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The science of skin ageing: From radicals to herbal remedies

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Abstract

Skin ageing is a multifaceted process influenced by both intrinsic and extrinsic factors. The mechanisms underlying skin ageing, focus on molecular pathways such as oxidative stress, inflammation, and photoaging. This review explores the flourishing field of herbal interventions in the treatment of ageing, exploring the potential of various plant-based remedies in promoting longevity and maintaining youthful vitality. The free radical theory of ageing suggests that the accumulation of reactive oxygen species (ROS) leads to cellular damage, contributing to skin ageing. Mitochondrial dysfunction and DNA damage further exacerbate this process, resulting in reduced collagen synthesis and increased matrix metallopeptidase (MMP) expression, leading to skin laxity and wrinkles. Inflammation also plays a pivotal role in skin ageing, with proinflammatory cytokines inducing cellular senescence and collagen degradation. Chronic exposure to ultraviolet (UV) radiation accelerates skin ageing through direct DNA damage and collagen breakdown. Various antiageing strategies are discussed, including the use of antioxidants to neutralize oxidative stress, inflammation, photoaging and promoting collagen synthesis. The botanicals discussed possess antioxidant, anti-inflammatory, and collagen-stimulating properties making them valuable ingredients in antiageing skincare formulations. Understanding the molecular mechanisms of skin ageing and exploring natural remedies can pave the way for innovative skincare interventions targeting age-related changes in the skin.

1. Introduction

Ageing is a universal, dynamic, and irreversible process that all living organisms experience over time. It involves a series of physiological, cellular, and molecular changes that result in a gradual decline of an organism's functional capacity. In humans, ageing encompasses a broad spectrum of changes, from the molecular and cellular levels to the whole organism, affecting various systems such as the musculoskeletal, cardiovascular, and nervous systems. The skin is structurally divided into three layers: the epidermis, dermis, and subcutaneous tissue. The skin serves as a protective barrier against the external environment, with its primary functions being the regulation of temperature, maintenance of fluid balance, and protection against harmful microbes and UV radiation from sunlight (Purohit *et al.,* 2016; Monti *et al.,* 2017). There are two distinct types of skin ageing: age-dependent or chronological ageing, and premature ageing, also known as photoaging. Chronological ageing is the natural progression of ageing based on the passage of time. Biological ageing also known as physiological ageing; refers to the gradual decline in the body's ability to function optimally. It is influenced by genetic factors, lifestyle choices, and environmental exposures. Photoaging is primarily caused by extrinsic factors and is characterized by manifestations such as a leathery appearance, variations in pigmentation (dark or light), and the development of deep furrows (Calcinotto *et al.,* 2019). Skin ageing can lead to cutaneous disorders such as dermatoses, benign and malignant tumours, itching, chronic wounds, dry skin, and depigmentation. These conditions can negatively impact skin health and prevent healthy ageing.

Skin ageing is primarily characterized by features such as skin laxity and the formation of wrinkles. These aspects are closely linked to the ageing of skin cells, accompanied by a reduction in collagen synthesis or an increase in degradation. Exogenous and endogenous variables can be used to categorise the causes of skin ageing. Inherent physiological characteristics and the passage of time are the two main examples of endogenous variables. On the other hand, exogenous factors encompass external elements like ultraviolet radiation, smoking, exposure to wind, and contact with harmful chemicals. Particularly, exogenous factors can induce structural damage at the macromolecular level and bring about functional alterations in skin cells, thereby accelerating the ageing process (Klaips *et al.*, 2018; Madiha *et al*., 2018). Dermatologists have access to several antiageing techniques these days, each with their own benefits and drawbacks. Skin ageing can be prevented and treated through cosmetic beauty products, UV protection, non-intrusive treatments, topical therapies with antioxidant compounds and cell regulators, invasive treatments (*e.g.,* chemical peelings, radiofrequency, injectable skin biostimulators, and fillers), systemic agents (antioxidants and hormone therapy), and strategies to limit or reduce exogenous factors (*e.g.,* correcting one's lifestyle). Consumers emphasise their health and well-being, seeking non-invasive, safe, and effective skincare products based on natural bioactive ingredients (Ahmed *et al.,* 2020). Plant biodiversity is a rich source of newly active molecules, despite being displaced by new biotechnologies, chemical compound synthesis, and international biodiversity regulations. Plants contain a broad range of secondary chemical substances, including phenol, flavonoids, anthocyanidins, anthocyanins, tannins, coumarins, terpenoids, stilbenes, and alkaloids. Plant species provide valuable raw materials for developing standardised herbal medicines that have

