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Condensed Review of Cutaneous Formulations Addressing Gender Differences and Exposome Factors in the Asia Pacific

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Abstract— *This study synthesizes evidence on exposome-driven cutaneous aging in Asia-Pacific populations and outlines formulation and assessment strategies that address regional pollution, solar exposure, ethnic variation, and gender-specific biology. Ambient pollutants, including PM 2.5, ozone, nitrogen oxides, and volatile organic compounds interact with UV and infrared radiation to increase reactive oxygen species, activate the aryl hydrocarbon receptor, induce matrix metalloproteinases, and promote collagen degradation and hyperpigmentation. Ethnic patterns in photoaging emphasize early pigmentary alterations in East and Southeast Asians and preserved dermal architecture in individuals with greater phototypes, while hormonal trajectories and structural sex differences modulate vulnerability to oxidative damage and barrier compromise. Topical solutions reviewed include low-pH, high-purity vitamin C combined with di- and tri-peptides, retinoids with gender-sensitive dosing and vehicle choice, antioxidant and peptide complexes, humectants and occlusives, and botanical extracts such as green tea polyphenols and rosmarinic acid, noting allergy and matrix-dependent stability concerns. Objective evaluation is highlighted through instruments measuring hydration, transepidermal water loss, pigmentation indices, Cutometer elasticity metrics, and high-frequency ultrasound, alongside controlled pollutant exposure using a cutaneous pollution exposure system (CPES) and ex vivo reactive oxygen species assays via DCFH DA. Emerging personalization avenues incorporate SNP-based clustering of genes for collagen, hydration, and oxidative defense to guide product selection. Integrating exposome-relevant actives, vehicle optimization for barrier status, standardized exposure models, instrumented endpoints, and genotypic risk stratification offers a pathway for region and gender-aware skincare interventions in urbanized Asia-Pacific settings.*

Keywords— Anti-aging formulations, Asia-Pacific exposome, Cutaneous dimorphism, Ethnic dermatology, Topical delivery systems.

I. INTRODUCTION

Demand for products that target visible signs of skin aging such as wrinkles, ptosis, vascular disorders, and uneven pigmentation has grown in parallel with increasing longevity and interest in youthful appearance. Skin is the first organ in direct contact with solar radiation and air pollution, so early manifestations of aging are often cutaneous. All exposures from conception to death, integrating internal biological factors and external environmental factors, are encompassed in the concept of the exposome, and these exposures influence the pathophysiology of skin aging, with oxidative processes playing a major role. Vitamin C and bioactive peptides have emerged as key antioxidant and anti-aging ingredients within this context, underscoring the importance of formulation for cutaneous performance [1].

Ambient air pollution is now recognized as a major global health risk, with particulate matter, volatile organic compounds, ozone, nitrogen dioxide, and sulfur dioxide varying by geography and level of industrialization. Outdoor pollution predominantly affects urban environments and forms complex mixtures including fine PM2.5 and coarse particles that can be coated with anthropogenic pollutants and microbial components. Secondary pollutants such as ozone and peroxyacetyl nitrates arise from photochemical reactions between primary pollutants, heat, and UV radiation and accumulate as smog in the troposphere. Despite extensive data on respiratory and cardiovascular effects, cutaneous consequences of pollution and their

relevance for sensitive skin are only beginning to be systematically reviewed, motivating interest in cosmetic strategies that prevent or relieve pollution-induced damage. Sensitive skin, associated with barrier dysfunction, shows increasing prevalence in industrialized countries, including Asian skin types, indicating a specific need for tailored management in highly polluted urban areas [2].

Oxidative stress links lifestyle, environmental exposures, and cellular aging pathways. Reactive oxygen species generated by mitochondrial dysfunction can contribute to inflammatory signaling, cellular dysfunction, and apoptosis and, thereby, to disease development and aging. Poor diet, smoking, infection, and chronic inflammation act as upstream drivers of mitochondrial fragmentation, membrane permeabilization, and reduced respiratory capacity, with downstream increases in mitochondrial ROS and altered antioxidant enzyme activities. This framework has been used to describe how antioxidants such as astaxanthin may inhibit oxidative stress-induced mitochondrial dysfunction and thereby modulate disease and aging trajectories. Within dermatology, anti-aging skincare focuses strongly on UV protection, free radical scavenging, and cell-protecting agents, including both synthetic and natural compounds that enhance antioxidant enzyme levels and mitigate UV-mediated damage. Novel delivery systems and nanomaterials are increasingly deployed in cosmetic formulations to improve penetration, stability, and sensory attributes, and transdermal nanoformulations for hormonal therapy have been reported as safe and effective options for relieving menopausal symptoms and restoring serum hormone levels. These developments highlight that the choice of actives, verification of activity and stability in formulation, and ability to reach living skin layers where ROS are generated are critical determinants of clinical anti-aging efficacy [3].

