles. The stratum lucidum is a thin, transparent layer found in hairless regions of the skin, including the palms, fingertips, and soles. This layer, composed of 3 to 5 cell layers, serves as a water barrier and provides additional protection to the skin (1). The stratum corneum (SC) consists of 20 to 30 layers of cells and forms the outermost layer of the epidermis. A unique feature of the SC is composed of a protein-lipid complex of the cornified cell envelope, composed of proteins such as involucrin, envoplakin, and periplakin. Internally, the SC contains keratin, dead keratinocytes (nucleated squamous cells), small proline-rich proteins (SPRs), natural moisturizing factors (NMF), and the protein filaggrin, all of which play essential roles in skin hydration and barrier function. The SC also exhibits the greatest thickness variation, especially in calloused skin.

The dermis is attached to the epidermis by the basement membrane and is composed of two layers of connective tissue: the papillary and reticular layers, which merge without distinct borders. The papillary layer is the uppermost, thinnest, and is made up of loose connective tissue in contact with the epidermis. The reticular layer is deeper, thicker, and less cellular, consisting of dense connective tissue with bundles of collagen fibers. The dermis contains sweat glands, hair, hair follicles, muscles, sensory neurons, and blood vessels (1).

3.2 Formulation of Emulsion

Emulsions are colloidal systems

consisting of two immiscible liquids, in which one liquid is dispersed in the other as small droplets (0.1–100 microns). Emulsions can be categorized based on the dispersed phase and the dispersing medium: oil-in-water (O/W), water-in-oil (W/O), and multiple emulsions such as oil-in-water-in-oil (O/W/O) and water-in-oil-in-water (W/O/W) (10). The aqueous phase of an emulsion typically contains water and alcohol (11). Additives such as gallic acid and NaCl in the internal aqueous phase can improve the stability and functionality of W/O/W double emulsions by reducing interfacial tension (12). The oil phase contributes occlusive effects to the skin (13), and oils rich in essential fatty acids further enhance skin hydration (14,15). Properties such as viscosity, permeability, stability, and drug release are influenced by the composition of the oil phase (13). Common oils used in emulsions include isopropyl myristate, paraffin, and various vegetable oils like pomegranate seed oil and rice bran oil (16–18). Surfactants, which are key excipients in emulsion formulation and are selected based on their hydrophilic-lipophilic balance, act as emulsifying agents (19). They prevent coalescence of emulsion droplets by reducing the interfacial tension between the aqueous and oil phases (7). At appropriate concentrations, surfactants stabilize emulsions by adsorbing at the oil–water interface, increasing the strength and thickness of the interfacial film. However, excessive surfactant, reaching the critical micelle concentration, can decrease emulsion stability by weakening the interface film (20). Types of surfactants used in emulsions include anionic (e.g., sodium laureth sulfate, sodium lauryl sulfate), cationic (e.g., quaternary ammonium salts), nonionic (e.g., Tween 80, Span 80), and amphoteric (e.g., cocamidopropyl betaine) (21). Most

surfactants can be harsh on the stratum corneum by dissolving lipids and disrupting the skin barrier, potentially causing irritation and other side effects. In contrast, mild surfactants such as amphoteric types like cocamidopropyl betaine can be beneficial. These not only help form stable emulsion droplets but also lower surface tension, allowing the emulsion to spread more easily and interact gently with the skin. This promotes hydration of the stratum corneum and enhances penetration of moisturizing agents into deeper skin layers (22).

3.3. Skin Hydration Mechanism due to the Presence of Water and Oil in the Emulsion

Skin hydration results from changes in the molecular structure and dynamics of corneocytes in the stratum corneum (SC). The SC, as the outermost layer of the human body, plays a critical role in environmental protection. It not only guards against friction but also acts as a barrier to prevent both water loss and excessive water uptake (23). The primary function of the epidermis is to generate and maintain the SC (24). The outer cells of the SC are composed of three highly insoluble, transglutaminase cross-linked proteins—*involucrin*, *envoplakin*, and *periplakin*—along with lipids (25). These proteins are covalently bound to lipids, providing the integrity required for effective skin barrier function.

Corneocyte hydration is maintained by keratin, natural moisturizing factor (NMF), and filaggrin, all of which have

water-binding capacity, as well as by intercellular lipids that prevent transepidermal water loss (TEWL), as illustrated in Figure 2 (26). Healthy skin contains 10–30% water in the stratum corneum and 75–85% water in the stratum basale (27).

