International Journal of Design & Nature and Ecodynamics
Vol. 20, No. 6, June, 2025, pp. 1409-1417
Journal homepage: http://iieta.org/journals/ijdne

Patchouli Oil as a Natural Antioxidant in Cosmetics: Phytochemicals, Mechanisms, and Applications in Skin Protection

Nadia Isnaini[1,2,3], Allysa Salsabila Lestari[1], Sadli Sadli[1], Vicky Prajaputra[2,3,4*], Syaifullah Muhammad[2,5]

[1] Department of Pharmacy, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[2] ARC-PUIPT Nilam Aceh, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[3] Research Center for Marine Sciences and Fisheries, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[4] Department of Marine Sciences, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[5] Department of Chemical Engineering, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia

Corresponding Author Email: vicky_prajaputra@usk.ac.id

https://doi.org/10.18280/ijdne.200621

Received: 4 March 2025
Revised: 22 May 2025
Accepted: 26 May 2025
Available online: 30 June 2025

Keywords:
antioxidant, cosmetic product, cosmetology, environmental chemistry, patchouli oil, sustainable chemistry

ABSTRACT

Skin, as the body's largest organ, faces constant threats from oxidative stress induced by both internal processes and external factors like UV radiation. Antioxidants are essential for counteracting reactive oxygen species (ROS) and safeguarding the skin against harm. The essential oil obtained from the patchouli plant (*Pogostemon cablin* Benth.) has gained attention for its significant antioxidant capabilities. This literature review explores the utilization of patchouli oil as a natural antioxidant in cosmetic formulations, offering insights into its botanical description, chemical composition, and antioxidant components. The review included peer-reviewed articles published between 2017 and 2024, obtained from Scopus, Web of Science, and Google Scholar using the keywords "patchouli," "antioxidant," and "cosmetics." Studies were selected based on relevance to antioxidant activity, chemical composition, and application in skincare. Data collected revealed patchouli oil's rich phytochemical profile, with major constituents such as patchouli alcohol (50.52%), pogostone (5.45%), β-caryophyllene (1.86%), and β-patchoulene (1.23%), as determined through GC-MS analysis. These compounds exhibit diverse antioxidant and anti-inflammatory effects, contributing to skin health and protection against photoaging induced by UV radiation. Mechanistic insights into how patchouli oil mitigates UV-induced skin damage through modulation of intracellular signaling pathways are discussed. Furthermore, skincare products containing patchouli oil and other essential oils are presented, highlighting their growing popularity in the natural skincare market. The integration of patchouli oil into cosmetic formulations aligns with the industry's trend towards natural, plant-based, and multifunctional active ingredients, offering a sustainable alternative to synthetic antioxidants. This incorporation enhances product claims for anti-aging, skin regeneration, and photoprotection, thereby meeting the growing consumer demand for eco-conscious and effective skincare solutions.

1. INTRODUCTION

As the global cosmetics market continues to expand rapidly, there is a rising demand for natural bioactives that offer safe and effective alternatives to synthetic chemicals. Among the most sought-after natural actives are antioxidants, which play a pivotal role in protecting the skin from oxidative damage. Unlike synthetic antioxidants, which may raise concerns about toxicity and long-term safety, natural antioxidants offer biocompatibility and multifunctionality aligned with consumer preferences for eco-conscious and plant-based skincare products [1-3]. In this context, essential oils rich in phytochemicals—particularly those derived from aromatic plants—are being investigated for their therapeutic skin benefits, including their antioxidant potential.

Patchouli oil (*Pogostemon cablin* Benth.), an essential oil widely cultivated in tropical regions such as Indonesia, has emerged as a unique candidate in the realm of natural antioxidants for cosmetic applications [4, 5]. Its rich composition of sesquiterpenes and flavonoids, especially patchouli alcohol, pogostone, and β-caryophyllene, exhibits powerful reactive oxygen species (ROS)-scavenging abilities, wound healing, anti-inflammatory, and anti-photoaging properties [6-8]. These multifunctional effects position patchouli oil as a high-value ingredient with advantages that surpass many other essential oils commonly used in the cosmetic sector. Notably, the IC_{50} values of patchouli oil are comparatively lower than other members of the Lamiaceae family, reflecting its superior radical neutralization capacity.

Despite this promising potential, patchouli oil remains underrepresented in mainstream commercial cosmetic formulations when compared to essential oils like lavender, rosemary, or tea tree. This gap indicates an untapped opportunity for innovation and further exploration, particularly in elucidating the molecular mechanisms underlying its antioxidant and photoprotective actions. Furthermore, limited comparative analyses exist regarding its efficacy relative to other essential oils with similar applications, presenting a valuable direction for future research.

Given Indonesia's position as one of the world's leading producers of patchouli oil and the country's exposure to high UV radiation levels [9, 10], optimizing the use of this botanical in skincare products aligns with both scientific potential and local resource utilization. Therefore, this literature review explores in depth the phytochemical constituents, mechanisms of antioxidant action, and potential applications of patchouli oil in cosmetic formulations.

2. DATA COLLECTIONS

Literature spanning from 2017 to 2024 was collected from reputable databases including Scopus, Web of Science, and Google Scholar. The keywords "patchouli," "antioxidant," and "cosmetics" were used to retrieve and analyze literature data from these databases. The inclusion criteria for the selected literature comprised peer-reviewed journal articles, reviews, and conference proceedings published in English, specifically focusing on the chemical composition, antioxidant properties, and cosmetic applications of patchouli oil (*Pogostemon cablin*). Studies involving in vitro, in vivo, or clinical investigations relevant to antioxidant activity and skin protection were prioritized. In contrast, exclusion criteria included non-peer-reviewed publications such as blogs or magazines, articles not written in English, studies unrelated to the bioactivity or cosmetic relevance of patchouli oil, and publications centered solely on agricultural aspects. Duplicate entries and preprints replaced by peer-reviewed versions were also excluded.

3. DISCUSSION

3.1 Botanical description of patchouli plant (PP)

Patchouli is the name derived from the Tamil word "pacchilai" or "paculli," meaning green leaf. This plant is recognized by various names in local languages. In Indonesia, it is commonly referred to as nilam in Sumatra or dilem wangi in Java, names that gained popularity during the Dutch colonial era. Some patchouli oil exporters mention that the term NILAM stands for "Netherlands Indische Landbouw Aceh Maatschappij".

