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Formulation And Evaluation of Under Eye Cream

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***Abstract*—The periocular region is one of the most delicate and anatomically sensitive areas of human skin due to its thin epidermis, reduced sebaceous gland activity, low collagen content, and increased trans epidermal water loss. These physiological characteristics make the under-eye area highly susceptible to premature aging manifestations such as wrinkles, fine lines, puffiness, dehydration, hyperpigmentation, and dark circles. Environmental pollution, ultraviolet radiation, stress, inadequate sleep, nutritional imbalance, and prolonged digital screen exposure further accelerate periocular skin damage, increasing the global demand for effective under-eye cosmetic preparations. Under-eye creams have therefore emerged as important cosmeceutical formulations intended to improve hydration, skin elasticity, microcirculation, pigmentation control, and antioxidant protection.**

Modern under-eye creams incorporate a wide variety of active pharmaceutical and cosmetic ingredients including humectants, peptides, antioxidants, vitamins, retinoids, botanical extracts, caffeine derivatives, ceramides, and nano-based delivery systems to achieve multifunctional therapeutic benefits. The effectiveness of these formulations depends upon appropriate selection of excipients, emulsifying agents, preservatives, rheology modifiers, and advanced delivery systems that ensure product stability, safety, and enhanced skin penetration.

This project comprehensively discusses the anatomy and physiology of periocular skin, formulation approaches, active ingredients, preparation methods, evaluation parameters, analytical techniques, regulatory considerations, and recent technological advancements in under-eye cream development. The review additionally highlights formulation challenges, safety aspects, and future perspectives associated with advanced cosmeceutical products. Current evidence suggests that optimized formulations utilizing biocompatible ingredients, nanotechnology-based carriers, and clinically validated actives demonstrate improved efficacy, stability, and consumer acceptability in modern under-eye skincare applications.

***Index Terms*—Under-eye cream, Periocular skin, Antiaging, Hyperpigmentation, Skin hydration, Topical delivery systems**

I. INTRODUCTION

1.1. Under-eye creams are specialized topical semisolid formulations developed specifically for application to the delicate periocular region with the objective of improving skin hydration, elasticity, microcirculation, and overall aesthetic appearance. These formulations are designed to target common dermatological and cosmetic concerns associated with the infraorbital area, including dark circles, puffiness, wrinkles, fine lines, dehydration, and uneven pigmentation. Unlike conventional facial creams, under-eye creams are formulated using milder excipients, lower irritancy potential ingredients, and enhanced moisturizing systems due to the extreme sensitivity and thinness of the periocular skin [1].

The global cosmetic industry has witnessed substantial growth in the demand for eye care products over the past decade due to increasing consumer awareness regarding facial aesthetics, anti-aging interventions, and preventive skincare strategies. Rapid urbanization, environmental pollution, occupational stress, digital screen exposure, irregular sleep cycles, and lifestyle-associated oxidative stress have significantly contributed to premature aging manifestations around the eyes [2]. As a result, under-eye creams have evolved from simple moisturizing preparations into multifunctional cosmeceutical systems possessing anti-aging, antioxidant, depigmenting, anti-inflammatory, and skin-rejuvenating properties.

Cosmeceuticals represent a bridge between pharmaceuticals and cosmetics and are designed to provide both aesthetic enhancement and therapeutic benefits. In dermatological practice, cosmeceuticals have gained significant importance due to their ability to deliver biologically active compounds capable of influencing skin physiology at the cellular and molecular levels [3]. Under-eye creams constitute an important category within the cosmeceutical market because the periocular area is highly susceptible to visible signs of aging and fatigue. Modern formulations incorporate advanced active ingredients such as peptides, retinoids, ceramides,

botanical antioxidants, caffeine derivatives, and nanotechnology-based delivery systems to improve product efficacy and dermal penetration [4].

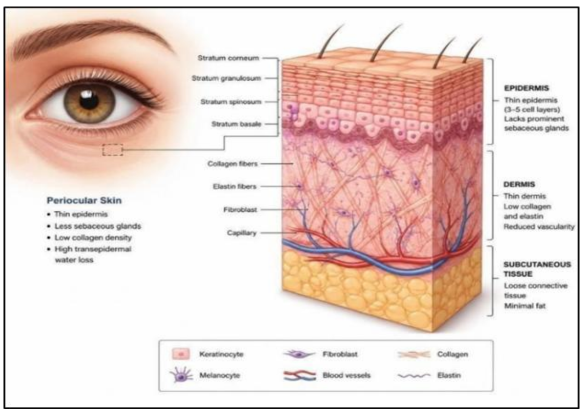

Figure 1. Anatomical representation of the periocular skin showing epidermal and dermal layers.

1.2 Importance of Under-Eye Skin Care

The periocular skin possesses unique anatomical and physiological characteristics that differentiate it from other facial regions. The skin surrounding the eyes is significantly thinner, measuring approximately 0.5 mm in thickness, compared to other facial areas where thickness may exceed 2 mm [5]. This reduced thickness is attributed to a thinner epidermis and dermis, lower collagen density, and diminished subcutaneous fat deposition. Furthermore, the periocular area contains fewer sebaceous glands and sweat glands, thereby reducing natural moisturization and increasing susceptibility to dryness and irritation [6].

The under-eye region is continuously exposed to repetitive facial movements associated with blinking, smiling, and squinting, resulting in progressive collagen degradation and elastin fragmentation. Such physiological stress accelerates the formation of wrinkles and fine lines, particularly with advancing age [7]. Additionally, increased trans epidermal water loss in the periocular area compromises barrier integrity and promotes dehydration-associated skin dullness and roughness.

Dark circles are among the most common cosmetic concerns associated with the under-eye area and may arise due to multiple etiological factors including vascular congestion, excessive melanin deposition, dermal thinning, genetic predisposition, and post-inflammatory hyperpigmentation [8]. Puffiness and edema commonly occur as a result of impaired lymphatic drainage, fluid retention, sleep deprivation, allergic reactions, and aging-induced weakening of periocular connective tissues [9]. Fine lines and wrinkles develop primarily due to collagen depletion, oxidative stress, ultraviolet radiation exposure, and repetitive muscular contractions. Furthermore, dryness and hyperpigmentation contribute significantly to diminished skin radiance and aesthetic appearance.

The increasing emphasis on facial aesthetics and preventive skincare has enhanced the importance of specialized periocular formulations capable of addressing multiple pathological and cosmetic concerns simultaneously. Effective under-eye skincare not only improves physical appearance but also enhances psychological well-being and self-confidence among consumers [10].