Gender-specific physiology further modulates how exposomes impact skin and how formulations should be designed. Aging involves intrinsic chronological processes and extrinsic factors such as chronic sun exposure, leading to wrinkles, sagging, and drooping. Hormonal changes with age, including declines in estrogen, testosterone, DHEA, and DHEAS, alter sebum production, hydration, skin thickness, and antioxidant defenses. Estrogen functions as an innate antioxidant, regulating molecules like superoxide dismutase, whereas men exhibit higher susceptibility to free radical damage and steeper declines in aerobic capacity. Structural differences such as thinner epidermis and dermis, lower hair follicle density, reduced sebum and sweat production, and distinct hypodermal fat distribution contribute to divergent wrinkle patterns and atrophy in males and females. External factors including sunlight, lifestyle, and pollutants accelerate these intrinsic trajectories and influence predisposition to acne, actinic keratosis, eczema, psoriasis, and premature aging syndromes. These findings underscore the need for gender-specific cosmetic and therapeutic strategies that account for differential responses to extrinsic aging drivers [4].

Against this backdrop, formulation science must align antioxidant, peptide, retinoid, and hormonal technologies with regional pollution profiles, lifestyle patterns, and gender-specific biology to optimize cutaneous outcomes in diverse Asia Pacific populations.

II. METHODOLOGY

2.1 Search Strategy

A rigorous review strategy was implemented using systematic search protocols. Literature searches were conducted across electronic databases including Google Scholar, PubMed, MEDLINE, and Scopus, utilizing keywords and Boolean operators organized around three conceptual axes:

A. Cutaneous sexual dimorphism and hormonal trajectory profiles;

B. Dynamic Asia-Pacific exposome characteristics; and

C. Strategic formulation efficacy parameters.

The search covered publications from January 2000 to April 2024, with priority given to peer-reviewed articles, systematic reviews, and randomized controlled trials. Search terms included combinations of: ("skin aging" OR "cutaneous aging" OR "photoaging") AND ("exposome" OR "pollution" OR "UV radiation" OR "particulate matter") AND ("gender" OR "sex differences" OR "hormonal") AND ("formulation" OR "topical" OR "cosmeceutical" OR "anti-aging") AND ("Asia Pacific" OR "Asian" OR "ethnic").

2.2 Eligibility Criteria

Retrieved papers were screened by title, abstract, and full text against defined eligibility criteria. Included were peer-reviewed randomized controlled trials, non-randomized studies, ex vivo explant assays, and published author reviews in high-impact

dermatological, cosmetic, or pharmacological journals. Exclusion criteria encompassed self-administered questionnaire surveys without objective biophysical measurements, trials on rejuvenation devices outside topical interventions, or studies lacking clearly defined demographic parameters.

2.3 Data Extraction and Synthesis

Extracted data included participant demographics, intervention regimens, biophysical endpoints, and mechanistic evidence. Findings were subsequently mapped into actionable formulation guidelines. Quality assessment of included studies was performed using appropriate tools (Cochrane Risk of Bias for RCTs, Newcastle-Ottawa Scale for observational studies). Given the heterogeneity of study designs and outcomes, findings were synthesized narratively rather than through meta-analysis, with evidence graded according to the strength and consistency of available data.

III. BIOLOGY OF SKIN AGING UNDER INTRINSIC AND EXTRINSIC INFLUENCES

Cutaneous aging arises from the cumulative impact of genetically programmed processes and environmental insults that progressively disrupt cells, the extracellular matrix, and intercellular communication. Intrinsic, or chronological, aging is genetically determined, whereas extrinsic aging results from external factors such as chronic sun exposure and pollution. Clinically, aging is characterized by wrinkles, sagging, drooping, and textural changes, with intrinsically aged skin typically appearing dry and exhibiting fine wrinkles while retaining relatively preserved architecture. These alterations reflect irreparable damage and maladaptation at multiple levels of cutaneous organization, ultimately contributing to age-related diseases and increased mortality [3,4,5].

UV radiation represents the dominant extrinsic driver, accounting for a substantial proportion of facial aging in sun-exposed areas. Repetitive UV exposure produces marked morphological, histological, biochemical, and biophysical changes described as photoaging, with manifestations that include fine and coarse wrinkles, actinic keratoses, solar elastosis, yellowing, pigmentation disorders, premalignant lesions, atrophy, senile purpura, solar comedones, telangiectasia, laxity, roughness, and extreme dryness. At the molecular level, UV damage reduces cohesion and mechanical integrity of the stratum corneum and alters protein and lipid structures. DNA damage is a central early event, with persistent lesions accumulating despite endogenous repair mechanisms. UVB-driven reactive oxygen species formation induces activator protein 1 overexpression and upregulation of matrix metalloproteinases, promoting collagen degradation, inhibiting procollagen biosynthesis, and driving wrinkle formation and chronic matrix disruption [3,5,6].

Multiple lifestyle and environmental exposures within the exposome further aggravate extrinsic aging pathways. Atmospheric pollution, including PM 2.5 and ozone, is associated with increased skin aging manifestations; particles act as carriers for chemicals and metals that localize to mitochondria, generating reactive oxygen species and collagen degradation. Ozone exposure can enhance UV-induced depletion of protective vitamin E in the stratum corneum. Smoking, including secondhand exposure, provokes elastosis, telangiectasia, roughness, and premature wrinkles through nicotine-mediated vascular constriction, increased metalloprotein and tropoelastin expression, altered proteoglycans, and reduced procollagen synthesis. Sleep deprivation correlates with higher intrinsic aging scores, uneven pigmentation, reduced elasticity, slower barrier recovery, and characteristic facial features such as hanging eyelids and droopy mouth corners. Dietary patterns that favor hyperglycemia accelerate cross-linking of collagen fibers, contributing to rhytides, sagging, and loss of elasticity [3,5].