Figure 1 shows the morphology of the patchouli plant from Aceh. The patchouli plant has intrinsic characteristics such as spherical foliage and a stem height ranging from 0.5 to 1.2 meters (equivalent to approximately 1.6 to 3.9 inches) [11]. The lengths of patchouli leaves range between 5 and 11 cm, exhibiting a green color, a thin texture, a lack of rigidity, and a hairy upper surface. Notably, the dorsal surface of its leaves is densely covered with hairs and exhibits lobed borders [12]. The presence of glandular trichomes on the leaves is widely recognized as a storage site for essential oils. In addition, the shrub yields petite, pale pink, and white blossoms.

Figure 1. Patchouli plant from Aceh

Patchouli is highly sensitive to drought; therefore, prolonged dry seasons after harvest can lead to plant death. It can grow in various types of soil (andosols, latosols, regosols, podzols, and cambisols), but it thrives best in loose, humus-rich soil.

Recent scientific interest has increasingly focused on the essential oil obtained from Pogostemon cablin, known as patchouli oil (PO), due to its rich composition of bioactive constituents including terpenoids, flavonoids, organic acids, phytosterols, glycosides, lignins, aldehydes, and alcohols [10]. Due to its aromatic properties and potential therapeutic benefits, patchouli cultivation has expanded across many tropical and subtropical regions, especially in Indonesia [13]. There are three types of patchouli in Indonesia: *Pogostemon cablin* Benth (Aceh patchouli), *Pogostemon hortensis* Backer (Java patchouli), and *Pogostemon heyneanus* Benth (soap patchouli). Among these, the Acehnese patchouli plant is known to produce patchouli oil with a higher patchouli alcohol (PA) content.

3.2 Chemical composition of patchouli oil

Patchouli oil is rich in various volatile compounds such as patchouli alcohol (PA), trans-caryophyllene, δ-guaiene, pogostone, β-caryophyllene, α-guaiene, α-patchoulene, β-elemene, and β-patchoulene [14]. Among them, PA—a tricyclic sesquiterpene—stands out as the dominant constituent. Its extraction from patchouli stems and leaves typically employs analytical methods like gas chromatography (GC), gas chromatography-mass–mass spectrometry (GC-MS), and nuclear magnetic resonance (NMR) [15]. Due to its diverse pharmacological properties, PA is widely regarded as a marker of high-quality patchouli oil. Other notable sesquiterpenes, including patchoulene epoxide and β-patchoulene, are also present in considerable quantities. Numerous investigations have concentrated on examining the chemical characteristics and biological functions of these compounds [10]. Along with its volatile components, patchouli oil contains a significant range of non-volatile bioactives, listed in Table 1.

More than fifty non-volatile constituents have been discovered in patchouli through diverse analytical methods, enabling in-depth analysis of their molecular structures. These constituents fall into several chemical categories, including terpenoids, glycosides, flavonoids, organic acids, aldehydes, and lignin-related compounds. Compounds including pachypodol, retusine, ombuin, and others like stigmasterol and tschimganical A have been the focus of extensive scientific research due to their notable properties. Pachypodol, in particular, has emerged as a compound of great interest due to its diverse pharmacological potential. It is mainly extracted from species like Croton ciliatoglanduliferus and Croton floribundus using mass spectrometry-based separation, and its structure is commonly determined through spectroscopic techniques. The broad biological potential of flavonoids—a dominant polyphenol class in patchouli and many plants—has been well documented, with studies underscoring their anti-inflammatory, antioxidant, antifungal, and antimicrobial effects relevant to therapeutic development.

Table 1. The major components of patchouli oil

Name of Compound	Type of Compound	Formula
Non-volatile components		
Stigmasterol	Phytosterols	$C_{29}H_{48}O$
β-Sitosterol	Phytosterols	$C_{29}H_{50}O$
Tilianin	Glycosides	$C_{22}H_{22}O_{10}$
Isocrenatoside	Glycosides	$C_{29}H_{34}O_{15}$
3-O-Methylcrenatoside	Glycosides	$C_{29}H_{36}O_{15}$
Tschimganical A	Other	$C_{11}H_{16}O_3$
Dibutyl phthalate	Organic Acids	$C_{16}H_{22}O_4$
Apigenin	Flavonoids	$C_{15}H_{10}O_5$
Ombuin	Flavonoids	$C_{17}H_{14}O_7$
Retusine	Flavonoids	$C_{19}H_{18}O_7$
Pachypodol	Flavonoids	$C_{18}H_{16}O_7$
Volatile components		
Pogostone	Pyrone	$C_{12}H_{16}O_4$
Limonene	Monoterpene	$C_{10}H_{16}$
α, β-Pinene	Monoterpene	$C_{10}H_{16}$
Trans-Caryophyllene	Sesquiterpene	$C_{15}H_{24}$
β-Elemene	Sesquiterpene	$C_{15}H_{24}$
β-Caryophyllene	Sesquiterpene	$C_{15}H_{24}$
α, β-Patchoulene	Sesquiterpene	$C_{15}H_{24}O$
Patchoulene epoxide	Sesquiterpene	$C_{15}H_{24}O$
α, β-Guaiene	Sesquiterpene	$C_{15}H_{24}$
Patchouli alcohol	Sesquiterpene	$C_{15}H_{26}O$

3.3 Potential antioxidant components in patchouli oil

Reactive oxygen species (ROS), commonly referred to as free radicals, are highly reactive molecules generated during normal oxidative processes. Although these species play roles in physiological functions, their excessive accumulation—particularly due to ultraviolet (UV) radiation—can cause significant cellular damage, especially in skin tissue. UV exposure accelerates ROS production, which initiates inflammatory pathways and contributes to photoaging. One of the major consequences is the stimulation of matrix metalloproteinases (MMPs), enzymes that break down structural elements of the extracellular matrix, such as collagen and elastin. This enzymatic activity contributes to visible signs of aging, including fine lines, reduced skin firmness, and dryness. To counteract these effects, the antioxidant constituents of patchouli oil have been explored for their potential incorporation into skincare products, as highlighted in Table 2, offering natural protection against oxidative skin damage.

Patchouli alcohol, the predominant active constituent in patchouli oil, has been reported to effectively enhance the recovery of skin damaged by ultraviolet radiation, mainly due to its potent anti-inflammatory action and powerful antioxidant capabilities. As a result, it suppresses the expression of matrix metalloproteinases MMP-1 and MMP-3—enzymes responsible for breaking down key components of the extracellular matrix—thereby helping maintain skin structure and function [16, 17]. The antioxidant activity of patchouli extract has been examined using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging method [18]. In this assay, different doses of methanol-based patchouli extract (ranging from 0.25 to 4 mg/mL) were combined with 3 mL of a 0.004% (w/v) methanolic DPPH solution and kept in the dark at ambient temperature for half an hour. The reduction in absorbance at 517 nm was measured with a UV-Vis spectrophotometer (UV-1800, Shimadzu). Figure 2 illustrates that patchouli extracts obtained through supercritical CO_2 extraction at pressures of 150 and 200 bar displayed potent antioxidant properties, as evidenced by low IC50 values of 0.676 ± 0.035 mg/mL and 0.581 ± 0.036 mg/mL, respectively, where lower IC_{50} values signify higher antioxidant efficacy. Besides patchouli alcohol, other essential antioxidant compounds in patchouli oil include α-pinene, β-caryophyllene, pogostone, caryophyllene oxide, and β-elemene, all of which act synergistically to enhance the oil's overall therapeutic effects.