As described in Figure 3a, skin hydration occurs when water enters corneocytes by penetrating the intercellular lipid matrix, and is found particularly in regions with less lipid content. This process is facilitated by passive diffusion and sorption, as well as gradients between environmental water concentration and the corneocyte. Water enters the cells via the intracellular (transcellular) pathway, migrating and binding to natural moisturizing factors (NMF) and keratin within the cell. The dry weight of SC contains ca 85% of keratin. Water filled with keratin filaments cause corneocytes swell up to 50% in height (28,29). Water molecules bind to keratin at polar functional groups, such as amide and hydroxyl groups, as illustrated in Figure 3b. An increased number of polar sites in the keratin structure greatly enhances hydrogen bonding with water.

The structure of keratin filaments and their side-chain interactions include: 1) hydrogen bonds between N–H and C=O groups, 2) disulfide bonds between cysteine side-chains, 3) free cysteine side-chains not forming disulfide bonds, 4) buried tyrosine side-chains, 5) exposed tyrosine side-chains, and 6–8) water molecules hydrogen-bonded to keratin chains (30).

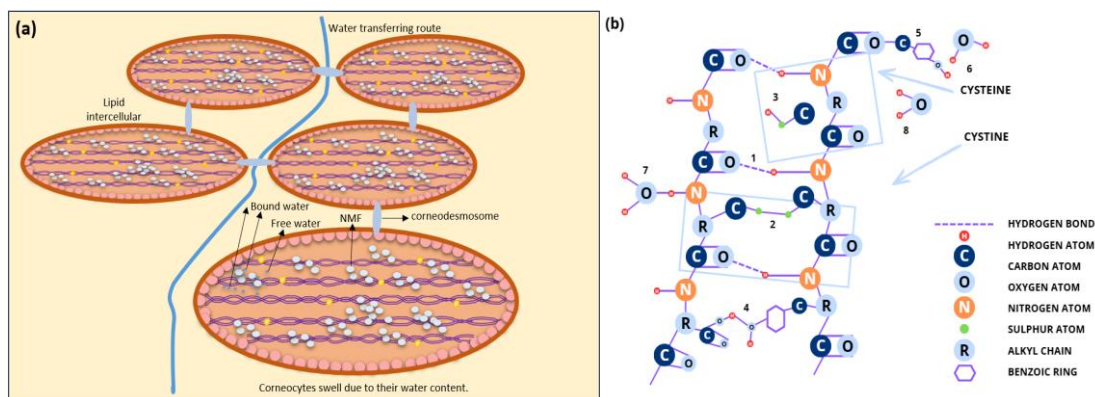


Figure 3. Mechanism of keratin binding water in skin hydration: Water molecules penetrate the intercellular matrix and enter corneocytes, where they bind to NMF and keratin (Figure 3a). Water binds to keratin at its polar groups (Figure 3b)

Filaggrin is a protein essential for epidermal differentiation and the formation of the stratum corneum (SC). By binding to intermediate keratin filaments, as depicted in Figure 2, filaggrin compacts keratin and flattens SC cells. Proteolysis of filaggrin produces hygroscopic amino acids and their derivatives, which serve as natural moisturizing factor (NMF) components that retain water and provide skin hydration. Further breakdown of these amino acids generates trans-urocanic acid (UCA) and pyrrolidone-5-carboxylic acid (PCA), both of which help regulate the pH of the SC. A deficiency of filaggrin reduces corneodesmosome density and intercellular junctions, causes abnormalities in the extracellular lipid matrix, and is associated with dermatological diseases such as atopic dermatitis and ichthyosis vulgaris. Mutations in the *FLG* gene, which encodes filaggrin, are strongly linked to ichthyosis vulgaris (31).

Natural moisturizing factor (NMF) in the SC includes polar osmolyte compounds derived from filaggrin, as well as sweat constituents and triglycerides. NMF makes up about 10%

of the dry weight of corneocytes and 20–30% of the SC. In addition to PCA and UCA, NMF is composed of inorganic salts (such as chloride, phosphate, sodium citrate, potassium, calcium, and magnesium), sugars, lactic acid, urea, and glycerol (32).

The oil phase of an emulsion can penetrate the skin through four main pathways: the transcellular route (involving proteins within corneocytes), the intercellular route, hair follicles with associated sebaceous glands, and sweat ducts. Emulsions support skin hydration by interacting with the lamellar structure of intercellular lipids, thereby helping to prevent transepidermal water loss (TEWL) (33).

3.4. Substance to Improve Skin Hydration

Skin hydration could be improved by adding humectants, occlusive agents, and emollients in the formulation. Those combinations of substances could work together to improve skin hydration and prevent water loss (34). The differences between humectants, occlusive agents, and emollients are illustrated in Figure 4.