On the intrinsic side, aging skin undergoes structural and functional declines in immune surveillance and repair capacity. Elderly skin shows reduced density of antigen-presenting Langerhans cells, diminished migration in response to cytokines, and decreased T lymphocyte numbers and reactivity to specific antigens. Production of cytokines such as interleukin 2 decreases, whereas interleukin 4 increases, leading to blunted delayed hypersensitivity reactions and greater susceptibility to photocarcinogenesis and chronic infections. Mitochondrial DNA accumulates damage, including a common deletion that is far more frequent in photodamaged than protected skin, driving further reactive oxygen species production and impaired cellular energetics. UV exposure also accelerates telomere shortening and activates DNA damage response pathways, promoting proliferative senescence or apoptosis depending on cell type [5,6].

Gender-specific hormonal trajectories modulate these intrinsic and extrinsic mechanisms. With age, estrogen, testosterone, DHEA, and DHEAS decline, and supplementation can increase sebum production, hydration, and skin thickness. Estrogen acts as an innate antioxidant, regulating superoxide dismutase expression, whereas men exhibit greater susceptibility to free radical damage and steeper declines in aerobic capacity, changes that contribute to accelerated cutaneous aging. Reduced estrogen in postmenopausal women leads to wrinkling, dryness, atrophy, laxity, delayed wound healing, and loss of collagen, changes that

can be partially ameliorated by hormone replacement or local estrogen therapy. These hormonal influences intersect with UV, pollution, and lifestyle exposures, reinforcing the need for strategies that address both intrinsic biology and extrinsic drivers of aging in diverse populations [4,5].

IV. REGIONAL, ETHNIC, AND GENDER DETERMINANTS OF SKIN HEALTH IN ASIAN POPULATIONS

Evidence from clinical and epidemiological investigations indicates that skin aging patterns differ across ethnic groups and anatomical sites and that these differences persist after adjustment for major behavioral factors such as personal sun exposure, smoking, and sun protection habits. In comparative analyses using the SCINEXA instrument, pigment spots and wrinkles occur with distinct age trajectories in Caucasian and East Asian women, and these ethnic differences vary by facial region. The observed variation was independent of educational level and reported exposure habits, suggesting a role for genetic predispositions and for ethnic-specific interactions between genetic makeup and environmental factors such as ultraviolet radiation and air pollutants. Genetic variation in the SLC45A2 gene, which influences skin, hair, and eye color, has been associated with ethnic-specific occurrence of pigment spots in Caucasians and Asians, supporting a mechanistic basis for these regional differences in visible aging markers [7].

Patterns of photoaging in skin of color have been described in detail for Asians and for populations with African ancestry. People commonly grouped as ethnic skin or skin of color encompass Fitzpatrick skin phototypes III to VI and include East Asians, Southeast Asians, and South Asians, as well as Hispanics and Africans. East Asians, such as Chinese, Japanese, and Koreans tend to be lighter, whereas Southeast Asians are more brown, and South Asians of Caucasian ethnic background exhibit brown to dark brown skin. These gradations correlate with differential responses to sunlight and the severity and timing of photodamage. In African Americans, who often have mixed African, Caucasian, and Native American ancestry, photoaging is typically delayed and most evident in lighter-complexioned individuals, with fine wrinkling, mottled pigmentation, and dermatosis papulosa nigra appearing predominantly in the late fifth or sixth decade. Histologic preservation of epidermal and dermal components in sun-exposed African American skin compared with Caucasian skin has been documented and underlies a more youthful clinical appearance into later life [8].

For East and Southeast Asians living at latitudes closer to the equator, chronic UV exposure drives characteristic pigmentary photoaging. Discrete changes such as actinic lentigines, flat pigmented seborrheic keratoses, and mottled hyperpigmentation dominate clinical presentations, and sun-induced facial melasma is more prevalent than in whites and can be considered a form of actinic dyspigmentation. Wrinkling becomes more common in East Asian women from approximately the fifth decade, and seborrheic keratoses have been reported in up to 88% of males older than 40 years. Darker-skinned Hispanics residing in tropical climates exhibit photoaging manifestations similar to South Asians and African Americans, again characterized by fine wrinkling and mottled pigmentation in the late fourth through sixth decades. These observations underscore that, across Asian and adjacent populations, pigmentary disorders are often earlier and more prominent features than deep rhytides, with implications for prioritizing skin tone evening and pigment control in regional formulation strategies [7,8].

Gender-related physiology interacts with these ethnic patterns. Females have thinner epidermis and dermis, lower hair follicle density, and reduced sebum and sweat production compared with males, along with a decreased ratio of muscle to subcutaneous tissue. Aging-associated loss of hypodermal adipose tissue therefore produces deeper expression lines in men, whereas women more commonly develop superficial rhytides. Hormonal trajectories differ, with estrogen, testosterone, DHEA, and DHEAS all declining with age but with men experiencing steeper reductions in testosterone and aerobic capacity. Estrogen provides innate antioxidant defense by regulating superoxide dismutase expression, while men are more susceptible to free radical damage and higher oxidative stress. These gender-specific differences contribute to distinct aging phenotypes and modify responses to extrinsic exposures such as sunlight and pollutants, supporting the need for gender-adapted approaches to prevention and rejuvenation in Asian contexts where pigmentary change and superficial wrinkling coexist with variable dermal thickness and oxidative stress burdens [4].