1.3 Need for Under-Eye Cream Formulations

The need for scientifically developed under-eye cream formulations has increased substantially due to growing exposure to environmental and lifestyle-related stressors. Environmental pollutants such as particulate matter, nitrogen oxides, and heavy metals induce oxidative stress through the generation of reactive oxygen species, thereby accelerating collagen degradation and melanogenesis in periocular skin [11]. Chronic ultraviolet radiation exposure further contributes to photoaging, DNA damage, matrix metalloproteinase activation, and dermal inflammation, resulting in visible aging manifestations around the eyes [12].

Lifestyle-associated factors including inadequate sleep, psychological stress, smoking, excessive alcohol consumption, poor nutritional habits, and prolonged digital device usage adversely affect cutaneous microcirculation and skin barrier function.

These factors collectively contribute to edema formation, pigmentation abnormalities, dehydration, and premature wrinkle development in the under-eye area [13].

Aging represents another major contributor to periocular skin deterioration. Intrinsic aging is associated with reduced fibroblast activity, decreased collagen synthesis, elastin degeneration, diminished hyaluronic acid production, and impaired epidermal turnover [14]. Consequently, aging skin exhibits reduced elasticity, increased dryness, dermal thinning, and impaired wound healing capacity. Such physiological alterations necessitate the use of targeted under-eye formulations capable of restoring hydration, improving dermal matrix integrity, and enhancing skin resilience.

Consumer awareness regarding cosmeceutical products and anti-aging therapies has expanded considerably due to social media influence, dermatological education, and increasing disposable income. Modern consumers seek multifunctional formulations that combine hydration, anti-aging, depigmenting, antioxidant, and soothing effects within a single product [15]. Therefore, the development of advanced under-eye creams utilizing innovative delivery systems and clinically validated active ingredients has become an important area of research within cosmetic science and pharmaceutical technology.

1.4 Scope and Objectives of the project

The present review aims to comprehensively summarize the scientific principles associated with the formulation and evaluation of under-eye creams. The review focuses on understanding the anatomical and physiological characteristics of periocular skin and their relevance in formulation development. Additionally, the review discusses the various categories of active pharmaceutical and cosmetic ingredients utilized in under-eye cream formulations, including moisturizers, antioxidants, peptides, depigmenting agents, botanical extracts, and nanocarrier systems.

Special emphasis is provided on formulation strategies involving conventional emulsions, herbal formulations, nano formulations, and advanced delivery systems designed to improve dermal penetration, stability, and therapeutic efficacy. The review also critically examines evaluation parameters including physicochemical characterization, microbiological analysis, stability studies, skin compatibility assessments, in-vitro release studies, and in-vivo clinical evaluations.

Furthermore, recent technological advancements including liposomal systems, nanostructured lipid carriers, peptide therapeutics, microbiome-based cosmetics, stem cell extracts, and artificial intelligence-assisted personalized skincare approaches are highlighted. The review also addresses regulatory guidelines, safety considerations, formulation challenges, and future research perspectives associated with under-eye cosmeceutical development.

Table 1. Common Under-Eye Problems and Associated Causes

Under-Eye Condition	Major Causes	Clinical Manifestations
Dark circles	Hyperpigmentation, vascular congestion, genetics	Infraorbital discoloration
Puffiness	Fluid retention, edema, poor lymphatic drainage	Swelling under eyes
Wrinkles	Collagen degradation, aging, UV exposure	Fine lines and creases
Dryness	Reduced sebaceous Activity dehydration	Rough and flaky skin
Hyperpigmentation	Melanin Accumulation inflammation	Uneven skin tone

II. ANATOMY AND PHYSIOLOGY OF UNDER-EYE SKIN

2.1 Structure of Periocular Skin

The periocular region represents one of the most structurally specialized and physiologically delicate anatomical areas of the human integumentary system. The skin surrounding the eyes exhibits significant histological and biochemical differences compared with other facial regions due to its reduced thickness, lower lipid content, diminished connective tissue density, and continuous exposure to dynamic muscular activity. These unique structural characteristics render the under-eye area highly susceptible to dehydration, vascular prominence, edema formation, premature wrinkling, and pigmentation abnormalities. The epidermis of the periocular region is remarkably thin and consists of fewer cellular layers compared to the epidermis present on the cheeks and forehead. The stratum corneum possesses a reduced barrier function due to lower concentrations of natural moisturizing factors and intercellular lipids. Keratinocyte turnover in the periocular region is relatively rapid, which contributes to increased sensitivity toward environmental irritants and cosmetic ingredients [16]. Melanocyte distribution within the basal layer also plays an important role in determining pigmentation patterns and the development of infraorbital dark circles. Beneath the epidermis lies the dermis, which is composed primarily of collagen fibers, elastin networks, fibroblasts, glycosaminoglycans, blood vessels, and lymphatic structures. In the periocular area, the dermal layer contains significantly lower amounts of collagen and elastin fibers, thereby reducing tensile strength and elasticity. The diminished dermal support contributes to early wrinkle formation and sagging associated with intrinsic and extrinsic aging processes. Furthermore, the vascular plexus within the superficial dermis is highly prominent due to the thin overlying epidermis, resulting in increased visibility of bluish or purplish discoloration under the eyes.

The subcutaneous tissue underlying the periocular skin contains sparse adipose deposits compared with other facial regions. This limited fat cushioning reduces structural support and increases the visibility of underlying vasculature and orbital musculature [17]. Age-associated atrophy of subcutaneous fat further accentuates hollowing and shadow formation beneath the eyes. The orbicularis oculi muscle located beneath the subcutaneous tissue continuously undergoes repetitive contraction during blinking and facial expressions, thereby contributing to dynamic wrinkle development over time. The periocular area is richly supplied with blood vessels and lymphatic channels that regulate tissue nutrition and fluid drainage. Impaired lymphatic circulation or vascular congestion frequently leads to edema and puffiness in the infraorbital region. Additionally, the close anatomical relationship between the periocular skin and ocular structures necessitates the use of highly biocompatible and non-irritating cosmetic formulations [18].

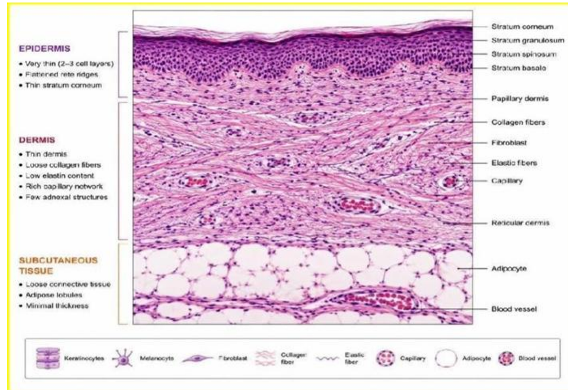

Figure 2. Histological structure of periocular skin showing epidermis, dermis, and subcutaneous tissue.