Table 2. Potential antioxidant sources in patchouli oil for cosmetic preparation

Composition	Function	Ref.
Patchouli alcohol	Act as an antioxidant to reduce the production of MMP-1 and MMP-3, which cause skin wrinkles.	[16-18]
α-Pinene	Protects the skin from photoaging caused by exposure to UV-A.	[19]
β-Caryophyllene	Act as an antioxidant to promote wound healing and skin regeneration.	[20, 21]
Pogostone	Improves the function of antioxidant enzymes; Decreases malondialdehyde (MDA) levels and downregulates the atypical expression of MMP-3 and MMP-1.	[22]
β-Patchoulene	Improves oxidative stress resistance and inflammation control by influencing the NF-κB pathway.	[23]
β-Elemene	Reduces the occurrence of skin tumors.	[24]

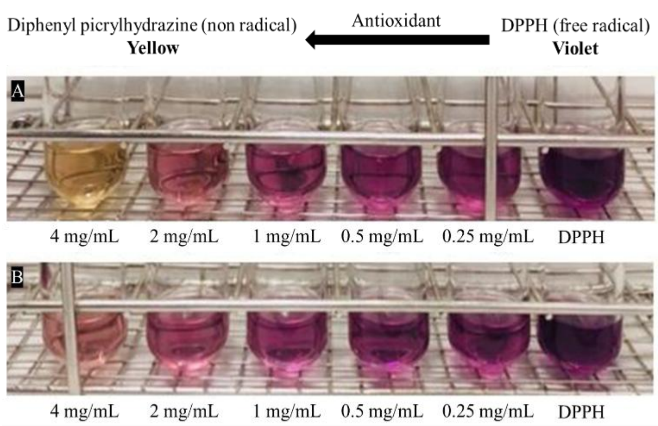

Figure 2. Patchouli extract solution at varying concentrations mixed with DPPH (SC-CO_2 extraction pressure: (A) 200 bar and (B) 150 bar)

The research performed by Karthikeyan et al. [19] identified the role of α-Pinene in protecting mice from skin damage triggered by UVA irradiation. Administration of α-Pinene prior to UVA exposure was shown to help maintain the activity of antioxidant enzymes, which would otherwise be reduced, and to limit the extent of lipid peroxidation. In addition, α-Pinene demonstrated strong inhibitory effects on the UVA-induced activation of various pro-inflammatory and pro-angiogenic mediators, such as vascular endothelial growth factor (VEGF), cyclooxygenase-2 (COX-2), inducible nitric oxide synthase (iNOS), interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), and the transcription factor NF-κB p65. This compound also led to a reduction in proteins involved in apoptotic pathways, including Bcl-2, Bax, caspase-9, and caspase-3. Moreover, it significantly lowered the expression levels of matrix metalloproteinases (MMP-2, MMP-9, and MMP-13), enzymes known to break down essential structural components of the skin. Histological analysis further confirmed that treatment with α-Pinene preserved the structural integrity of the skin in mice exposed to UVA, underscoring its role as a potential agent in protecting against photoaging and skin tissue deterioration.

Gushiken et al. [20] conducted research on the antioxidant effects of β-caryophyllene when incorporated into an emulgel formulation. Their study demonstrated that a 1% β-caryophyllene emulgel exhibited wound-healing properties when tested on rats using an excision model. This sesquiterpene showed antioxidative and anti-inflammatory activities, along with improvements in tissue remodeling and re-epithelialization pathways. These findings are consistent with a study by Koyama et al. [21], which demonstrated enhanced re-epithelialization of skin wounds in mice following the administration of β-caryophyllene oil. Furthermore, histological assessments using Masson's trichrome staining indicated β-caryophyllene's involvement in skin regeneration. The compound enhanced collagen production in the wound core during the initial phase of healing, showing superior outcomes in tissue remodeling compared to standard medications.

Conversely, Pogostone has shown strong potential in reducing the appearance of wrinkles, as reported by Junren et al. [22]. In mouse models exposed to ultraviolet (UV) radiation, topical administration of pogostone led to notable improvements in both surface-level and histological skin damage. This compound was found to boost the activity of key antioxidant enzymes—glutathione peroxidase (GSH-PX), superoxide dismutase (SOD), and catalase (CAT)—while simultaneously lowering malondialdehyde (MDA) levels, a marker of oxidative stress. Additionally, Pogostone suppressed the abnormal expression of matrix metalloproteinases MMP-1 and MMP-3, which are enzymes responsible for breaking down collagen and other extracellular matrix components. Since photoaging is largely driven by ROS-induced upregulation of MMPs, which accelerates wrinkle development, pogostone offers promising protective effects against premature skin aging.

An interesting study by Liu et al. [23] reported the impact of β-patchoulene on the expression of proteins associated with the NF-κB signaling pathway. The findings indicated a significant inhibition ($P < 0.05$) of the increased protein ratio following β-patchoulene administration, surpassing the effect observed with patchouli alcohol. These results align with previously mentioned antioxidant and anti-inflammatory outcomes, suggesting that β-patchoulene enhances antioxidant and anti-inflammatory properties by modulating the NF-κB signaling pathway.

Another active compound found in patchouli oil, β-elemene, was investigated by Feng et al. [24]. The study demonstrated that administering β-elemene at a dosage of 50 mg/kg reduced the formation of skin tumors in mice subjected to DMBA/TPA-induced skin carcinogenesis. Restoration of antioxidant levels in the mouse model was achieved by increasing the expression of non-enzymatic antioxidants, including GSH, vitamin E, and vitamin C. Moreover, β-elemene induced programmed cell death by inhibiting NF-κB transcription and reducing the levels of inflammatory cytokines such as IL-6, IL-2, and TNF. In addition, it promoted the expression of pro-apoptotic proteins, including Bax, caspase-9, and caspase-3, thereby enhancing the apoptotic pathway. These findings suggest that β-elemene holds therapeutic potential for the treatment of experimentally induced skin cancer.