V. EXPOSOME COMPONENTS RELEVANT TO CUTANEOUS AGING IN THE ASIA-PACIFIC

Ambient air pollution constitutes a major external component of the skin exposome, with particulate matter, volatile organic compounds, ozone, nitrogen dioxide, and sulfur dioxide identified as pollutants of public health concern generated by household combustion devices, motor vehicles, industrial facilities, and forest fires. Composition and concentration of these pollutants vary between developed and developing countries, and ambient air pollution is predominantly an urban problem, which is highly relevant for rapidly industrializing Asia-Pacific megacities. Sensitive skin, associated with barrier dysfunction, shows increasing prevalence in industrialized settings, including Asian skin types, indicating that populations in polluted urban

environments represent a particularly vulnerable subgroup that may require specific management strategies. In response to this concern, expert groups have begun to review cutaneous effects of air pollution and to propose cosmetic measures aimed at preventing or relieving pollution-related skin damage [2].

Detailed analyses of pollutant classes clarify how different airborne components contribute to cutaneous aging phenotypes. Primary pollutants include particulate matter and gaseous species such as CO2, CO, SO2, NO, NO2, and NOx, as well as volatile organic compounds. Fine particles (PM 2.5) are typically produced by combustion, whereas larger particles derive from mechanical processes that suspend dust. Under strong sunshine, secondary pollutants such as ozone and peroxyacetyl nitrates form via photochemical reactions between primary pollutants, heat, and UV radiation, remaining within the troposphere as smog that blankets urban and rural areas. Dust particles can be coated with complex mixtures of anthropogenic chemicals and microbial flora, further modifying their interaction with the skin barrier. Temporal variation in pollutant levels across seasons and times of day, with ozone peaking in summer, adds dynamic stress to exposed facial and acral sites in outdoor workers and commuters [2].

Solar radiation is another central exposome element, and UV radiation has been identified as the primary factor in extrinsic skin aging, accounting for about 80% of facial aging. Chronic exposure induces fine and coarse wrinkles, actinic keratoses, solar elastosis, pigment disorders, and multiple other manifestations of photoaging. At the molecular level, UV exposure reduces mechanical integrity of the stratum corneum, alters protein and lipid structures, and generates DNA lesions that accumulate despite repair mechanisms. Through reactive oxygen species formation, UVB overexpresses activator protein 1 and upregulates matrix metalloproteinases, driving collagen degradation and inhibiting procollagen biosynthesis, which culminates in wrinkle formation and dermal matrix disruption. These UV-driven pathways are directly relevant to Asia-Pacific populations with high ambient UV indices and outdoor lifestyles [3].

Beyond UV, other environmental and lifestyle factors contribute to the exposome relevant for cutaneous aging. Infrared radiation and heat represent significant fractions of solar energy reaching the skin and can induce metalloproteinase expression, cytokine production, macrophage recruitment, mast cell increases, tryptase expression, angiogenesis, and inflammatory infiltration, collectively disrupting dermal extracellular matrix and promoting premature aging. Pollution exposure has been associated with xerotic skin, sensitive skin, wrinkle formation, abnormal pigmentation, dryness, acne, eczema, rashes, and skin cancers, with ozone capable of inducing damage through signal transduction even without deep percutaneous penetration. Smoking provokes elastosis, telangiectasia, roughness, and premature facial wrinkles via nicotine-mediated vascular constriction and altered collagen homeostasis, while sleep deprivation correlates with fine lines, uneven pigmentation, reduced elasticity, and slower recovery of barrier function. Dietary practices that increase advanced glycation end products through grilling, frying, and roasting contribute to collagen cross-linking and structural deterioration of the dermis [3].

Epidemiological assessments underscore the scale of pollution-related health burdens and hint at regional relevance. Global figures attribute millions of deaths to ambient air pollution, with particulate matter and ozone increasing respiratory and cardiovascular morbidity and contributing to certain cancers. Urbanization has placed a large fraction of the world population in environments with elevated fine particulate exposure, and PM, ozone, and cigarette smoke have been identified as particularly noxious for city dwellers, with the skin as one of the main target organs due to its role as the first line of defense. Mechanistic work links particulate matter and associated polycyclic aromatic hydrocarbons to aryl hydrocarbon receptor activation, reactive oxygen species generation, matrix metalloproteinase induction, collagen degradation, hyperpigmentation, and photocarcinogenesis. These findings provide a framework for understanding how rapidly urbanizing Asia-Pacific regions, characterized by fossil fuel combustion and dense traffic, may face intensified extrinsic aging pressures that must be considered in formulation strategies [2].