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been scientifically evaluated for efficacy, safety, and quality control. They can help prevent and cure skin problems such as ageing (Krutmann *et al.,* 2021). In this review, we summarise plant-based products with effectiveness, safety, quality control, and pharmacological impacts on skin ageing mechanisms such as elasticity, wrinkle development, moisture, pigmentation, and the effects of oxidative stress.

2. Mechanism of skin ageing processes

2.1 Free radicals and oxidative stress theory

The free radical theory of ageing proposes that the ageing process is largely influenced by the cumulative damage from free radicals and reactive oxygen species (ROS). Free radicals, which are molecules or atoms with unpaired electrons, are inherently unstable and seek stability by acquiring electrons from other molecules, a process that can damage cellular components such as lipids, proteins, and DNA. This phenomenon is known as oxidative stress. The oxidative stress results from a disparity between the body's ability to mitigate or repair such damage and the generation of free radicals, a disparity that, if left unchecked, may lead to increased cellular damage and contribute to the ageing process (Forrester *et al.,* 2018; Liguori *et al.,* 2018). Mitochondria produce ROS during cell metabolism through oxidative processes. When an excessive amount of ROS accumulates in cells, it damages mitochondria, lowering the potential of the mitochondrial membrane and decreasing the synthesis of ATP within the cell. This initiates a chain reaction that accelerates the ageing process. Free radicals can be generated as byproducts of normal cellular processes, such as metabolism, or due to external factors like exposure to ultraviolet (UV) radiation, pollution, and certain chemicals. Excessive ROS can also break down the structure of DNA, leading to signs of ageing such as impaired cell activity and problems with cell reproduction (Letsiou, 2021; Shin *et al.,* 2019). Significantly raising ROS levels causes skin relaxation and wrinkles by accelerating the ageing process of skin replication and by encouraging a reduction in collagen levels in skin tissue (Petruk *et al.*, 2018). Increased matrix metallopeptidase (MMP) expression is linked to the molecular mechanism (Lephart, 2016; Dunaway *et al.,* 2018). Endogenous protease MMP is zinc-dependent. MMP can precisely break down collagen and other components of the extracellular matrix. This damage to the matrix eventually results in ageing skin. As a result, eliminating too much ROS from skin cells has emerged as one of the approaches that is most commonly used for preventing skin ageing. Several studies are performed on herbal formulation such as in the research conducted by Zhaowei Zhong *et al.* (2018). The study explores the antioxidant and antiageing properties of *Rhodiola rosea* L. extract using *Drosophila melanogaster* as the experimental model. The findings elucidate that the extract of *R. rosea* demonstrates significant antioxidant and antiageing effects by augmenting the activity of antioxidant enzymes and mitigating oxidative damage within *Drosophila melanogaster*. This investigation offers information on the various processes by which *R. rosea* extract exerts its antiageing benefits, offering useful insights into its therapeutic uses (Pu *et al.*, 2020).

2.2 Inflammation theory

Inflammation plays a major role in cellular senescence, *i.e.*, 'inflammatory ageing' which is defined by increased body concentrations of proinflammatory substances. Many age-related disorders are linked to these changes, which also accelerate the ageing process of many cell types, particularly skin cells (Waaijer *et al.,* 2019; Foster *et al.,* 2020). Proinflammatory cytokines such as TNF-α, IL-1, IL-6, IFN-γ, and MMPs are among the many 'senescence-associated secretory phenotypes (SASP)' released by senescent fibroblasts and keratinocytes within the skin's surface (Schumacher *et al.*, 2021; Zade and Wanjari, 2023). These proinflammatory cytokines play a role in inducing senescence in skin cells by stimulating reactive oxygen species (ROS) production and activating the ATM/p53/p21-signaling pathway. Simultaneously, skin cell inflammation contributes to an elevated release of MMPs, leading to collagen degradation and subsequently causing skin cell relaxation, wrinkles, and other visible signs of ageing (Papaccio *et al.,* 2022; Kim *et al.,* 2021). Effectively restraining inflammation in skin cells emerges as a crucial strategy for managing the ageing process in these cells.