2.2 Characteristics of Under-Eye Area

The under-eye area possesses several unique physiological and biochemical characteristics that distinguish it from the remaining facial skin. One of the most important features is the reduced density of sebaceous glands. Sebaceous glands play a critical role in maintaining skin hydration by secreting sebum, which forms a protective lipid barrier on the skin surface. The lower sebaceous activity in the periocular region compromises barrier function and predisposes the area to dryness, scaling, and increased trans epidermal water loss. Another defining characteristic of the under-eye skin is its relatively low collagen and elastin content. Collagen fibers provide structural integrity and mechanical strength, whereas elastin fibers contribute to elasticity and resilience. Reduced collagen synthesis and accelerated collagen degradation within the periocular dermis result in diminished firmness and increased wrinkle susceptibility. Matrix metalloproteinases induced by ultraviolet radiation and oxidative stress further accelerate collagen fragmentation and dermal matrix deterioration. The periocular area also demonstrates increased trans epidermal water loss due to its compromised lipid barrier and thinner stratum corneum. Elevated water loss contributes significantly to dehydration- associated fine lines, roughness, and reduced skin radiance [19]. In addition, the under-eye region exhibits high vascular permeability and fluid accumulation tendencies, which contribute to edema and puffiness formation. Sleep deprivation, sodium imbalance, hormonal fluctuations, and allergic reactions further exacerbate fluid retention in this anatomically sensitive area. The skin surrounding the eyes is continuously subjected to repetitive mechanical stress resulting from blinking and facial expressions. An individual may blink approximately 10,000 times per day, subjecting the periocular skin to constant folding and stretching. Over time, repetitive mechanical stress contributes to dynamic wrinkle formation and loss of dermal elasticity [20].

2.3 Causes of Under-Eye Problems

Under-eye dermatological concerns arise due to a complex interaction between intrinsic biological processes and extrinsic environmental factors. The etiopathogenesis of infraorbital dark circles, puffiness, wrinkles, dehydration, and hyperpigmentation involves multifactorial mechanisms including dermal thinning, vascular congestion, melanogenesis, oxidative stress, impaired lymphatic drainage, and connective tissue degeneration.

2.3.1 Intrinsic Factors

Intrinsic aging represents one of the primary endogenous factors contributing to under-eye skin deterioration. Chronological aging is associated with progressive reduction in fibroblast activity, decreased collagen synthesis, elastin degeneration, and reduced hyaluronic acid production within the dermal extracellular matrix. These changes result in loss of skin elasticity, increased wrinkle formation, dermal thinning, and diminished moisture retention capacity. Genetic predisposition significantly influences the appearance of the under-eye region. Individuals with hereditary tendencies toward hyperpigmentation, thin skin, vascular prominence, or deep tear trough anatomy are more likely to develop dark circles and infraorbital hollowing at an earlier age . Ethnic variations in melanin distribution and dermal thickness further contribute to differences in under-eye appearance among populations. Hormonal imbalance also plays a crucial role in periocular skin physiology. Fluctuations in estrogen, progesterone, cortisol, and thyroid hormones can influence skin hydration, vascular permeability, sebaceous activity, and melanogenesis [21]. Hormonal disturbances may therefore contribute to edema formation, pigmentation abnormalities, and altered skin texture in the under-eye area.

2.3.2 Extrinsic Factors

Extrinsic factors play a major role in accelerating periocular skin aging and promoting under- eye abnormalities. Ultraviolet radiation exposure is among the most significant environmental contributors to photoaging. Chronic exposure to ultraviolet A and ultraviolet B radiation stimulates matrix metalloproteinase activity, collagen degradation, elastin fragmentation, and melanocyte activation. Consequently, prolonged sun exposure results in hyperpigmentation, wrinkle formation, skin laxity, and oxidative damage within the under-eye region. Environmental pollution is another important extrinsic factor associated with premature skin aging. Pollutants such as particulate matter, polycyclic aromatic hydrocarbons, ozone, and heavy metals generate reactive oxygen species and induce inflammatory signaling pathways within cutaneous tissues . Such oxidative stress damages cellular proteins, lipids, and nucleic acids, thereby impairing barrier function and accelerating periocular aging manifestations. Psychological stress significantly influences skin physiology through activation of the hypothalamic-pituitary-adrenal axis and increased cortisol secretion. Elevated cortisol levels impair skin barrier function, reduce collagen synthesis, and promote inflammatory responses. Chronic stress may therefore contribute to dark circles, dehydration, edema, and impaired wound healing in the under-eye region. Sleep deprivation is strongly associated with vascular congestion, fluid retention, and increased visibility of blood vessels beneath the thin periocular skin. Inadequate sleep reduces tissue oxygenation and impairs lymphatic drainage, thereby contributing to puffiness and infraorbital discoloration [22]. Similarly, poor nutritional habits characterized by inadequate intake of vitamins, antioxidants, proteins, and essential fatty acids compromise skin regeneration and barrier function.

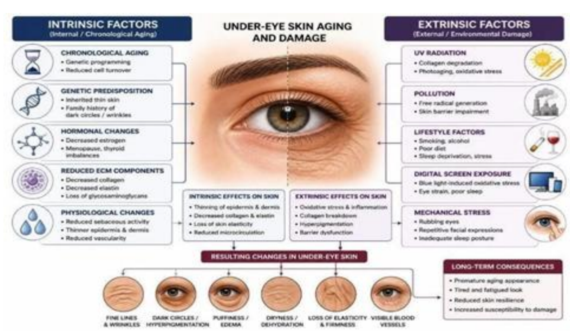

Figure 3. Intrinsic and extrinsic factors involved in under-eye skin aging and damage.

Table 2. Intrinsic and Extrinsic Factors Responsible for Under-Eye Problems

Factor Type	Specific Factors	Effects on Under-Eye Skin
Intrinsic factors	Aging, genetics, hormonal imbalance	Wrinkles, thinning, pigmentation
Environmental factors	UV radiation, pollution	Oxidative stress, collagen degradation
Lifestyle factors	Stress, smoking, alcohol	Dehydration and premature aging
Behavioral factors	Lack of sleep, screen exposure	Puffiness and dark circles
Nutritional factors	Vitamin deficiency, poor diet	Dullness and impaired skin repair

III. OVERVIEW OF UNDER EYE CREAMS

3.1 Definition and Classification

Under-eye creams are semisolid topical formulations specifically designed for application to the delicate infraorbital and periocular regions of the face. These formulations are intended to provide therapeutic, protective, and cosmetic benefits through hydration enhancement, reduction of pigmentation, improvement of dermal elasticity, suppression of inflammation, and prevention of premature skin aging. Unlike conventional facial moisturizers, under-eye creams are formulated using carefully selected ingredients possessing low irritancy potential, optimized rheological characteristics, and enhanced compatibility with the sensitive periocular tissue environment. The development of under-eye creams has evolved significantly with advancements in cosmetic dermatology, pharmaceutical technology, and skin biology.