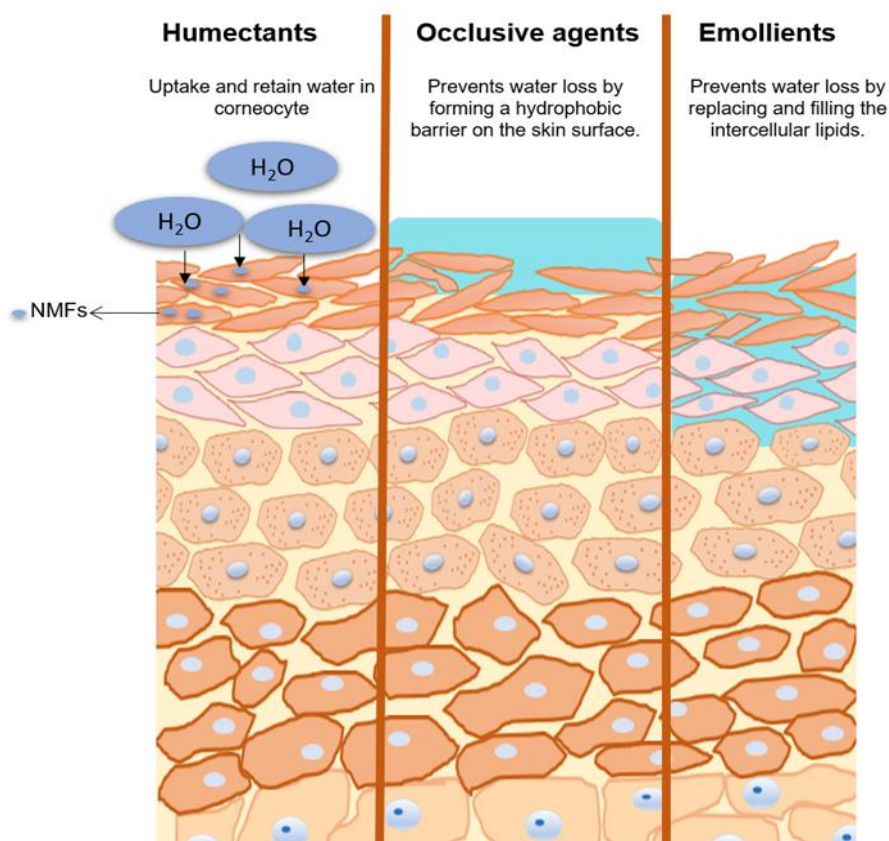


Figure 4. Different mechanisms of humectant, occlusive, and emollient agents in maintaining skin hydration

a. Humectants, such as lactic acid, urea, and glycerin, are substances that increase the water content of emulsions—often exceeding 70%—by attracting water to the skin (34,35). These agents are effective through several mechanisms, including boosting ceramide levels (34). Urea enhances stratum corneum hydration by reducing transepidermal water loss, increasing water retention and stratum corneum resistance to osmotic stress, and substituting for water under low-humidity conditions (36). Glycerin is an excellent humectant, providing moisture retention and reduced evaporation at concentrations below 60 wt%, and can absorb additional water at 70 wt% (37).

b. Occlusive agents—such as hydrocarbons, silicones, vegetable oils,

wax esters, and sterols—reduce water evaporation or transepidermal water loss by forming a physical barrier over the skin (34). Examples of hydrocarbons include petrolatum and mineral oil, with petrolatum being more effective at reducing moisture loss. Silicones like dimethicone and cyclomethicone permit water vapor emission and are commonly used in oil-free products. Vegetable oils (e.g., olive oil, macadamia nut oil, castor oil, camellia oil, grape seed oil) enhance skin moisture, but should be combined with antioxidants due to their tendency to oxidize (38). Vegetable oils swell the stratum corneum by 10–20%, while petrolatum induces 40–60% swelling, making petrolatum a more effective occlusive agent (39). Waxes such as beeswax (typically used on the lips) and

lanolin (which reduces water loss but may cause itching) are also included (40). Sterols, including cholesterol and ceramides, help enhance intercellular lipids (41).

c. Emollients are substances that smooth and soften the skin by filling the spaces between desquamating corneocytes (34,42). Examples of emollients include collagen, elastin, glyceryl stearate, and shea butter (42).

4. Conclusion

Emulsion is considered an advanced first choice for skin hydration products due to its comprehensive composition of both water and oil phases, including surfactants. The addition of various excipients and active substances that act as humectants, occlusives, and emollients further enhances its effectiveness. Careful selection of excipients and active substances will provide optimal skin hydration.

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