VI. TOPICAL FORMULATION STRATEGIES FOR GENDER-DIFFERENTIATED SKINCARE

Gender-related differences in skin structure and barrier function shape how topical formulations need to be designed and tolerated, especially when targeting photodamaged skin and other age-associated changes. Vehicles have a distinctive impact on local bioavailability of active molecules, which directly influences desired and undesired effects. Comparative work on cream and gel formulations demonstrated that concentration and vehicle both modulate facial tolerability, yet vulnerability of the stratum corneum barrier may be the dominant determinant of local reactions, implying that individuals with compromised barrier, including many women and sensitive skin phenotypes, may require gentler vehicles and lower irritancy profiles. Because vehicle modifications alter bioavailability, new or improved systems for known actives need renewed regulatory

approval, and some adapalene, tretinoin, and tazarotene formulations are not approved across all indications, underscoring that tailoring vehicles to gender-specific barrier properties must proceed within strict clinical and regulatory frameworks [9].

6.1 Retinoid-Based Formulations

Topical retinoids are widely recognized as therapies for photodamaged skin defined by fine wrinkles, mottled hyperpigmentation, and tactile roughness. Different retinoid molecules, vehicles, and dosage regimes exist, and newer actives such as niacinamide, seletinoid G, adapalene, and alitretinoin have been investigated for improved tolerability and safety profiles. Combination strategies with agents like hydroquinone or retinaldehyde and physical methods including non-ablative laser have been explored, although regulatory approval for many such approaches is still lacking. Given that males and females exhibit distinct patterns of wrinkling, pigmentation, and dermal atrophy driven by hormonal trajectories and oxidative stress differences, visible signs of aging provide a pragmatic trigger for initiating topical retinoid treatment, with product choice calibrated to gender-specific tolerability and risk-benefit ratios [4,9].

6.2 Antioxidant and Peptide Formulations

Antioxidant and peptide-based formulations represent another major pillar of gender-adapted skincare aligned with exposome-related oxidative stress. Vitamin C supports collagen synthesis, provides antioxidant protection against UV-induced photodamage, and inhibits tyrosinase, thereby suppressing melanin formation and contributing to depigmenting and brightening effects. A formulation containing pure vitamin C at 10% combined with rice and lupin-derived di- and tripeptides was intentionally developed at low pH to maintain active and stable antioxidant function, drawing on evidence that tissue levels of L-ascorbic acid in pig skin were enhanced only when the formulation pH was below 3.5. The peptide complex, optimized for rapid assimilation and barrier passage, has been shown in vitro to stimulate fibroblast proliferation and messenger RNA expression of procollagen, collagen VII, and fibrillin 1, supporting dermal matrix rebuilding and wrinkle reduction. Such technologies are highly relevant to Asia Pacific populations facing strong UV and pollution exposures and to gender-specific antioxidant needs, since estrogen provides innate antioxidant protection while men are more susceptible to free radical damage and steeper declines in aerobic capacity [1,4].

6.3 Moisturization and Barrier Support

Daily cosmetological care further contributes to exposome-responsive strategies. Healthy barrier function protects against dehydration, microorganisms, allergens, irritants, reactive oxygen species, and radiation, and daily routines of protection, prevention, cleansing, and moisturizing can increase regeneration, elasticity, and smoothness. Classical moisturizers deploy humectants such as hyaluronic acid, urea, and polyols along with occlusives including petrolatum and mineral oil; more sophisticated peptides and proteins, including quaternary N-alkyl derivatives and biomimetic peptides, have been introduced to improve binding to the horny layer and percutaneous absorption. Small fragments of hyaluronic acid have been proposed for better penetration, addressing age-related declines in epidermal hyaluronic acid and hydration status. Selection between oil-in-water and water-in-oil systems depends on dryness and barrier status, parameters that vary between male and female skin and across polluted urban versus less industrialized environments, thereby requiring gender and region-sensitive formulation choices [3,10].

6.4 Hormonal and Systemic Considerations

Recent biomarker work suggests that sex hormones and age interact with systemic markers of inflammation and cellular maintenance such as sirtuin 1 and NAD+, which may in turn influence cutaneous repair processes and barrier resilience; these findings imply that sex-specific hormonal milieus could modulate response and tolerability to topical actives and should be considered when interpreting clinical reactions [11]. Such systemic differences appear to vary with age and body composition and may help explain why middle-aged and older women sometimes show distinct patterns of skin reactivity compared to men, a nuance that clinicians and formulators might want to weigh when selecting vehicle type and dosing.

VII. Natural Bioactive Ingredients and Botanicals in Asia-Pacific Dermocosmetics

Botanical and other natural bioactive ingredients occupy a central position in contemporary anti-aging skincare, owing to their abundance of polyphenols, flavonoids, and other molecules with antioxidant and cell-modulating properties. These agents can be incorporated as topical antioxidants and cell regulators, either alone or in combination with retinol, vitamin C, and growth factors, to influence collagen production and extracellular matrix metabolism. Green tea, aloe vera, chamomile, and lavender are cited as commonly used botanicals in such formulations, reflecting a long history of plant-derived remedies in both conventional and alternative dermatology. Hormone-related therapies, mushroom-derived ingredients, and hemp plant products

are also identified as promising natural routes for improving skin dryness, texture, elasticity, and wrinkle patterns, particularly in estrogen-deficient states. Mushroom extracts rich in veratric acid provide antioxidative and anti-inflammatory effects and have been associated with wound healing support, redness reduction, soothing, moisturization, wrinkle reduction, and skin brightening, with species such as shiitake, reishi, and chaga mentioned for cosmetic use. Dietary supplementation with herbal and fungal extracts possessing documented antioxidant and anti-inflammatory properties is proposed as a means to extend healthy skin longevity alongside topical approaches [4].