2.3 Photoaging theory

The term 'photoaging' describes the ageing process of the skin that is mostly brought on by extended sun exposure (UV) rays. The photoaging theory emphasizes the role of UV radiation in accelerating the ageing of the skin, leading to visible signs such as wrinkles, fine lines, pigmentation changes, and loss of skin elasticity. UV rays can cause direct damage to the DNA in skin cells which can result in mutations and impaired cellular function, contributing to premature ageing. Antiageing approaches often focus on protecting the skin from UV radiation, using broad-spectrum sunscreens to block both UVA and UVB rays. The essential protein collagen gives the skin its shape and rigidity. UV radiation accelerates the breakdown of collagen fibers, resulting in wrinkle development and a decrease in the firmness of the skin (Si *et al.*, 2022). Antiageing interventions may involve promoting collagen synthesis through the use of topical treatments containing retinoids, peptides, or growth factors. Elastin is another protein responsible for maintaining skin elasticity. UV exposure can lead to the degradation of elastin fibers, contributing to sagging and laxity (Rohilla and Singh, 2022). The skin produces extremely reactive chemicals called free radicals as a result of UV radiation, which can harm cellular structures and hasten the ageing process. Antioxidants, such as vitamins C and E, are commonly incorporated into antiageing skincare products to neutralize free radicals and minimize oxidative stress (Krutmann *et al.,* 2021; Sharma *et al.,* 2022).

2.4 Nonenzymatic glycosyl chemistry theory

The nonenzymatic glycosylation theory, also referred to as the Maillard reaction or glycation, is a crucial biochemical process implicated in the ageing process. This theory proposes that the buildup of advanced glycation end-products (AGEs) results from nonenzymatic reactions between free reducing sugars and free amino groups of proteins, DNA, and lipids (Niu *et al.,* 2008). Accumulation of AGEs disrupts cellular homeostasis and protein structure, causing skin darkening and ageing. Accumulation of AGEs causes ROS generation and inflammation, which accelerates skin ageing. AGEs development is irreversible. These AGEs have the propensity to cross-link with neighbouring proteins, thereby modifying their structure and function. This cross-linking can compromise tissue elasticity and function, leading to ageing-related changes such as the stiffening of blood vessels, skin, and other connective tissues. The formation of AGEs can induce oxidative stress by generating reactive oxygen species and reactive carbonyl species, which in turn damage cellular components like DNA, proteins, and lipids (Zheng *et al.,* 2022; He *et al.,* 2023). This oxidative stress contributes to cellular dysfunction and accelerates the ageing process. AGEs can bind to their receptors (RAGE) on cell surfaces, triggering signaling pathways that lead to inflammation and tissue damage. Chronic inflammation is a characteristic of ageing and age-related diseases, with AGE-RAGE interactions playing a significant role in this process. The accumulation of AGEs in various tissues and organs can lead to functional decline and increase susceptibility to age-related diseases such as diabetes, cardiovascular diseases, neurodegenerative disorders, and renal dysfunction (Pageon*,* 2010).

3. Natural herbs used for antiageing

Natural herbs have acquired popularity in antiageing formulas, ranging from old traditional medicines to current scientific research (Sundarrajan, 2023). Various herbs used for antiageing are shown in Figure 1.

Figure 1: Schematic representation of herbs used for antiageing.