Contemporary formulations are multifunctional systems that combine moisturizing agents, antioxidants, peptides, vitamins, botanical extracts, anti-inflammatory compounds, depigmenting agents, and nanocarrier technologies to address multiple under-eye concerns simultaneously [23]. The classification of under-eye creams is generally based on their primary functional objectives and active ingredient composition.

3.1.1 Moisturizing Eye Creams

Moisturizing eye creams are primarily formulated to restore hydration and maintain the integrity of the periocular skin barrier. Due to the reduced density of sebaceous glands and increased trans epidermal water loss in the under-eye region, dehydration is a common concern leading to dullness, rough texture, and fine line formation. Moisturizing eye creams commonly contain humectants such as glycerin, hyaluronic acid, sorbitol, and propylene glycol, which attract and retain water within the stratum corneum. In addition to humectants, these formulations often include emollients and occlusive agents such as shea butter, jojoba oil, ceramides, and dimethicone to improve barrier function and minimize moisture evaporation. Proper hydration contributes to enhanced skin smoothness, elasticity, and optical brightness of the under-eye area. Moisturizing formulations are particularly beneficial for individuals with xerotic skin, age-associated dryness, or sensitivity induced by environmental stressors [24].

3.1.2 Anti-aging Eye Creams

Anti-aging eye creams are formulated to reduce the visible signs of intrinsic and extrinsic skin aging, including wrinkles, fine lines, sagging, and reduced elasticity. These products incorporate biologically active compounds capable of stimulating collagen synthesis, reducing oxidative stress, and enhancing dermal matrix repair. Retinoids, peptides, coenzyme Q10, ceramides, and growth factors are among the most commonly employed anti-aging ingredients in under-eye formulations. Retinol and its derivatives function by increasing epidermal turnover and stimulating fibroblast-mediated collagen production. Peptides act as signaling molecules capable of modulating extracellular matrix synthesis and reducing wrinkle depth. Antioxidants such as vitamin E and coenzyme Q10 neutralize reactive oxygen species generated by ultraviolet radiation and pollution, thereby minimizing oxidative degradation of collagen and elastin fibers. The efficacy of anti-aging eye creams is strongly dependent on formulation stability, ingredient penetration, and sustained delivery within the periocular tissue. Consequently, modern anti-aging formulations frequently utilize encapsulation technologies and nanocarrier systems to improve active ingredient bioavailability and minimize irritation [25].

3.1.3 Depigmenting Eye Creams

Depigmenting under-eye creams are intended to reduce hyperpigmentation and infraorbital dark circles associated with melanin accumulation, vascular congestion, post-inflammatory changes, or dermal thinning. These formulations contain active ingredients capable of inhibiting melanogenesis, suppressing tyrosinase activity, and improving microcirculation.

Vitamin C is commonly incorporated due to its antioxidant and skin-brightening properties. It inhibits melanin synthesis by interacting with copper ions at the active site of tyrosinase and also promotes collagen synthesis. Niacinamide reduces melanosome transfer from melanocytes to keratinocytes, thereby improving skin tone uniformity. Other depigmenting agents such as kojic acid, arbutin, licorice extract, and azelaic acid are also utilized in under-eye formulations to minimize pigmentation abnormalities. Depigmenting formulations often include anti- inflammatory and antioxidant agents to prevent oxidative stress-mediated melanocyte activation. Since the periocular area is highly sensitive, the concentration of depigmenting agents must be carefully optimized to avoid irritation, erythema, or barrier disruption [26].

3.1.4 Anti-puffiness Formulations

Anti-puffiness eye creams are specifically developed to reduce edema, swelling, and fluid retention in the under-eye area. Puffiness is commonly associated with impaired lymphatic drainage, vascular permeability, fatigue, sleep deprivation, allergies, and age-associated weakening of periocular connective tissue. Caffeine is one of the most widely used active ingredients in anti-puffiness formulations due to its vasoconstrictive and diuretic properties. It promotes microcirculatory improvement and reduces fluid accumulation by constricting superficial blood vessels. Additional ingredients such as green tea extract, cucumber extract, peptides, and anti-inflammatory botanical compounds are incorporated to soothe irritated tissues and enhance lymphatic drainage. Cooling gel-based systems and lightweight emulsions are often preferred for anti-puffiness formulations because they provide rapid absorption and transient vasoconstrictive effects. Some advanced products utilize metal applicators or cryotherapy-inspired packaging systems to further enhance edema reduction [27].

3.1.5 Multifunctional Eye Creams

Multifunctional under-eye creams represent advanced cosmeceutical systems designed to simultaneously address multiple periocular concerns including dehydration, pigmentation, wrinkles, puffiness, and oxidative damage. Such formulations integrate several active ingredients within a single delivery system to provide comprehensive skin rejuvenation and protection [28]. Modern multifunctional formulations frequently combine humectants, antioxidants, peptides, botanical extracts, ceramides, vitamins, and nanotechnology-based carriers to achieve synergistic therapeutic outcomes. These formulations are increasingly favored by consumers due to convenience, reduced product layering, and enhanced cost- effectiveness. The formulation of multifunctional eye creams presents significant technological challenges due to potential ingredient incompatibilities, stability limitations, and the necessity for controlled release profiles. Therefore, advanced emulsification techniques, encapsulation systems, and polymer-based delivery technologies are commonly employed to maintain formulation stability and maximize bioactivity.

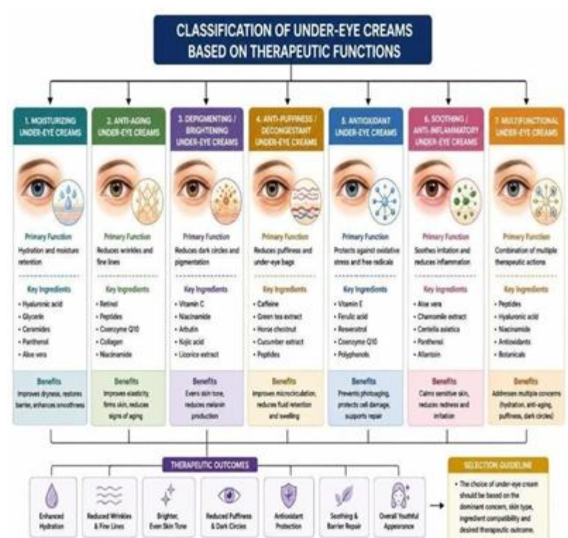

Figure 4. Classification of under-eye creams based on therapeutic functions.