Detailed assessments of noninvasive treatments discuss green tea polyphenols and Rosmarinus officinalis extract as representative botanicals with mechanistic evidence relevant to dermocosmetics. Green tea contains catechins such as epigallocatechin gallate that inhibit collagenase and elastase, thereby limiting collagen and elastin degradation in the dermis and contributing to preservation of structural integrity. These polyphenols also exhibit potent antioxidant activity, and topical application has been associated with increased minimal erythema dose, decreased Langerhans cell density, and reduced DNA damage before UV exposure, findings that align with photoprotection and immunomodulation. Rosmarinus officinalis displays antimicrobial, antimycotic, antiviral, anti-inflammatory, anti-mutagenic, and antioxidative actions, including inhibition of UV-induced matrix metalloproteinase 1, and has been used in treatment of cellulitis. However, biodegradation of its active components depends on the cosmetic product matrix, such as oil versus methanol or ethanol extracts, and allergic contact dermatitis has been reported as an adverse effect, emphasizing the importance of formulation and tolerability assessment. Mushroom-derived ethanolic extracts from Agaricus bisporus, Pleurotus ostreatus, and Lentinula edodes are characterized as anti-inflammatory, anti-tyrosinase, antioxidant, and antibacterial, although a lack of evidence-based clinical trials and potential allergy are noted as limitations [4].

In parallel, modern facial serums integrate high-purity botanicals with novel synthetic molecules to address a spectrum of aging concerns, including periocular wrinkles, rough texture, and sensitive skin. One described serum combines an antioxidant complex of methyl carboxymethylphenyl aminocarboxypropylphosphonate, rosmarinic acid, and rutin, together selected to fortify the skin and defend against environmental aggressors. This blend mitigates reactive oxygen species-driven damage and photo-induced aging by scavenging intracellular free radicals, while rosmarinic acid helps reduce pruritus and transepidermal water loss in sensitive skin. Rutin-containing creams have been associated with increased skin elasticity and reduced wrinkle size and number, via upregulation of collagen 1 alpha 1 expression. A second botanical blend in the same serum uses Indian kino extract and sandalwood-related xymenynic acid, solubilized in omega 6 glycerol esters to enhance penetration; ex vivo data show increases in barrier lipids and proteins such as ceramides, filaggrin, and transglutaminase 1, biomarkers correlated with improved barrier function and moisture retention. Short proprietary peptides targeting inflammatory pathways are added to counter inflammaging processes that reduce collagen synthesis and boost matrix metalloproteinases, cytokines, and chemokines, illustrating how botanicals and peptides can be coformulated for synergistic anti-aging benefit. Additional ingredients, including hydroxyapatite for firmness and barrier formation, niacinamide and adenosine for cellular energy and texture, lecithin as an emollient humectant, sodium acetylated hyaluronate for water binding, asiaticoside, and a urea derivative, complement the botanical core to produce a multifunctional dermocosmetic product [12].

Herbal anti-aging facial serums described in Ayurvedic-oriented reviews further highlight regional interest in plant-based solutions. These assessments emphasize that herbal cosmetics operate by impacting biological functions of the skin and providing required nutrition, with more than half of drugs worldwide estimated to be natural products or derivatives, and plant-based remedies described as promising. Specific aims include evaluating hibiscus, ber fruit, and lavender extracts for their capacity to diminish wrinkles, refine texture, and boost collagen synthesis in facial serums, and to clarify advantages, drawbacks, and practical considerations associated with herbal formulations. Advantages cited for face serums include maintaining hydration, assisting in elimination of imperfections, combating signs of aging, and shielding the skin from harm, whereas disadvantages encompass limited suitability for all concerns, high cost, difficulty in product selection, and potential wastage through improper use. Oil-based serums using high-quality dry carrier oils are noted as relatively simple to formulate and represent one major category of botanical-rich facial products. Evaluation parameters for anti-aging serums include physical appearance, spreadability, pH in the target range 4.1 to 6.7, viscosity, irritancy assessed by erythema and edema over 24 hours, and semi-liquid smooth consistency, underscoring the need to align herbal actives with appropriate vehicle properties and safety testing [13].

VIII. ASSESSMENT APPROACHES FOR EVALUATING ANTI-AGING AND PROTECTIVE FORMULATIONS

Objective evaluation of anti-aging and protective formulations relies on biophysical instrumentation and controlled exposure systems that quantify structural, functional, and molecular end points in skin. Several devices measure hydration, barrier

function, pigmentation, erythema, elasticity, and thickness, providing a multidimensional assessment of formulation performance in vivo.

8.1 Hydration and Barrier Function Assessment

Hydration of the stratum corneum is commonly captured via capacitance-based probes that exploit the high dielectric constant of water to detect changes in electrical properties of the skin, with results expressed in arbitrary units. Barrier integrity is monitored through transcutaneous water loss, where elevated values indicate reduced barrier quality and increased permeability, making this parameter central for judging whether antioxidant, retinoid, or botanical formulations improve barrier function or inadvertently impair it [14,15,16].