3.1 *Panax ginseng* (Ginseng)

Ginseng comes from the root of *Panax ginseng,* belongs to the family Araliaceae, a perennial plant native to the mountainous regions of East Asia, particularly Korea and China. There are different species of ginseng such as Asian or Korean ginseng. The key bioactive compounds in ginseng responsible for its medicinal properties are known as ginsenosides. Ginsenosides are triterpene saponins, and the specific composition can vary among different ginseng species. Other components include polysaccharides, peptides, panaxosides, and polyacetylenes (Jiang *et al.*, 2020). Ginsenosides exhibit potent antioxidant activity, helping to neutralize free radicals in the body. Free radicals are chemicals that accelerate ageing and have the potential to destroy cells. By reducing oxidative stress, ginseng may play a role in preventing premature ageing. It also promotes the synthesis of collagen. An increase in collagen synthesis can help to keep the skin elastic and lessen the visibility of wrinkles and fine lines. Collagen is a glycoprotein that gives the skin structural support (Han *et al.*, 2021). Ginseng also has anti-inflammatory properties, which may help mitigate inflammation and contribute to overall skin health. Ginseng has been linked to improved blood circulation. Enhanced circulation can benefit the skin by ensuring adequate delivery of nutrients and oxygen, supporting overall skin health and vitality. Ginseng is classified as an adaptogen, as it may help the body adapt to stress and restore balance (Xu *et al.*, 2021). Chronic stress is a known contributor to premature ageing, and ginseng's adaptogenic properties may play a role in reducing the impact of stress on the ageing process.

3.2 *Curcuma longa* (Turmeric)

It is a flowering plant belonging to the ginger family Zingiberaceae. The rhizomes or underground stems of *Curcuma longa* are harvested for medicinal and culinary purposes. Curcumin is a polyphenol with potent antioxidant, anti-inflammatory, and anticancer properties. In addition to curcumin, turmeric contains other bioactive compounds such as turmeric essential oils, turmerones, and curcuminoids. Other curcuminoids include demethoxycurcumin and bisdemethoxy curcumin. Curcuminoids are responsible for the yellow color of turmeric and its therapeutic effects. Turmeric also contains volatile oils such as turmerone, atlantone, and zingiberene, which contribute to its aroma and potential health benefits (Kotha and Luthria *et al.*, 2019). Natural curcuminoids exhibit strong inhibitory effects. Curcumin analogs demonstrate elevated tyrosinase activity concerning o-diphenols and m-diphenols when compared to other compounds (Ben *et al.,* 2017; He *et al.,* 2023). The inhibitory action of curcuminoids on tyrosinase activity involves the restraint of L-dopa oxidation. Partially purified *C. longa* diminishes the levels of tyrosinase-related proteins such as MITF and TRP1. Curcumin may inhibit melanin production, helping to reduce hyperpigmentation and age spots. They possess potent antioxidant properties, by neutralizing oxidative stress, turmeric helps protect skin cells from premature ageing caused by environmental factors such as UV radiation and pollution. Curcumin has been shown to inhibit inflammatory pathways and reduce the production of pro-inflammatory cytokines that help alleviate skin conditions associated with inflammation, such as acne, eczema, and psoriasis, and supports overall skin health (Bahrami *et al.,* 2021). They also stimulate collagen synthesis in dermal fibroblasts, the cells responsible for collagen production helps improve skin firmness, and reduce the appearance of wrinkles and fine lines, and inhibit MMP expression and activity, thereby preserving collagen integrity and preventing premature ageing of the skin (Zia *et al.,* 2021). It also has photoprotective properties and can mitigate UV-induced damage by scavenging free radicals, reducing inflammation, and enhancing DNA repair mechanisms (Heng, 2010; Naikodi *et al.,* 2021).

3.3 *Gingko biloba* (Gingko)

It is derived from the leaves of the ancient maidenhair tree, and belongs to a member of the Ginkgoaceae family. The key bioactive components in *Ginkgo biloba* are flavonoids, quercetin, kaempferol derivatives, terpenoids (ginkgolides and bilobalide), and organic acids. Flavonoids, such as quercetin and kaempferol possess antioxidant properties, while terpenoids are known for their anti-inflammatory, antivasculature, and tyrosinase properties (Guo *et al.,* 2023). *G. biloba* extract contains vasodilatory properties, indicating that it helps open blood vessels and improves blood circulation which aids in the removal of toxins and metabolic waste from the skin, resulting in a healthier and more youthful appearance. Also, its extract has been shown to inhibit the activity of matrix metalloproteinases (MMPs), enzymes that break down collagen and elastin fibers in the skin. Kaempferol exhibits sun-protection properties. In a study involving mice exposed to ultraviolet B(UVB), the extract demonstrated the capacity to minimize sunburn cells, highlighting its potential as a natural defense against UV-induced skin damage (Evans *et al.,* 2013; Eisvand *et al.,* 2020).