3.2 Functions of Under-Eye Creams

Under-eye creams perform multiple physiological and cosmetic functions aimed at preserving the structural integrity and aesthetic appearance of the periocular skin. One of the primary functions is hydration enhancement. Humectants and occlusive agents increase water retention within the stratum corneum, thereby improving skin smoothness, elasticity, and barrier function Proper hydration minimizes the appearance of dehydration-induced fine lines and promotes a healthier skin texture. Another important function is skin tightening and wrinkle reduction. Bioactive peptides, retinoids, antioxidants, and collagen-stimulating compounds improve dermal matrix organization and increase skin firmness. These ingredients support fibroblast activity and reduce matrix metalloproteinase-mediated collagen degradation.

Reduction of pigmentation constitutes a major therapeutic objective in under-eye formulations. Depigmenting agents inhibit melanin synthesis and improve skin tone uniformity, thereby minimizing dark circles and uneven pigmentation [29]. Simultaneously, vascular stabilizers and anti-inflammatory compounds reduce erythema and vascular congestion associated with periocular discoloration.

IV. IDEAL CHARACTERISTICS OF UNDER EYE CREAM

An ideal under-eye cream should possess physicochemical, microbiological, dermatological, and sensory characteristics that ensure maximum efficacy, safety, stability, and consumer acceptability. Because the periocular region is highly delicate and physiologically vulnerable, under-eye formulations must be specifically optimized to avoid irritation, ocular discomfort, and barrier disruption while delivering active ingredients effectively. One of the most essential characteristics of an ideal under-eye cream is non-irritancy. The formulation should not induce erythema, itching, burning sensation, lacrimation, or inflammatory responses upon application near the eyes. Ingredients with high sensitization potential, strong fragrances, excessive alcohol concentrations, and harsh preservatives should therefore be minimized or eliminated. Ophthalmological compatibility testing is often necessary to ensure formulation safety. An ideal formulation should also be non-comedogenic and hypoallergenic. Although the periocular region contains relatively fewer sebaceous glands, occlusive or comedogenic ingredients may contribute to milium formation or follicular blockage in sensitive individuals. Hypoallergenic formulations minimize the probability of allergic contact dermatitis and are particularly important for individuals with reactive or sensitive skin conditions [30].

Table 3. Ideal Characteristics of Under-Eye Cream Formulations

Characteristic	Functional Importance
Non-irritating	Prevents redness, burning, and ocular discomfort
Hypoallergenic	Minimizes allergic reactions and sensitivity
Smooth texture	Enhances application and consumer acceptance
Good spreadability	Ensures uniform distribution on periocular skin
Rapid absorption	Prevents greasy residue and product migration
Stable formulation	Maintains efficacy and shelf life
Appropriate pH	Preserves skin barrier integrity
Pleasant appearance	Improves aesthetic appeal and compliance

V. INGREDIENTS USED IN UNDER EYE CREAM FORMULATION

The therapeutic efficacy, safety profile, sensory attributes, and stability of under-eye creams are predominantly determined by the selection and optimization of active pharmaceutical ingredients, cosmetic actives, botanical constituents, and functional excipients incorporated into the formulation. Since the periocular skin is exceptionally delicate and highly susceptible to irritation, ingredient selection requires careful consideration of biocompatibility, penetration capability, molecular stability, and dermatological safety.

Modern under-eye formulations are designed as multifunctional systems capable of simultaneously addressing hydration deficiency, oxidative stress, hyperpigmentation, inflammation, wrinkle formation, and edema. Therefore, a combination of humectants, emollients, antioxidants, depigmenting agents,

peptides, botanical extracts, vasoconstrictors, and barrier-repair molecules is generally employed to achieve synergistic therapeutic outcomes
[31]

VI. EXCIPIENTS USED IN FORMULATION

Excipients are pharmacologically inactive yet functionally indispensable components of under- eye cream formulations that influence product stability, rheology, spreadability, sensory properties, dermal penetration, and microbiological integrity. The careful selection of excipients is particularly important in periocular formulations because inappropriate excipient systems may induce irritation, instability, or reduced therapeutic efficacy.

6.1 Bases and Vehicles

The base or vehicle system serves as the primary carrier for active ingredients and significantly affects formulation aesthetics, release kinetics, and skin penetration characteristics. Under-eye creams are commonly formulated as oil-in-water emulsions, water-in-oil emulsions, or gel- based systems depending on therapeutic objectives and consumer preferences. Oil-in-water creams are widely preferred due to their non-greasy texture, rapid absorption, and superior cosmetic elegance. These systems are particularly suitable for daytime use and oily skin types because they provide hydration without excessive conclusiveness. Water-in-oil emulsions possess higher lipid content and enhanced occlusive properties, making them beneficial for dry or mature skin conditions requiring intensive moisturization. Gel creams represent hybrid systems combining the lightweight properties of gels with the moisturizing effects of emulsions. Such formulations exhibit enhanced spreadability, cooling sensation, and rapid absorption, thereby improving consumer acceptability in anti-puffiness and hydration-focused products [32].

6.2 Emulsifying Agents

Emulsifying agents stabilize the interface between oil and aqueous phases and prevent phase separation during storage. The selection of emulsifiers significantly influences emulsion stability, droplet size distribution, rheological behavior, and skin compatibility. Tween series surfactants are hydrophilic nonionic emulsifiers commonly used in oil-in-water systems. Span series emulsifiers are comparatively lipophilic and are often utilized in combination with Tween surfactants to achieve optimal hydrophilic-lipophilic balance. Cetostearyl alcohol functions both as a co-emulsifier and viscosity-enhancing agent while contributing to formulation stability and texture enhancement. Nonionic emulsifiers are generally preferred in under-eye formulations because of their lower irritancy potential compared with ionic surfactants.