Hydration measurement protocols require attention to repeatability and within-site variability. Devices such as Nova DPM 9003BT and Scalar Moisture Checker MY 808S estimate relative hydration by skin impedance or capacitance, with electric fields penetrating approximately 15 μm and output scales ranging from 0 to 120 arbitrary units. Manufacturer guidelines specify that repeated readings should not differ by more than 4 arbitrary units; if two or more of five measurements exceed this tolerance, a sixth measurement is mandated to refine the estimate of true water content. Such procedures are important when documenting improvements in moisture and barrier status following application of humectant-rich or astaxanthin-containing formulations [16].

8.2 Pigmentary and Vascular Assessment

Pigmentary and vascular changes induced by photoaging or by protective interventions are quantified with narrow wavelength reflectance instruments. A Mexameter-type probe calculates a melanin index from light absorption at 660 nm and 880 nm and an erythema index from 568 nm and 660 nm signals, enabling precise tracking of mottled pigmentation, dyspigmentation, and vascular erythema in response to sunscreens, vitamin C-based depigmenting serums, or antioxidant gels [14,15].

8.3 Elasticity and Mechanical Properties

Elasticity, which reflects dermal matrix integrity and is highly relevant to wrinkle-targeted formulations, is measured by Cutometer probes applying controlled vacuum to deform the skin and calculating vertical displacement in arbitrary units. High-frequency ultrasound scanning at 20 MHz further adds quantitative data on total skin thickness and visualization of epidermal and dermal layers, supporting assessment of interventions that claim dermal remodeling or anti-atrophic effects [14,15].

8.4 Controlled Pollutant and Radiation Exposure Systems

Beyond physical parameters, controlled pollutant and radiation exposure systems allow direct testing of anti-pollution and photoprotective claims. A dedicated cutaneous pollution exposure system (CPES) was engineered to enable controlled exposure of human skin explants or in vivo skin to pollutants including ozone, ambient dust, and diesel particles at defined concentrations and flux. This platform addresses a major limitation of anti-pollution cosmetics, namely the lack of standardized methods to substantiate their efficacy on human skin. By exposing donor skin to specific pollutants and monitoring biomarker changes, the CPES facilitates identification of optimal end points for claim substantiation, such as intracellular reactive oxygen species generation, matrix degradation markers, or pigmentary alterations [17].

Intracellular reactive oxygen species provide a mechanistic readout of oxidative stress mitigation by antioxidants and sunscreens. In ex vivo trials, human skin discs are loaded with the nonfluorescent probe DCFH DA, which is converted to fluorescent DCF in proportion to ROS production. Following incubation, discs are subjected to cigarette smoke, UVA, UVB, combined UV, or blue light, alone or in photo-pollution combinations, and fluorescence is quantified with a multimode microplate reader. By comparing ROS levels in treated versus untreated explants, investigators can objectively assess whether antioxidant formulations, such as vitamin C and peptide serums or astaxanthin gels, confer protection under complex light and pollution challenges [17].

8.5 Clinical Assessment of Photoprotection

Clinical assessment of anti-photoaging benefits of sunscreens complements these instrumental approaches. A single-arm, 52-week study in women with mild to moderate photodamage evaluated daily use of a broad-spectrum, photostable sunscreen with 30 SPF containing avobenzone, homosalate, octisalate, octocrylene, and oxybenzone, while excluding other anti-aging actives. Eligibility was based on photonumeric scales for overall facial photodamage, crow's feet coarse wrinkles, and mottled pigmentation, and adherence was monitored by weighing product containers. This design permits attribution of changes in

wrinkles and pigmentation to photoprotection alone and illustrates how long-term clinical studies can be structured to isolate the effects of protective formulations against cumulative UV exposure [18].

IX. FUTURE DIRECTIONS IN EXPOSOME-RESPONSIVE AND PERSONALIZED SKINCARE IN THE ASIA-PACIFIC

Future progress in exposome-responsive and personalized skincare in the Asia Pacific will depend on integrating biologically grounded anti-aging strategies with quantitative assessment tools and emerging concepts in genetic and molecular profiling. Research on gender-specific skin aging underscores that nutrition, sleep, and physical activity must be considered alongside genetics, ethnicity, sex hormones, lifestyle, and environmental factors when designing interventions, and it explicitly calls for cosmetics and skin care products tailored to female and male physiology to address pathological conditions and premature aging [4].

Moving forward, such tailoring will need to be aligned with regional exposomes dominated by air pollution, UV exposure, and culturally specific behaviors, which were discussed in Section IV. Objective measurement platforms provide a foundation for validating next-generation formulations against these complex exposures. Noninvasive devices that capture hydration, barrier integrity, elasticity, and mechanical anisotropy, including Corneometer, Nova DPM 9003, Scalar Moisture Checker MY 808S, Cutometer, and Reviscometer systems, enable detailed characterization of skin responses to topical antioxidants, moisturizers, and anti-aging actives in vivo. These instruments quantify stratum corneum hydration via capacitance or conductance, transepidermal water loss as a barrier marker, and viscoelastic parameters such as R0 to R8 that reflect firmness, recovery, fatigue, and stress relaxation. Their use in biomedical and cosmetic testing will be essential to substantiate claims for exposome-targeted products that aim to restore elasticity and barrier function under chronic pollution and UV stress [16].