3.4 *Magnolia officinalis* (Hima champa)

Magnolia officinalis belongs to the family Magnoliaceae, commonly known as Hima champa, and is a species of flowering tree native to China. The bark of *M. officinalis* is often utilized in traditional medicine for its potential health benefits. Honokiol and magnolol are two major bioactive constituents found in the bark and stems of *M. officinalis*, known for their antioxidant, anti-inflammatory, and antiageing properties (Luo *et al.,* 2019). They promote the growth of new skin cells, leading to smoother, more radiant skin with improved texture and tone, it also accelerates wound healing and tissue repair, contributing to overall skin rejuvenation. It also displays antispasmodic, anticancer, and antidiabetic properties. The extract of *M. officinalis* hinders melanogenesis through pre-translational regulation of the tyrosinase gene expression, demonstrating depigmenting effects also helps regulate sebum production by inhibiting the activity of sebaceous glands, helps maintain a balanced complexion, and reduces the risk of acne and other skin issues (Rajgopal *et al.,* 2016). Additionally, the fermented methanol bark extract exhibits significant antityrosinase activity, reducing melanin formation by 99.8% (Wu *et al.,* 2018).

3.5 *Aloe vera* (Aloe)

It is scientifically known as *Aloe barbadensis*, and is a succulent plant belonging to the family Liliaceae. It is characterized by its fleshy leaves that contain a gel-like substance with numerous therapeutic properties. The gel of aloe contains a rich array of phytoconstituents, including polysaccharides (acemannan), glycoproteins, vitamins (vitamin E and C), minerals, enzymes (catalase and superoxide dismutase), amino acids, and phyto-chemicals (anthraquinones and flavonoids). Anthraquinone glycoside and barbaloin in the form of isobarbaloin, β-barbaloin, aloe-emodin, and resins are the primary constituents obtained from the aloe (Michalak*,* 2023; Hes *et al.,* 2019). Aloin A and B from aloe stimulates the synthesis of collagen, a crucial protein for skin elasticity and firmness. This contributes to the reduction of fine lines and wrinkles, promoting a more youthful appearance. It is a source of vitamins A, C, and E. These vitamins act as antioxidants, protecting the skin from oxidative stress. Aloe gives rapid soothing effects on sunburned skin helping alleviate symptoms and promote faster recovery. This contributes to the skin's defence against ageing caused by sun exposure (Vaidya *et al.,* 2021).

3.6 *Emblica officinalis* (Amla)

This comprises both dehydrated and fresh fruits of the *Emblica officinalis* plant, which is a member of the Euphorbiaceae family. Amla is a potent source of various phytoconstituents such as vitamin C, tannins, flavonoids, minerals, phyllembelin, mucic acid, sesquiterpenoids, *etc*. Vitamin C is responsible for showing antioxidant property that scavenges free radicals and neutralizes oxidative stress (Chaikul *et al.*, 2021). Amla promotes collagen production helps improve skin texture and reduces the signs of ageing such as sagging skin and wrinkles. Tannins and flavonoids present in Amla possess skin-lightening properties, these compounds inhibit the activity of tyrosinase, the enzyme responsible for melanin production and it fades dark spots, hyperpigmentation, and age spots, resulting in a more even complexion and youthful appearance (Nashine *et al.,* 2019; Ahuja *et al.*, 2021). Amla exhibits anti-inflammatory properties that help soothe inflamed skin and reduce redness and irritation also contributes to skin brightening, reduced hyperpigmentation, and tone enhancement. It has been traditionally used for wound healing due to its ability to accelerate tissue repair and regeneration by promoting collagen synthesis and enhancing the formation of new blood vessels, leading to faster wound closure and reduced scarring (Wu *et al.*, 2022).