3.4 Antioxidant activity of patchouli and other plants

Table 3 presents the antioxidant activity of major volatile components derived from patchouli and several other medicinal plants, including clove, perilla, lemon, sage, and basil. The antioxidant activity is expressed through the IC_{50} value (μg/mL), indicating the concentration required to scavenge 50% of DPPH free radicals, where a lower IC_{50} signifies stronger antioxidant potential.

Table 3. Antioxidant activity (AA) of major natural components in patchouli and other plants

Plant Sources	Components	AA IC_{50} (μg/mL)	Ref.
Patchouli	β-patchoulene (1.23%), caryophyllene (1.86%), pogostone (5.45%), patchouli alcohol (50.52%)	49.74	[25]
Clove	Eugenol (77.61%), Eugenol acetate (6.54%), β-Cis-caryophyllene (2.53%), Prehnitene (2.73%), Psi-cumene (3.03%)	30.27	[26]
Perilla leaves	Isoelemicin (3.29%), α-Farnesene (4.44%), Caryophyllene (10.21%), Isoegomaketone (20.40%), and Perillaketone (35.56%)	3.77	[25]
Lemon	Limonene (39.74%), β-Pinene (25.44%), α-Terpineol (7.30%), Nerolidol (6.91%), Farnesol (4.28%), Linalool (2.16%), Esters (Total ~11%)	15.06	[27]
Sage leaves	Tanacetone (27.99%), Camphor (16.21%), Viridiflorol (7.85%), Eucalyptol (5.11%), Humulene (6.44%)	11.86	[25]
Basil	Trans-β-Guaiene (16.89%), α-Cadinol (15.66%), Phytol (11.68%), 9-Methoxybicyclo nona-triene (11.36%), Eucalyptol (3.03%)	13.21	[28]

Among the listed plants, Perilla leaves exhibit the highest antioxidant activity, with an IC_{50} of 3.77 μg/mL, attributed to the high content of perillaketone (35.56%), isoegomaketone (20.40%), and caryophyllene (10.21%). Clove follows, with an IC_{50} of 30.27 μg/mL, largely due to its high eugenol content (77.61%), which is well-known for its strong radical scavenging ability.

Lemon essential oil displays moderate antioxidant activity (IC_{50} = 15.06 µg/mL), containing compounds such as limonene (39.74%), β-pinene (25.44%), and α-terpineol (7.30%). Sage leaves (IC_{50} = 11.86 µg/mL) and basil (IC_{50} = 13.21 µg/mL) also show promising activity due to the presence of components like camphor, viridiflorol, eucalyptol (in sage), and phytol, trans-β-guaiene, and α-cadinol (in basil).

Patchouli, although slightly less potent (IC_{50} = 49.74 µg/mL) compared to the others, still demonstrates substantial antioxidant capacity through active compounds such as patchouli alcohol (50.52%), pogostone (5.45%), β-patchoulene (1.23%), and caryophyllene (1.86%). The data suggest that the antioxidant efficacy of essential oils is closely related to their specific volatile composition.

Patchouli, in particular, contains a diverse range of bioactive compounds with notable antioxidant properties, making it a strong candidate for incorporation into skincare and cosmetic formulations aimed at mitigating various skin conditions. Singh and Agrawal [14] further support this potential, reporting that patchouli oil exhibits significant antioxidant activity in mice, effectively protecting against UV-induced skin photoaging. This protective effect is associated with a reduction in malondialdehyde (MDA) levels and an upregulation in the activity of key antioxidant enzymes, including catalase (CAT), superoxide dismutase (SOD), and glutathione peroxidase (GSH-Px).

An independent study conducted by Feng et al. [29] explored the protective role of patchouli alcohol when applied topically to mouse skin in response to UV-induced aging. The research aimed to assess the effectiveness of this naturally derived compound—recognized for its anti-inflammatory and antioxidant functions—in alleviating signs of photoaging. The experimental model involved six-week-old mice whose dorsal skin had been shaved prior to treatment. The animals received topical applications of either a patchouli alcohol formulation or a control solution, followed by continuous UV exposure over a nine-week period. To determine the protective impact of PA, researchers evaluated both visual and microscopic skin changes, measured the activity of antioxidant enzymes such as superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px), and analyzed inflammatory cytokines including IL-10, IL-6, and TNF-α. They also quantified the expression levels of matrix metalloproteinases MMP-1 and MMP-3. The results indicated that patchouli alcohol significantly promoted skin recovery by mitigating oxidative stress and inflammation, as well as by downregulating MMPs associated with collagen degradation and photoaging.

3.5 Mechanism of antioxidant protects skin from photoaging

Since ultraviolet (UV) exposure is the foremost external contributor to skin aging, the term photoaging is often applied to describe this phenomenon. While other environmental stressors—such as tobacco smoke, ozone, and allergens—also promote skin aging through similar mechanisms involving the production of reactive oxygen species (ROS), they are not discussed in detail in this section.

The aging of skin caused by prolonged UV-A, UV-B, and IR exposure—especially long-wave IR with its thermal effects—is known as photoaging [30]. Table 4 compares the effects of UV-A and UV-B on skin layers. UV-B primarily damages the epidermis by directly harming DNA, suppressing immunity, and triggering inflammation. An important molecular event in UV-B–mediated photoaging is the conversion of free cytoplasmic tryptophan into formylindolo[3,2-b]carbazole (FICZ). This metabolite activates the aryl hydrocarbon receptor (AhR), also known as the dioxin receptor, in human keratinocytes. AhR activation subsequently upregulates the expression of matrix metalloproteinases (MMPs) and induces key enzymes, including cytochrome P450 1A1 and cyclooxygenase-2 (COX-2), all of which contribute to the degradation of the skin matrix and inflammatory responses [31].