6.3 Preservatives

Preservatives are incorporated into under-eye creams to prevent microbial contamination and ensure product safety throughout storage and consumer use. Because cosmetic creams contain aqueous phases and nutrient-rich ingredients, they are susceptible to bacterial and fungal growth. Parabens have historically been widely used due to their broad-spectrum antimicrobial activity and formulation compatibility. However, concerns regarding potential endocrine- disrupting effects have encouraged the development of alternative preservative systems [95]. Phenoxyethanol is now commonly employed because of its effective antimicrobial properties and relatively favorable safety profile. Natural preservatives derived from essential oils, organic acids, and plant extracts are increasingly incorporated into clean-label and herbal formulations.
However, natural preservatives may exhibit limitations in antimicrobial spectrum and long- term stability [33].

6.4 Thickening Agents Thickening agents are utilized to improve viscosity, stability, texture, and spreadability of under-eye creams. Proper rheological characteristics are essential for ensuring ease of application and preventing product migration into the eyes. Carbopol is a synthetic high molecular weight polymer widely used due to its excellent thickening efficiency and transparent gel-forming properties. Xanthan gum, a natural polysaccharide, provides viscosity enhancement and emulsion stabilization [34]. Cetyl alcohol additionally contributes to viscosity modification and emollient effects. The concentration and compatibility of thickening agents significantly influence formulation consistency, stability, and sensory attributes.

6.5 Fragrances and Colorants

Fragrances and colorants are incorporated into cosmetic formulations primarily to enhance aesthetic appeal and consumer satisfaction. However, their use in under-eye creams requires careful consideration because the periocular region is highly sensitive and susceptible to allergic reactions. Fragrances are among the most common causes of cosmetic-related contact dermatitis and irritation. Consequently, fragrance-free or minimally fragranced systems are increasingly preferred in ophthalmologically tested formulations [35]. Colorants must also comply with regulatory safety standards and should not migrate into ocular tissues. Modern trends in cosmeceutical development increasingly emphasize hypoallergenic, fragrance-free, and clean-label formulations to improve safety and consumer confidence

VII. METHOD OF PREPARATION

The preparation of under-eye creams involves systematic processing steps aimed at producing stable, homogeneous, aesthetically acceptable, and therapeutically effective semisolid formulations. The manufacturing process significantly influences droplet size distribution, rheological properties, stability, ingredient dispersion, and skin penetration characteristics [36].The preparation method must ensure proper incorporation of thermolabile active ingredients while maintaining microbiological integrity and physicochemical stability throughout shelf life. 7.1 Selection of Ingredients

The formulation process begins with the careful selection of active ingredients, excipients, emulsifiers, preservatives, thickening agents, antioxidants, fragrances, and colorants based on therapeutic objectives and skin compatibility requirements.

Ingredient compatibility studies are essential to prevent physicochemical instability, precipitation, oxidation, hydrolysis, or phase separation. The selected ingredients should exhibit low irritancy potential and excellent dermatological safety because of the sensitivity of the periocular region [37].

7.1. Preparation of Oil Phase

The oil phase consists of lipophilic ingredients including oils, waxes, fatty alcohols, emollients, and oil-soluble emulsifiers. These ingredients are weighed accurately and heated together at controlled temperatures generally ranging between 70°C and 75°C until complete melting and uniform mixing occur. Proper temperature control is essential to avoid thermal degradation of sensitive compounds and ensure uniformity of the lipid phase [38].

7.2 Preparation of Aqueous Phase

The aqueous phase contains purified water along with hydrophilic ingredients such as humectants, water-soluble preservatives, polymers, and hydrophilic emulsifiers. The ingredients are dissolved separately under continuous stirring while maintaining appropriate temperature conditions. pH adjustment may also be performed during this stage to ensure compatibility with skin physiology and formulation stability.

7.3Heating and Mixing

Both oil and aqueous phases are heated separately to similar temperatures to facilitate efficient emulsification and prevent premature solidification. Uniform heating minimizes viscosity differences between phases and promotes formation of stable emulsions. Continuous mixing is required to ensure homogeneous ingredient dispersion and proper interfacial stabilization.

7.4. Emulsification Process

The emulsification process involves gradual incorporation of one phase into another under continuous agitation. High-shear mixers or homogenizers are frequently employed to reduce droplet size and improve emulsion stability. The speed and duration of mixing significantly influence droplet distribution, viscosity, and physical stability of the final formulation.

7.5 Homogenization

Homogenization is performed to produce fine and uniformly distributed emulsion droplets. This process improves texture, spreadability, physical stability, and ingredient dispersion.

High-pressure homogenization additionally enhances penetration efficiency and sensory characteristics of under-eye creams [39].

7.6 Cooling and Packaging

Following homogenization, the formulation is gradually cooled under gentle stirring to prevent air entrapment and ensure proper viscosity development. Thermolabile ingredients such as vitamins, fragrances, peptides, and botanical extracts are generally added during the cooling stage to minimize thermal degradation. The finished formulation is filled into suitable containers such as laminated tubes, airless pumps, or opaque jars to protect the product from contamination, oxidation, and photodegradation. Proper packaging additionally improves consumer convenience and product shelf life.

VIII. EVALUATION PARAMETERS OF UNDER EYE CREAM

The evaluation of under-eye cream formulations is an essential component of cosmetic and pharmaceutical product development because it determines formulation quality, stability, efficacy, safety, and consumer acceptability. Due to the highly sensitive nature of the periocular region, under-eye creams require extensive physicochemical, microbiological, dermatological, and performance-based assessments before commercialization.

Evaluation parameters are designed to ensure that the formulation maintains its structural integrity, exhibits desirable rheological behavior, remains microbiologically safe, and delivers therapeutic efficacy without causing irritation or ocular discomfort. Comprehensive characterization additionally facilitates optimization of formulation variables and compliance with regulatory requirements [40].

8.1 Physical Evaluation

Physical evaluation involves assessment of organoleptic and sensory properties that significantly influence consumer perception and product acceptance. These parameters provide preliminary information regarding formulation quality and consistency.

8.1.1 Color

Color evaluation is important because it directly affects consumer perception of product quality and aesthetic appeal. The color of under-eye creams should remain uniform and stable throughout storage without evidence of discoloration or pigment separation.

Color changes may indicate oxidation, microbial contamination, ingredient incompatibility, or degradation of sensitive compounds such as botanical extracts and vitamins. Visual inspection under standardized lighting conditions is generally employed for color assessment.

8.1.2 Odor

Odor evaluation is performed to determine formulation acceptability and detect possible degradation or contamination. An ideal under-eye cream should possess a mild and pleasant odor or remain fragrance-free depending on formulation objectives.

Development of unpleasant odor during storage may indicate microbial growth, oxidation of oils, or decomposition of volatile ingredients.

8.1.3 Appearance

Appearance evaluation includes assessment of homogeneity, phase separation, grittiness, glossiness, and consistency. A high-quality under-eye cream should exhibit smooth texture and uniform appearance without evidence of creaming, cracking, or coagulation [41]. Visual appearance significantly influences consumer confidence and perceived product effectiveness.