3.7 *Glycyrrhiza glabra* (Liquorice)

Glycyrrhiza glabra, a plant of the Leguminosae family, is the source of its roots and stolons. This perennial herbaceous plant is indigenous to regions of Asia and southern Europe. The key phytoconstituents in liquorice include glycyrrhizin (glycyrrhizic acid), glycyrrhezinic acid, flavonoids (liquiritin, liquiritigrnin, and isoliquiritigenin), coumarins, triterpenoids, polysaccharides, and amino acids. Glycyrrhizin is a sweet-tasting compound that also possesses anti-inflammatory, antioxidants, and antiviral properties. The primary characteristics include skin lightening, brightening of the skin, loss of pigment, antiageing, antierythemic, hydrating, anti-acne, and photoprotective properties (Ceccuzzi *et al.,* 2023). The flavonoids of liquorice, such as glabridin and isoliquiritigenin, have been shown to block UV induction and inhibit tyrosinase, an enzyme responsible for melanin production, potentially reducing skin pigmentation and improving skin tone (Nazari *et al.,* 2017).

3.8 *Vitex negundo* (Nirgundi)

It is commonly known as the five-leaved chaste tree, Indian privet, or nirgundi belongs to the family Verbenaceae. This plant is a shrub or small tree with aromatic leaves and clusters of small flowers. It contains various bioactive constituents such as negundin A, alkaloids, flavonoids, terpenoids and essential oils responsible for antioxidant, anti-inflammatory and wound healing activities. The leaves, seeds, and roots of *Vitex negundo* are rich in phytochemicals such as vitexin, negundoside, agnuside, flavonoids, and volatile oils (Ahuja *et al.,* 2015). The poultice of this plant is used for the treatment of melasma or ephelides (hyperpigmentation). They have been shown to possess anti-inflammatory properties by inhibiting pro-inflammatory cytokines and enzymes such as cyclooxygenase (COX) and lipoxygenase (LOX) and help soothe irritated skin and alleviate redness. It is also used as a skin-brightening agent, and a tyrosinase inhibitor, and impedes the formation of post-inflammatory pigmentation (Gill *et al.,* 2018; Khan *et al.,* 2017).

3.9 *Camellia sinensis* (Tea plant)

It is commonly known as the tea plant or tea shrub, and belongs to the Theaceae family. It is the source of various types of tea, including green tea, black tea, white tea, and oolong tea. The main bioactive constituents are catechins, polyphenols, alkaloids (caffeine and theobromine), amino acids (L-theanine), vitamins (vitamin C and vitamin E), and minerals (potassium and manganese), and flavonoids (Vishnoi *et al.*, 2018). Catechins are powerful antioxidants, Epigallocatechin gallate (EGCG) is a well-known catechin having photoprotective and collagen synthesis properties and can mitigate UV-induced damage by scavenging free radicals, reducing inflammation, and enhancing DNA repair mechanisms and helps maintain youthful and healthy skin (Musial *et al.*, 2020). Polyphenols in tea exhibit anti-inflammatory effects, which can contribute to preventing or reducing inflammation associated with ageing. Green tea polyphenols help regulate sebum production by inhibiting the activity of sebaceous glands maintain a balanced complexion and reduce the risk of acne and other skin issues.

3.10 *Acacia catechu* (Catechu)

It is commonly known by catechu, cutch, or khair, of a deciduous tree belonging to the family Fabaceae. The heartwood extract of *Acacia catechu* is rich in polyphenolic compounds such as catechin, epicatechin, catechuic acid, and procyanidins. The catechins and flavonoids in catechu possess antioxidant properties, aiding in the reduction of oxidative stress, a major factor in ageing, and preventing the buildup of free radicals (Adhikari *et al.*, 2021). The astringent properties of tannins in catechu may be beneficial for skin health. Tannins can tighten and tone the skin, potentially minimizing the visibility of wrinkles and fine lines. Antioxidants in acacia catechu may help protect collagen, a crucial protein for skin elasticity and firmness, from degradation (Stohs and Wagchi, 2015). Catechu contains compounds that inhibit melanin synthesis and promote skin brightening by fading dark spots, hyperpigmentation, and age spots, resulting in a more even complexion and youthful appearance.