Table 4. Comparison between the impacts of UV-B and UV-A on the skin

UVA (320-400 nm)	UVB (280-320 nm)
• UV erythema	• UV erythema (sunburn)
• Rapid pigmentation	• Long-term pigmentation
• Photocarcinogenesis (oxidative DNA damage)	• Photocarcinogenesis (direct DNA damage)

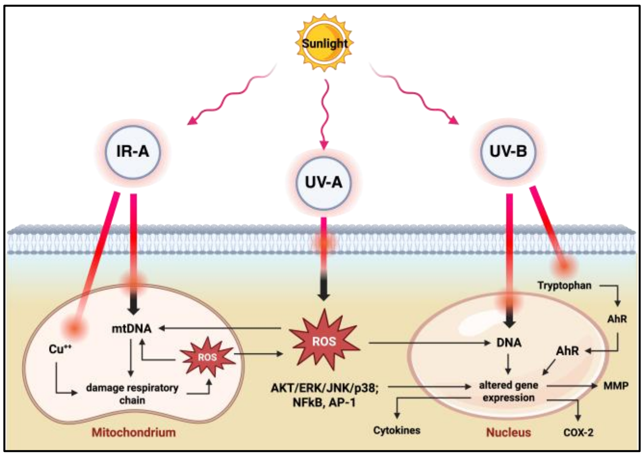

Figure 3. The origin and function of ROS in skin aging induced by UV light

Figure 3 illustrates the complex molecular mechanisms by which UV-induced reactive oxygen species (ROS) influence intracellular signaling pathways associated with skin photoaging. Ultraviolet (UV) radiation induces oxidative stress, which subsequently activates various cell surface receptors, including those for epidermal growth factor (EGF), tumor necrosis factor-alpha (TNF-α), insulin, and interleukin-1 (IL-1) [32]. Once these receptors are activated, they initiate a series of intracellular signaling events that ultimately result in the breakdown of the extracellular matrix (ECM). This process is largely mediated by the stimulation of mitogen-activated protein kinases (MAPKs), including p38, c-Jun N-terminal kinase (JNK), and extracellular signal-regulated kinase (ERK). These kinases, in turn, promote the activation of the transcription factor activator protein-1 (AP-1), which consists of the c-Jun and c-Fos protein subunits.

Various ultraviolet (UV) wavelengths impact the skin through different biological pathways. UV-B rays primarily induce direct genetic mutations by damaging DNA, whereas UV-A rays are more associated with the production of reactive oxygen species (ROS), particularly within the lipid raft domains of cellular membranes [33]. In contrast, Infrared-A (IR-A) is mainly taken up by mitochondria, where it interferes with the electron transport chain, leading to excessive ROS formation. These ROS subsequently damage DNA, disrupt mitochondrial activities, and create a feedback loop of oxidative stress, which promotes the release of proinflammatory cytokines and the enzyme matrix metalloproteinase-1 (MMP-1). Additionally, UV-B exposure triggers the aryl hydrocarbon receptor (AhR), which influences gene regulation related to skin aging.

The transcription factor AP-1 plays a central role in collagen degradation by stimulating the expression of MMPs, particularly MMP-1 (collagenase-1), MMP-3 (stromelysin-1), and MMP-9 (gelatinase B). MMP-1 is especially critical as it initiates the breakdown of type I collagen, a major structural component of the ECM. Notably, even a single suberythematogenic exposure to UV-B can significantly elevate MMP levels. This effect is amplified by oxidative stress and the generation of peroxynitrite, often associated with neutrophil infiltration. Importantly, this upregulation of MMPs is not adequately counterbalanced by tissue inhibitors of metalloproteinases (TIMPs), which normally serve to regulate MMP activity.

UV radiation also suppresses collagen synthesis. AP-1 inhibits the activity of transforming growth factor-beta (TGF-β), a pivotal cytokine involved in the production of type I and III collagen in dermal fibroblasts [34]. Additionally, the nuclear factor-kappa B (NF-κB) pathway is activated by UV-induced ROS, further promoting MMP expression and the release of proinflammatory cytokines such as TNF-α, TNF-β, IL-1β, IL-8, IL-6, and vascular endothelial growth factor (VEGF). These cytokines amplify the inflammatory response through receptor-mediated signaling. Collagen metabolism is also regulated by cysteine-rich protein 61 (CYR61), which exerts dual effects on both collagen synthesis and degradation. The accumulation of fragmented collagen in the ECM ultimately hinders the formation of new collagen and hyaluronan, compromising skin structure and elasticity.

Imbalance in the regulation of NF-κB, a key protein complex involved in immune system signaling, has been linked to numerous disease states such as chronic inflammation, tumor development, and the aging process [35]. When triggered by reactive oxygen species (ROS) or ultraviolet (UV) radiation, the subunits of NF-κB migrate into the cell nucleus, where they activate the expression of genes responsible for producing pro-inflammatory cytokines and matrix metalloproteinases (MMPs).

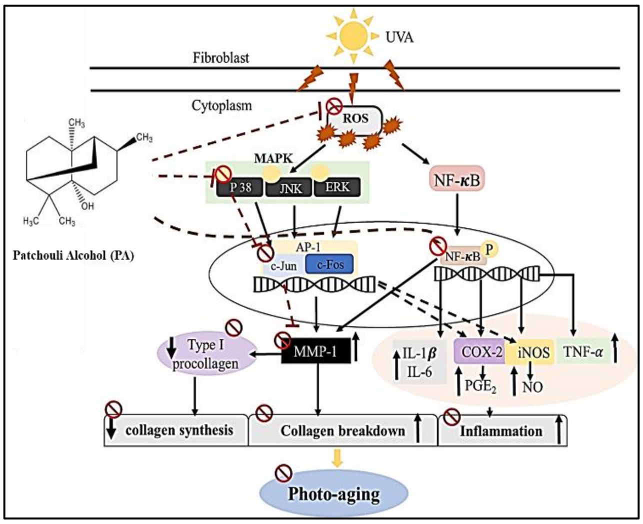

Figure 4. The proposed mechanism for reducing UVA-induced photoaging in human dermal fibroblast cells

Figure 4 presents the proposed mechanism by which patchouli alcohol (PA) mitigates UVA-induced photoaging in human dermal fibroblasts. PA has been found to block NF-κB signaling, thereby limiting the expression of MMP-1 and inflammatory mediators. Moreover, PA effectively limits the accumulation of ROS, nitric oxide (NO), and prostaglandin E2 (PGE2) induced by UVA radiation. It also suppresses the activation of AP-1 and p38 MAPK while enhancing collagen synthesis, collectively contributing to its anti-photoaging effects. Although further in-depth studies, including in vivo experiments and clinical trials, are necessary to fully validate PA's protective potential [36], current evidence strongly supports its application in anti-photoaging skincare formulations. Notably, the combination of marine collagen with essential oils, particularly patchouli oil, has been found to enhance the efficacy of cosmetic products targeting skin aging [37-39].