Anti-pollution cosmetics already represent a rapidly expanding market segment in the Asia Pacific, with more than 38% of new product launches in 2016 carrying anti-pollution claims, yet their development has been hampered by the absence of standardized efficacy evaluation methods. To address this gap, a cutaneous pollution exposure system was engineered to expose human skin explants or in vivo skin to defined concentrations and flux of pollutants such as ozone, ambient dust, and diesel particles. This platform was explicitly designed to identify optimal biomarkers for ex vivo and in vivo claim substantiation, including intracellular reactive oxygen species measured by DCFH DA conversion under combined cigarette smoke and light challenges [17]. Integration of such controlled exposure systems with instrumental readouts of hydration and elasticity will allow future Asia Pacific formulations to be tested under realistic photo-pollution scenarios and to demonstrate protection at molecular, cellular, and tissue levels.

9.1 Genetic and Molecular Stratification

Genetic and molecular stratification represents another trajectory toward personalization. Single nucleotide polymorphisms in genes encoding matrix metalloproteinases, aquaporins, filaggrin, superoxide dismutase, and glutathione peroxidase have been used to classify women into genotypic clusters associated with varying risks of collagen breakdown, barrier compromise, dehydration, and oxidative stress. Cluster-based analysis suggests that different skincare necessities depend on naturally occurring genetic variants, and researchers have identified 13 SNPs in key proteins related to elasticity, hydration, and oxidative defense. These insights support the design of regimens matched to specific genetic aging risk profiles, where individuals with high collagen cluster risk would prioritize matrix-preserving agents, and those with high hydration cluster risk would emphasize barrier-reinforcing and humectant-rich products [19].

As genotyping becomes more accessible in Asia Pacific urban centers, similar SNP-based frameworks could guide personalized recommendations of anti-pollution antioxidants, barrier repair systems, and gender-adapted anti-aging protocols. Future strategies also point toward broader lifestyle and nutraceutical components. An integrative review emphasizes that all known dermal aging prevention and rejuvenation procedures should be complemented by a healthy daily routine that avoids external aging factors and corrects harmful habits. It specifically highlights dietary supplementation with herbal and fungal extracts possessing documented antioxidative and anti-inflammatory properties as a means to extend healthy skin longevity, and identifies natural products from hemp plants and mushrooms as promising avenues for anti-aging remedies [4].

9.2 Implementation Considerations

Aligning such systemic approaches with topical formulations that are validated by standardized exposome models, instrument-based measurements, and genetic risk profiling offers a coherent roadmap for developing region-specific, gender-sensitive, and mechanistically grounded skincare in the Asia Pacific. However, several implementation challenges must be addressed:

1) **Accessibility and cost:** Genetic testing and advanced formulations may not be accessible to all populations in the region
2) **Regulatory frameworks:** Harmonization of regulatory standards across Asia-Pacific countries
3) **Cultural acceptance:** Integration of Western formulation science with traditional Asian skincare practices
4) **Sustainability:** Environmental impact of personalized and high-tech skincare products
5) **Clinical validation:** Need for more robust clinical trials demonstrating the superiority of personalized approaches

X. CONCLUSION

Synthesis of current evidence indicates that cutaneous aging in Asia-Pacific populations emerges from an interplay between intrinsic biology, sex hormone trajectories, and external exposures such as UV radiation, airborne pollutants, heat, tobacco smoke, sleep deprivation, and dietary glycation. UV remains the dominant extrinsic driver, accounting for about 80% of facial aging, while particulate matter and ozone act through aryl hydrocarbon receptor activation, reactive oxygen species generation, matrix metalloproteinase induction, collagen degradation, and hyperpigmentation. Ethnic and gender differences alter clinical expressions: pigmentary disorders often precede deep rhytides in many Asian groups, and hormone-linked antioxidant differences modulate susceptibility to oxidative damage between males and females. Formulation science therefore must align antioxidant, peptide, retinoid, and botanical strategies with regional exposure profiles and gender-specific barrier and dermal characteristics to achieve measurable skin benefits.

Progress will depend on integrating validated in vivo and ex vivo assessment systems with molecular profiling to support product claims and to match interventions to individual risk patterns. Instrumental readouts such as capacitance-based hydration measures, transepidermal water loss, Cutometer elasticity parameters, high-frequency ultrasound, Mexameter melanin and erythema indices, and controlled pollutant exposure platforms like CPES provide objective end points for antioxidative, anti-pollution, and photoprotective efficacy. Genetic stratification using SNP clusters in MMPs, aquaporins, filaggrin, SOD, and glutathione peroxidase offers a path for personalizing regimens that prioritize matrix preservation, barrier reinforcement, or hydration support. Combining well-characterized botanicals, peptides, and clinically appropriate retinoids within vehicles that respect gender-specific barrier tolerability, and validating outcomes with standardized exposome challenge models and instrument-based metrics will enable more precise and clinically meaningful interventions for aging skin across diverse Asia-Pacific populations.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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