3.11 *Apis mellifera* (Honey)

Honey is a natural sweet substance produced by bees using nectar from flowers, and belongs to the family Apidae. It is primarily sourced from the honeybee species *Apis mellifera*, although other bee species also contribute to honey production. Honey is composed of sugars (glucose and fructose), flavonoids, phenolic acids, vitamins, minerals and amino acids, *etc*. The presence of flavonoids and phenolic acids (benzoic acid and cinnamic acid) in honey contributes to its antioxidant effects, helping to neutralize free radicals and reduce oxidative stress (Diugan *et al.*, 2018). Honey has been used historically for wound healing due to its antibacterial properties. Enhanced wound healing can contribute to maintaining skin health and reducing the appearance of scars. Honey is a natural humectant, meaning it attracts and retains moisture. Applying honey to the skin can help keep it hydrated, contributing to a more youthful and supple appearance. Honey contains amino acids that may help promote the development of collagen, which is necessary for the flexibility and firmness of skin (Machado *et al.*, 2020).

3.12 *Nardostachvs jatamansi* (Jatamansi)

It is also known as tapasvini, spikenard, *etc*. It is a perennial herbaceous plant that belongs to the family Valerianaceae. The scientific name *Nardostachys* is derived from the Greek words 'nardos' meaning spikenard, and 'stachys' meaning an ear of wheat, referring to the spike-like shape of the flower heads. It contains various chief constituents such as valeranone, jatamansone, nardostachone, and dihydrojatamansone. Nardostachone shows antioxidant and neuroprotective properties by scavenging free radicals and reducing oxidative stress (Sahu *et al.*, 2016). It has adaptogenic properties, suggesting that it helps the body cope with stress and maintain homeostasis. By reducing stress levels, jatamansi promotes overall health and well-being, which in turn contributes to healthy ageing. Its extract has been found to protect collagen fibers from degradation by inhibiting the activity of the collagenase enzyme (Jugran *et al.*, 2019).

3.13 *Terminalia arjuna* (Arjuna)

It is scientifically known as *Terminalia arjuna*. It consists of dried stem bark of the plant belonging to the family Combretaceae. Arjuna contains various phytoconstituents such as arjunolic acid, tannins, flavonoids, phytosterols, triterpenoids saponins, arjungenin, ellagic acid, *etc*. Antioxidants found in abundance in arjuna aid in scavenging free radicals and lowering oxidative stress. These compounds also elevate skin hydration levels while reducing dryness and flakiness (Ramesh and Palaniappan, 2023; Kumar *et al.,* 2023). They fortify the skin's protective barrier, prompting the generation of sebum to alleviate symptoms of dry skin and shield against external stressors. Additionally, it supports enhanced blood circulation, leading to improved nutrient delivery to the skin. Pentacyclic terpenoids present in arjuna enhanced collagen production and the functioning of the epidermal barrier.

4. Essential oils used for antiageing

Essential oils are highly concentrated extracts from plants that have been utilized for their pharmacological and medical benefits for thousands of years. The ancient Egyptians were known to employ essential oils for antiageing and cosmetic treatments. Essential oils have recently regained popularity in both the healthcare and beauty sectors due to their antiageing properties. These oils commonly include antioxidants, anti-inflammatory agents, and skin-strengthening chemicals. Antioxidants assist in neutralize free radicals that harm skin cells, whereas anti-inflammatory drugs decrease inflammation, which can hasten ageing. Skin-strengthening molecules like collagen and elastin aid in keeping skin elasticity and firmness, which reduces the appearance of wrinkles and fine lines. Some oils, for example, include sesquiterpenes, which have been demonstrated to improve skin oxygenation and blood flow, resulting in a healthy, young appearance. Other oils include monoterpenes, which can help to minimize the visible signs of scars and blemishes, resulting in a smoother, more even complexion.