Table 5. Skincare formulations available in the market contain patchouli and other essential oils

Product Name	EO Used	Type of Treatment	Brand Name
Neelam Hand and Body Serum	Patchouli	Helps soften and hydrate the skin, alleviates dryness, shields against heat and humidity, and delays aging signs.	Neelam
Neelam Body Butter	Patchouli	Acts as a skin moisturizer, calms irritation, and is ideal for dry skin types.	Neelam
Neelam Hand Cream	Patchouli	Provides nourishment and enhances skin softness.	Neelam
Inveda Soothing Rose & Patchouli Face Cleanser	Rose and Patchouli	Gently purifies, hydrates, and calms the skin; especially suitable for those with sensitive skin.	Inveda
Khadi Natural Lavender Moisturizer	Lavender	Exfoliates dead skin cells, boosts regeneration, balances skin tone, reduces blemishes, and improves radiance.	Khadi Natural
Inveda Anti Pigmentation Blend with Rosemary & Bergamot Oil	Bergamot and Rosemary	Balances skin pH levels, provides clear, smooth, and radiant skin.	Inveda
Forest Essentials Night Treatment Cream Jasmine & Patchouli	Patchouli and Jasmine	Contains botanical antioxidants that support skin moisture and delay visible signs of skin aging.	Forest Essentials
Aroma Magic Lavender Face Wash	Rose and Lavender	Helps relieve dry, flaky skin, reduces acne flare-ups, and gently cleanses while soothing and revitalizing the face.	Blossom Kochhar Aroma Magic
The Man Company Charcoal Face Scrub	Lemon grass & Eucalyptus	Deep-cleans pores by eliminating impurities, dead skin, and blackheads; also offers antifungal and anti-inflammatory effects to combat acne.	The Man Company

3.6 Skincare products containing patchouli essential oil on the market

Various skincare and cosmetic products in the market harness the potent benefits of essential oils, including patchouli oil, renowned for its versatile properties. Several skincare products available in the market, containing patchouli and other essential oils, are presented in Table 5.

Essential oil is often incorporated into formulations due to its purported ability to soothe, rejuvenate, and balance the skin. These formulations encompass a wide range of products, including facial cleansers, toners, moisturizers, serums, and masks, catering to diverse skincare needs. Patchouli oil, along with other essential oils, serves as a key ingredient in natural and organic skincare lines, appealing to consumers seeking plant-based solutions for their skincare routines. Cosmetic or skincare formulations incorporated with essential oils improve antioxidant, anti-inflammatory, and antimicrobial properties, aiming to promote healthier and more radiant skin [40, 41].

Furthermore, the versatility of patchouli oil extends beyond skincare to face care, hair care, and aromatherapy products [42, 43]. Shampoos, conditioners, and hair masks infused with patchouli oil are designed to nourish the scalp, strengthen hair follicles, and impart a lustrous sheen to the hair [40]. Likewise, aromatherapy blends featuring patchouli oil are valued for their grounding, calming, and mood-enhancing effects.

Overall, the availability of patchouli and other essential oil-based formulations in the market underscores the growing demand for natural, holistic approaches to skincare and self-care. As consumers increasingly prioritize natural, sustainable ingredients, these products offer an appealing alternative to conventional skincare formulations, harnessing various advantages to promote overall skin well-being.

4. CONCLUSIONS

The utilization of patchouli oil as a natural antioxidant in cosmetic formulations presents a promising avenue for skincare innovation. The comprehensive exploration of patchouli oil's botanical description, chemical composition, and potential antioxidant components underscores its efficacy in combating oxidative stress and protecting the skin from premature aging induced by environmental factors such as UV radiation. This review emphasizes the presence of key antioxidant agents in patchouli oil, notably patchouli alcohol, pogostone, β-caryophyllene, and β-patchoulene. These compounds are known to function through several biological pathways, including neutralization of reactive oxygen species (ROS), suppression of matrix metalloproteinase (MMP) activity, and regulation of crucial signaling routes such as NF-κB and MAPK, which play essential roles in preventing inflammation and the breakdown of collagen in skin tissue. The diverse chemical composition of patchouli oil—encompassing α-pinene, β-caryophyllene, β-patchoulene, pogostone, β-elemene, and particularly patchouli alcohol—exhibits a broad spectrum of antioxidant and anti-inflammatory actions that support overall skin resilience and appearance. Moreover, the mechanism through which patchouli oil mitigates UV-induced photoaging by modulating intracellular signaling pathways and inhibiting the expression of matrix metalloproteinases elucidates its protective effects on the skin. In practical terms, this review supports the integration of patchouli oil as a scientifically substantiated, multifunctional ingredient in the cosmetics industry, meeting consumer demand for clean-label, natural, and sustainable skincare products. Its broad spectrum of bioactivity provides opportunities for product claims in anti-aging, wound healing, skin barrier repair, and photoprotection, reinforcing its market relevance and commercial potential. The availability of skincare products containing patchouli oil and other essential oils in the market further highlights the growing demand for natural and sustainable alternatives in the beauty industry. As consumers increasingly prioritize holistic skincare solutions, formulations enriched with patchouli oil offer a compelling option for promoting radiant, healthy skin. Thus, the integration of patchouli oil into cosmetic formulations represents a significant advancement in the quest for efficacious and eco-friendly skincare products. Future research should focus on clinical trials and long-term studies to further validate the efficacy and safety of patchouli oil in cosmetic applications, ensuring its continued use and development in the skincare industry.

ACKNOWLEDGMENTS

Support for this research was provided through an internal scheme initiated by the Institute for Research and Community Service (LPPM), Universitas Syiah Kuala (USK). Additionally, the implementation of this project was made possible through the technical assistance and facilities provided by the Atsiri Research Center USK, a specialized research unit within the university that focuses on the advancement of essential oil studies and their applications in science, health, and industry.

REFERENCES

[1] Wang, G., Yang, F., Zhou, W., Xiao, N., Luo, M., Tang, Z. (2023). The initiation of oxidative stress and therapeutic strategies in wound healing. Biomedicine & Pharmacotherapy, 157: 114004. https://doi.org/10.1016/j.biopha.2022.114004

[2] Jain, A., Shakkarpude, J. (2024). Oxidative stress: A biomarker for animal health and production: A review. Indian Journal of Animal Research, 58(1): 1-12. https://doi.org/10.18805/IJAR.B-5300

[3] Zhang, H., Lin, X., Cao, X., Wang, Y., Wang, J., Zhao, Y. (2024). Developing natural polymers for skin wound healing. Bioactive Materials, 33: 355-376. https://doi.org/10.1016/j.bioactmat.2023.11.012

[4] Isnaini, N., Khairan, K., Faradhilla, M., Sufriadi, E., Prajaputra, V., et al. (2022). A study of essential oils from patchouli (*Pogostemon cablin* Benth.) and its potential as an antivirus agent to relieve symptoms of COVID-19. Journal of Patchouli and Essential Oil Products, 1(2): 27-35. https://doi.org/10.24815/jpeop.v1i2.23763