8.1.4 Texture

Texture evaluation determines spreadability, smoothness, consistency, and sensory feel during application. Since periocular skin is extremely delicate, the formulation should exhibit soft texture and low drag force to minimize mechanical stress during application. Texture analysis may be performed subjectively through sensory evaluation or instrumentally using texture analyzers.

8.2 Physicochemical Evaluation

Physicochemical evaluation is critical for determining formulation stability, rheological behavior, and compatibility with skin physiology.

8.2.1 pH Determination

The pH of under-eye creams should remain compatible with physiological skin pH to prevent irritation and maintain barrier integrity. Typically, formulations are optimized within the pH range of 5.0 to 6.5. pH determination is generally performed using a calibrated digital pH meter after dispersing the formulation in distilled water. Significant pH changes during storage may indicate chemical instability or degradation of active ingredients.

8.2.2 Viscosity

Viscosity evaluation provides information regarding rheological behavior, spreadability, stability, and ease of application. Appropriate viscosity ensures adequate retention of the cream on the skin surface without excessive flow or migration into the eyes. Viscosity is commonly measured using Brookfield viscometers under controlled temperature and rotational conditions. Formulations exhibiting pseudoplastic flow behavior are generally preferred because they spread easily upon application while maintaining structural stability during storage [42].

8.2.3 Spreadability

Spreadability determines the ease with which a formulation can be uniformly distributed over the skin surface. Good spreadability minimizes frictional irritation and ensures efficient delivery of active ingredients. Spreadability is generally evaluated by measuring the area covered by a fixed quantity of cream under standardized pressure conditions. Formulations with poor spreadability may lead to uneven application and reduced consumer compliance.

8.2.4 Extrudability

Extrudability refers to the ease with which the formulation can be expelled from collapsible tubes or dispensing containers. Proper extrudability is essential for convenient application and dose uniformity. Highly viscous formulations may exhibit poor extrusion characteristics, whereas excessively fluid systems may cause leakage and wastage.

8.2.5 Homogeneity

Homogeneity evaluation determines the uniform distribution of ingredients throughout the formulation. A homogeneous cream should be free from aggregates, phase separation, and particulate matter [43]. Microscopic examination and visual inspection are commonly employed to assess formulation homogeneity.

8.3 Stability Studies

Stability studies are conducted to evaluate the ability of under-eye creams to maintain physicochemical integrity, microbiological safety, and therapeutic efficacy under different environmental conditions.

8.3.1 Accelerated Stability Testing

Accelerated stability testing involves storage of formulations under elevated temperature and humidity conditions to predict long-term stability within a shorter duration. Parameters such as color, odor, pH, viscosity, phase separation, and active ingredient content are periodically evaluated. Accelerated studies provide valuable information regarding shelf-life estimation and packaging suitability [44].

8.3.2 Freeze–Thaw Cycle

Freeze–thaw testing evaluates formulation stability against temperature fluctuations encountered during transportation and storage. The cream is subjected to alternating cycles of freezing and thawing to identify potential instability such as creaming, cracking, or phase separation. Nanoformulations and emulsions are particularly sensitive to freeze–thaw stress because temperature changes may alter droplet size distribution and emulsifier integrity.

8.3.3 Centrifugation Test

Centrifugation testing accelerates gravitational stress to evaluate emulsion stability. Formulations are centrifuged at high rotational speeds to determine susceptibility to phase separation and sedimentation. Stable formulations should remain homogeneous without visible separation following centrifugation.

8.3.4 Storage Condition Studies Storage studies involve maintaining formulations under different environmental conditions such as refrigeration, room temperature, and elevated temperatures for prolonged durations.

Periodic evaluation of physicochemical and microbiological parameters provides information regarding formulation robustness and packaging compatibility [45].

8.4 Microbiological Evaluation

Microbiological evaluation is essential because under-eye creams contain aqueous components that support microbial growth. Contaminated formulations may cause irritation, infections, and product deterioration. Microbial load testing is performed to determine total viable bacterial and fungal counts within the formulation. The microbial population should remain within acceptable regulatory limits. Preservative efficacy testing evaluates the ability of antimicrobial preservatives to inhibit growth of intentionally introduced microorganisms. Common challenge organisms include Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, and

Candida albicans [46]. An effective preservative system is particularly important in under-eye products because of their proximity to ocular tissues.

8.5 Skin Compatibility Studies

Skin compatibility studies are performed to ensure dermatological safety and minimize the risk of irritation or sensitization associated with long-term use.

8.5.1 Patch Test

Patch testing involves application of the formulation onto a small skin area under occlusive or semi-occlusive conditions to assess allergic or irritant reactions. Observations are made for erythema, edema, itching, and inflammation after specified durations.

8.5.2 Irritation Test

Irritation studies evaluate the potential of formulations to induce redness, burning sensation, or discomfort upon repeated application. Both human volunteer studies and alternative in-vitro methods may be utilized depending on ethical and regulatory considerations.

8.5.3 Sensitivity Test

Sensitivity testing assesses delayed hypersensitivity reactions and cumulative irritation following prolonged use of the product. These studies are particularly important for formulations containing retinoids, preservatives, fragrances, or botanical extracts.

IX. REGULATORY AND SAFETY ASPECTS

The development and commercialization of under-eye cream formulations require strict adherence to regulatory guidelines and safety standards established by international and national authorities. Because under-eye creams are applied in close proximity to ocular tissues and on highly sensitive periocular skin, these products must demonstrate acceptable safety, stability, microbiological quality, and substantiated efficacy claims before entering the consumer market. Regulatory compliance in cosmeceutical development involves evaluation of ingredient safety, permissible concentration limits, labeling accuracy, preservative systems, packaging compatibility, and product claims. The increasing incorporation of biologically active compounds and nanotechnology-based systems in under-eye formulations has further intensified the need for comprehensive toxicological and dermatological assessment [47].

X. RECENT ADVANCES IN UNDER EYE CREAM TECHNOLOGY

The field of under-eye cosmeceuticals has experienced significant technological advancements over the past decade due to progress in molecular biology, nanotechnology, dermatological science, and personalized skincare approaches. Modern formulations are increasingly designed to provide targeted delivery, enhanced bioavailability, sustained release, and multifunctional therapeutic benefits while minimizing irritation and instability. Emerging technologies are focused not only on improving cosmetic appearance but also on modulating biological pathways associated with skin aging, inflammation, oxidative stress, pigmentation, and barrier dysfunction [48].