[5] Deliana, F., Illian, D.N., Nadirah, S., Sari, F., Khairan, K. (2023). Therapeutic effects of Patchouli (*Pogostemon cablin*) essential oil in relieving eczema symptoms in infants and toddlers: A literature review. Journal of Patchouli and Essential Oil Products, 2(1): 1-8. https://doi.org/10.24815/jpeop.v2i1.32073

[6] Ginting, B., Sufriadi, E., Harnelly, E., Isnaini, N., et al. (2023). Identification of volatile compounds contained in the therapeutic essential oils from *Pogostemon cablin*,

Melaleuca leucadendra, and *Mentha piperita* and their purified fractions. Journal of Advanced Pharmaceutical Technology & Research, 14(3): 208-212. https://doi.org/10.4103/JAPTR.JAPTR_161_23

[7] Kumar, K.S., Vani, M.G., Chinnasamy, M., Lin, W.T., Wang, S.Y. (2024). Patchouli alcohol: A potent tyrosinase inhibitor derived from patchouli essential oil with potential in the development of a skin-lightening agent. Cosmetics, 11(2): 38. https://doi.org/10.3390/cosmetics11020038

[8] Fatima, S., Farzeen, I., Ashraf, A., Aslam, B., Ijaz, M.U., et al. (2023). A comprehensive review on pharmacological activities of pachypodol: A bioactive compound of an aromatic medicinal plant *Pogostemon cablin* Benth. Molecules, 28(8): 3469. https://doi.org/10.3390/molecules28083469

[9] Salsabila, S., Stenkina, M., Sakina, S.I., Lee, J.Y. (2024). Thermal effects of rayon and polyester hijabs in warm-humid and hot-dry environments. Fashion and Textiles, 11(1): 11. https://doi.org/10.1186/s40691-024-00374-y

[10] Bocheva, G., Slominski, R.M., Slominski, A.T. (2023). Environmental air pollutants affecting skin functions with systemic implications. International Journal of Molecular Sciences, 24(13): 10502. https://doi.org/10.3390/ijms241310502

[11] Ribeiro, A.S., Bertolucci, S.K.V., Carvalho, A.A.D., Tostes, W.N., Coelho, A.D., Pinto, J.E.B.P. (2021). Light intensities alter growth and essential oil of patchouli under shade nets. Ciência Rural, 52(5): e20210118. https://doi.org/10.1590/0103-8478cr20210118

[12] Suganthy, M., Mani, M. (2022). Pests and their management in aromatic plants: Basil, Davana, Jasmine, Lemongrass, Marjoram, Mint, Patchouli, Rosemary, Sage and Thyme. Trends in Horticultural Entomology, 2022: 1305-1329. https://doi.org/10.1007/978-981-19-0343-4_55

[13] Soibam, H., Chanu, N.Y., Lego, N., Nyodu, T., Pandey, D.K., et al. (2022). Influence of organic nutrients on growth, yield and essential oil composition of patchouli (Pogostemon cablin Benth.) under foothill conditions of Arunachal Pradesh, India. Journal of Essential Oil Bearing Plants, 25(3): 657-665. https://doi.org/10.1080/0972060X.2022.2105663

[14] Singh, S., Agrawal, N. (2024). Exploring the pharmacological potential and bioactive components of Pogostemon cablin (Blanco) Benth, traditional Chinese medicine. Pharmacological Research-Modern Chinese Medicine, 10: 100382. https://doi.org/10.1016/j.prmcm.2024.100382

[15] Nour, A.H., Modather, R.H., Yunus, R.M., Elnour, A.A., Ismail, N.A. (2024). Characterization of bioactive compounds in patchouli oil using microwave-assisted and traditional hydrodistillation methods. Industrial Crops and Products, 208: 117901. https://doi.org/10.1016/j.indcrop.2023.117901

[16] Nafissa, N., Isnaini, N., Desiyana, L.S., Prajaputra, V., Harnelly, E., et al. (2023). Antiaging mechanism of natural plant sources: A potential current product. Journal of Patchouli and Essential Oil Products, 2(2): 41-47.

[17] Isnaini, N., Khairan, K., Faradhilla, M., Sufriadi, E., Ginting, B., et al. (2022). Evaluation of physical quality of patchouli oil (*Pogostemon cablin* Benth.) body butter formulation. Journal of Patchouli and Essential Oil Products, 1(1): 22-26.

[18] Soh, S.H., Agarwal, S., Jayaraman, S., Tham, M.T., Lee, C.L.Y., Jain, A. (2018). A study of essential oil extraction and antioxidant activity of patchouli (*Pogostemon cablin*) using supercritical carbon dioxide. ON12, 1: 8-15.

[19] Karthikeyan, R., Kanimozhi, G., Madahavan, N.R., Agilan, B., Ganesan, M., Prasad, N.R., Rathinaraj, P. (2019). Alpha-pinene attenuates UVA-induced photoaging through inhibition of matrix metalloproteinases expression in mouse skin. Life Sciences, 217: 110-118. https://doi.org/10.1016/j.lfs.2018.12.003

[20] Gushiken, L.F.S., Beserra, F.P., Hussni, M.F., Gonzaga, M.T., Ribeiro, V.P., et al. (2022). Beta-caryophyllene as an antioxidant, anti-inflammatory and re-epithelialization activities in a rat skin wound excision model. Oxidative Medicine and Cellular Longevity, 2022(1): 9004014. https://doi.org/10.1155/2022/9004014

[21] Koyama, S., Purk, A., Kaur, M., Soini, H.A., Novotny, M.V., et al. (2019). Beta-caryophyllene enhances wound healing through multiple routes. PloS One, 14(12): e0216104. https://doi.org/10.1371/journal.pone.0216104

[22] Chen, J., Xie, X., Li, M., Xiong, Q., Li, G., et al. (2021). Pharmacological activities and mechanisms of action of Pogostemon cablin Benth: A review. Chinese Medicine, 16: 1-20. https://doi.org/10.1186/s13020-020-00413-y

[23] Liu, Y., Liang, J., Wu, J., Chen, H., Zhang, Z., et al. (2017). Transformation of patchouli alcohol to β-patchoulene by gastric juice: β-patchoulene is more effective in preventing ethanol-induced gastric injury. Scientific Reports, 7(1): 5591. https://doi.org/10.1038/s41598-017-05996-5

[24] Feng, Y., An, Q., Zhao, Z., Wu, M., Yang, C., et al. (2024). Beta-elemene: A phytochemical with promise as a drug candidate for tumor therapy and adjuvant tumor therapy. Biomedicine & Pharmacotherapy, 172: 116266. https://doi.org/10.1016/j.biopha.2024.116266

[25] Liu, M., Luo, F., Qing, Z., Yang, H., Liu, X., Yang, Z., Zeng, J. (2020). Chemical composition and bioactivity of essential oil of ten Labiatae species. Molecules, 25(20): 4862. https://doi.org/10.3390/molecules25204862

[26] Alfikri, F.N., Pujiarti, R., Wibisono, M.G., Hardiyanto, E.B. (2020). Yield, quality, and antioxidant activity of clove (*Syzygium aromaticum* L.) bud oil at the different phenological stages in young and mature trees. Scientifica, 2020(1): 9701701. https://doi.org/10.1155/2020/9701701

[27] Ben Hsouna, A., Ben Halima, N., Smaoui, S., Hamdi, N. (2017). Citrus lemon essential oil: Chemical composition, antioxidant and antimicrobial activities with its preservative effect against Listeria monocytogenes inoculated in minced beef meat. Lipids in Health and Disease, 16: 1-11. https://doi.org/10.1186/s12944-017-0487-5

[28] Sundararajan, B., Moola, A.K., Vivek, K., Kumari, B.R. (2018). Formulation of nanoemulsion from leaves essential oil of Ocimum basilicum L. and its antibacterial, antioxidant and larvicidal activities (*Culex quinquefasciatus*). Microbial Pathogenesis, 125: 475-485. https://doi.org/10.1016/j.micpath.2018.10.017

[29] Feng, X.X., Yu, X.T., Li, W.J., Kong, S.Z., Liu, Y.H., et al. (2014). Effects of topical application of patchouli

alcohol on the UV-induced skin photoaging in mice. European Journal of Pharmaceutical Sciences, 63: 113-123. https://doi.org/10.1016/j.ejps.2014.07.001

[30] Verma, A., Zanoletti, A., Kareem, K.Y., Adelodun, B., Kumar, P., et al. (2024). Skin protection from solar ultraviolet radiation using natural compounds: A review. Environmental Chemistry Letters, 22(1): 273-295. https://doi.org/10.1007/s10311-023-01649-4

[31] Sim, W.J., Lee, E., Yun, S., Lim, W., Lim, T.G. (2023). Particulate matter-induced skin inflammation is suppressed by polyphenol-enriched dietary supplement via inhibition of the AhR/ARNT signaling pathway. Journal of Functional Foods, 106: 105593. https://doi.org/10.1016/j.jff.2023.105593

[32] Sharma, P., Dhiman, T., Negi, R.S., Oc, A., Gupta, K., Bhatti, J.S., Thareja, S. (2024). A comprehensive review of the molecular mechanisms driving skin photoaging and the recent advances in therapeutic interventions involving natural polyphenols. South African Journal of Botany, 166: 466-482. https://doi.org/10.1016/j.sajb.2024.01.035

[33] Wölfle, U., Seelinger, G., Bauer, G., Meinke, M.C., Lademann, J., Schempp, C.M. (2014). Reactive molecule species and antioxidative mechanisms in normal skin and skin aging. Skin Pharmacology and Physiology, 27(6): 316-332. https://doi.org/10.1159/000360092

[34] Xia, Y., Zhang, H., Wu, X., Xu, Y., Tan, Q. (2024). Resveratrol activates autophagy and protects from UVA-induced photoaging in human skin fibroblasts and the skin of male mice by regulating the AMPK pathway. Biogerontology, 25(4): 649-664. https://doi.org/10.1007/s10522-024-10099-6

[35] García-García, V.A., Alameda, J.P., Page, A., Casanova, M.L. (2021). Role of NF-κB in ageing and age-related diseases: lessons from genetically modified mouse models. Cells, 10(8): 1906. https://doi.org/10.3390/cells10081906

[36] Taufik, M., Rizal, S., Harnelly, E., Muhammad, S., Syahrizal, D., Prajaputra, V., Isnaini, N. (2024). The therapeutic potential of aceh patchouli oil (*Pogostemon cablin* benth.) in enhancing full-thickness wound healing in mice. Tropical Journal of Natural Product Research, 8(1): 5840. https://doi.org/10.26538/tjnpr/v8i1.19

[37] Isnaini, N., Prajaputra, V., Syafhira, T., Maryam, S., Arisa, I.I., et al. (2024). Recent update: Collagen extraction from marine resources as a promising natural antiaging. In BIO Web of Conferences, Banda Aceh, Indonesia, p. 03020. https://doi.org/10.1051/bioconf/20248703020

[38] Isnaini, N., Prajaputra, V., Luthfanna, S.K., Sari, I. (2024). An update review: Several extraction methods for collagen isolation in vertebrate fish. BIO Web of Conferences, Banda Aceh, Indonesia, p. 03019. https://doi.org/10.1051/bioconf/20248703019

[39] Prajaputra, V., Isnaini, N., Maryam, S., Ernawati, E., Deliana, F., et al. (2024). Exploring marine collagen: Sustainable sourcing, extraction methods, and cosmetic applications. South African Journal of Chemical Engineering, 47(1): 197-211. https://doi.org/10.1016/j.sajce.2023.11.006

[40] Muhammad, S., Isnaini, N., Indra, I., Prajaputra, V., Sufriadi, E., Ernawati, E. (2024). Patchouli essential oil: Unlocking antimicrobial potential for dandruff control. IOP Conference Series: Earth and Environmental Science, 1356: 012095. https://doi.org/10.1088/1755-1315/1356/1/012095

[41] Isnaini, N., Annisa, A., Prajaputra, V., Maryam, S., Idroes, R., Khairan, K. (2024). Chemical composition and biological activities of essential oils in the family Lamiaceae. IOP Conference Series: Earth and Environmental Science, 1356: 012097. https://doi.org/10.1088/1755-1315/1356/1/012097

[42] Isnaini, N., Muhammad, S., Prajaputra, V., Indra, I., Sufriadi, E., Ernawati, E., Riski, C.D. (2025). Hybrid function of light fraction patchouli oil in hair care formulations for effective hair and anti-dandruff treatment. Narra J, 5(2): e1622-e1622. https://doi.org/10.52225/narra.v5i2.1622

[43] Isnaini, N., Harnelly, E., Zulkarnain, Z., Prajaputra, V., Muhammad, S., et al. (2025). Potential of patchouli (*Pogostemon cablin*) and champaca (*Magnolia champaca*) oils incorporated in facial wash formulation for effective anti-aging on human skin. Journal of Pharmacy & Pharmacognosy Research, 13: 459-474. https://doi.org/10.56499/jppres24.2031_13.2.459