10.1 Peptide-Based Formulations

Peptides have emerged as highly promising active ingredients in advanced under-eye formulations due to their ability to modulate cellular signaling pathways involved in collagen synthesis, extracellular matrix repair, and wrinkle formation [49]. Signal peptides stimulate fibroblast activity and increase production of collagen, elastin, and glycosaminoglycans within the dermal matrix. Neurotransmitter-inhibiting peptides reduce muscle contraction-associated wrinkle formation by interfering with acetylcholine release mechanisms. Peptides such as palmitoyl pentapeptide, acetyl hexapeptide, and copper tripeptide have demonstrated significant anti-aging effects including wrinkle reduction, improved elasticity, and enhanced skin firmness. Additionally, peptide formulations exhibit comparatively lower irritation potential than retinoids, making them highly suitable for periocular applications [50]. Advanced encapsulation systems and nanocarriers are frequently utilized to improve peptide stability and dermal penetration.

10.2 Stem Cell Extracts

Plant stem cell extracts have gained considerable attention in cosmeceutical research due to their antioxidant, regenerative, and protective properties. Stem cell-derived bioactive compounds may enhance skin renewal, improve cellular longevity, and protect against oxidative stress-induced damage [51].

Extracts derived from apple stem cells, grape stem cells, and alpine plant stem cells are commonly incorporated into anti-aging under-eye formulations. These ingredients contain polyphenols, growth factors, and antioxidants capable of supporting epidermal regeneration and reducing wrinkle formation [52]. Although promising, the mechanisms underlying stem cell extract efficacy remain an active area of scientific investigation, and further clinical validation is required to establish long-term therapeutic benefits.

10.3 Marine-Derived Ingredients

Marine biotechnology has emerged as an important source of novel cosmeceutical ingredients possessing antioxidant, anti-inflammatory, moisturizing, and anti-aging properties. Marine- derived compounds including algae extracts, marine collagen, peptides, polysaccharides, and minerals are increasingly incorporated into under-eye formulations. Marine collagen demonstrates excellent biocompatibility and contributes to improved skin elasticity and hydration. Algal extracts contain carotenoids, polyphenols, and sulfated polysaccharides that exhibit potent antioxidant and photoprotective effects [53]. Marine ingredients additionally provide sustainable alternatives to synthetic compounds and align with consumer demand for natural and eco-friendly cosmetic products.

10.4 Probiotic and Microbiome-Based Cosmetics

Recent advances in skin microbiome research have highlighted the importance of maintaining microbial balance for preserving skin barrier function and immune homeostasis. Probiotic and microbiome-based under-eye formulations aim to support beneficial microbial populations while suppressing inflammatory responses and barrier dysfunction. Probiotics, prebiotics, and postbiotic metabolites may improve hydration, reduce inflammation, and enhance resistance against environmental stressors. Such formulations are particularly promising for sensitive skin conditions characterized by impaired barrier function and chronic irritation [54]. Microbiome- based cosmetics represent an emerging frontier in personalized skincare and may provide novel therapeutic approaches for maintaining periocular skin health.

10.5 AI and Personalized Skincare

Artificial intelligence and digital dermatology technologies are increasingly influencing the development of personalized under-eye skincare products. AI-driven systems analyze skin characteristics including pigmentation, wrinkles, hydration status, texture, and environmental exposure to recommend customized formulations. Machine learning algorithms can predict ingredient compatibility, optimize formulation parameters, and improve consumer-specific treatment strategies. Personalized skincare systems may incorporate genetic, lifestyle, environmental, and microbiome-related data to develop individualized under-eye products. Digital imaging technologies and smartphone-based skin analysis tools additionally facilitate remote monitoring of treatment efficacy and consumer compliance. Such advancements are expected to transform future cosmeceutical development by enabling precision skincare tailored to individual physiological requirements.

XI. FUTURE PERSPECTIVES

The future of under-eye cream technology is expected to be strongly influenced by advancements in nanotechnology, biotechnology, molecular dermatology, artificial intelligence, and sustainable cosmetic science. Emerging research is increasingly directed toward developing multifunctional formulations capable of simultaneously addressing hydration, pigmentation, wrinkle formation, inflammation, oxidative stress, and skin barrier dysfunction through highly targeted mechanisms [55]. Nanotechnology integration is anticipated to play a transformative role in future under-eye formulations by improving dermal penetration, controlled release, stability, and bioavailability of active compounds. Advanced nanocarriers including lipid nanoparticles, polymeric nanoparticles, dendrimers, nano emulsions, and hybrid vesicular systems may enable precise targeting of bioactive ingredients while reducing irritation and improving therapeutic efficiency [56]. Personalized eye care represents another rapidly emerging area in cosmetic science. Future formulations may increasingly utilize genomic analysis, microbiome profiling, environmental exposure assessment, and artificial intelligence algorithms to develop individualized skincare products tailored to specific physiological and lifestyle requirements. Such precision skincare approaches may significantly improve treatment outcomes and consumer satisfaction. Sustainable formulation development is expected to become a dominant priority within the cosmetic industry. Future under-eye creams will likely emphasize biodegradable ingredients, green chemistry approaches, renewable raw materials, eco-friendly preservatives, and recyclable packaging systems. Biotechnology-derived ingredients produced through microbial fermentation and cell culture technologies may additionally reduce dependence on environmentally sensitive natural resources. Biotechnology-based active compounds including recombinant peptides, growth factors, exosomes, bioengineered collagen, and microbiome- derived metabolites are anticipated to revolutionize anti-aging and regenerative skincare approaches. Such compounds may provide enhanced biological specificity and targeted modulation of cellular pathways involved in skin aging and repair [57].

XII. CONCLUSION

Under-eye creams represent an important category of modern cosmeceutical formulations specifically designed to address the unique anatomical and physiological challenges associated with periocular skin. The delicate nature of the under-eye region, characterized by reduced epidermal thickness, lower collagen content, diminished sebaceous activity, and increased susceptibility to environmental stress, necessitates the development of carefully optimized formulations possessing high efficacy and excellent dermatological compatibility.

This project comprehensively discussed the anatomy and physiology of periocular skin, various classes of under-eye creams, ideal formulation characteristics, active ingredients, excipients, formulation approaches, preparation methods, evaluation parameters, analytical techniques, regulatory requirements, marketed products, formulation challenges, and recent technological advancements. The incorporation of active compounds such as peptides, antioxidants, humectants, depigmenting agents, botanical extracts, and vasoconstrictors has significantly improved the therapeutic potential of under-eye formulations targeting wrinkles, dark circles, puffiness, dryness, and hyperpigmentation.

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