4.1 *Lavandula angustifolia* (Lavender oil)

This is derived from the lavender plant, and belongs to the family Lamiaceae, which is commonly referred to as the mint family. It contains a variety of chemical compounds, including linalool, linalyl acetate, cineole, camphor, terpinen-4-ol, and various other terpenes and sesquiterpenes. Linalool and linalyl acetate, the major components of lavender oil, possess antioxidant properties that protect the skin from oxidative stress caused by environmental factors such as UV radiation and pollution (Kustrin *et al.,* 2019). Lavender oil has been shown to stimulate collagen synthesis in the skin, thereby improving its firmness and elasticity. This helps reduce the appearance of wrinkles and promotes a more youthful complexion. It promotes skin cell regeneration, which is essential for maintaining healthy, youthful-looking skin. By accelerating the turnover of skin cells, lavender oil helps slough off dead skin cells and promotes the growth of new, healthy cells. This results in smoother, more radiant skin with a reduced appearance of fine lines and wrinkles (Ayaz *et al.,* 2017). Lavender oil possesses anti-inflammatory properties that help soothe irritated skin and reduce redness and inflammation in chronic inflammation conditions such as acne, eczema, and psoriasis. It is well-known for its calming and relaxing properties, which can help reduce stress and promote better sleep quality. By reducing stress levels, lavender oil indirectly supports antiageing efforts by promoting overall skin health and well-being (Avanji *et al.,* 2019).

4.2 *Boswellia* (Frankincense oil)

It is derived from the resin of *Boswellia* tree. The tree belongs to the Burseraceae family, commonly known as the torchwood family. Frankincense trees are native to the Arabian Peninsula, Africa, and India. It contains various bioactive compounds, including boswellic acids, monoterpenes (such as α-pinene and limonene), sesquiterpenes (such as β-caryophyllene), and other aromatic molecules. The composition of frankincense oil can vary depending on species, geographic origin, and extraction method. Frankincense oil exhibits potent anti-inflammatory properties, primarily attributed to its boswellic acid content. Boswellic acids inhibit pro-inflammatory enzymes and cytokines, thereby reducing inflammation and promoting skin health (Siddiqui, 2011). It has been shown to stimulate collagen production in fibroblast cells, the primary cells responsible for collagen synthesis, and also improve skin firmness and reduce the appearance of wrinkles (Hussain *et al.,* 2013). It also contains antioxidant compounds, including terpenoids and phenolics, which scavenge free radicals and protect the skin from oxidative damage. It also has emollient properties that help hydrate and moisturize the skin, improving its texture and appearance (Yasiry and Kiczorowska, 2016).

4.3 *Daucus carota* (Carrot seed oil)

It is extracted from the seeds of the *Daucus carota* plant, commonly known as wild carrot or Queen Anne's lace. It belongs to the family Apiaceae, which includes other aromatic plants such as parsley and celery. The plant is widely cultivated for its edible root. The carrot seed oil contains a rich array of bioactive compounds, including carotenes (such as beta-carotene), tocopherols (vitamin E), carotenoids, and various fatty acids (including oleic, linoleic, and palmitic acids). These constituents contribute to the oil's antioxidant, moisturizing, and regenerative properties (Musnaini *et al.*, 2023). Beta-carotene, vitamin E, and vitamin A responsible for anti-oxidant, anti-inflammatory, and collagen synthesis properties which help improve skin texture, reduce wrinkles, and enhance overall skin tone and appearance. It promotes cell regeneration by accelerating the shedding of dead skin cells and promotes the growth of new, healthy cells, resulting in a more youthful and radiant complexion (Singh *et al.*, 2019).

4.4 *Santalum album* (Sandalwood oil)

It is extracted from the heartwood of *Santalum album*, commonly known as Indian sandalwood. Sandalwood trees belong to the Santalaceae family and are native to South Asia, particularly India, Sri Lanka, and Indonesia. It contains various chemical compounds, including α-santalol, β-santalol, α-trans-bergamotol, and other sesquiterpenes. Sandalwood oil exhibits potent antioxidant properties due to its high content of sesquiterpenes, particularly á-santalol and β-santalol (Dulal *et al.*, 2019; Newton *et al.*, 2021). It also possesses anti-inflammatory, moisturizing, and hydrating and promotes the growth of collagen synthesis reducing the appearance of fine lines and wrinkles.

4.5 *Citrus aurantium* (Neroli oil)

It is also known as orange blossom oil, is extracted from the blossoms of bitter orange trees belong to the family Rutaceae. These trees are native to Southeast Asia but are cultivated in various regions with suitable climates for their fragrant flowers.

It contains several bioactive compounds, including linalool, limonene, linalyl acetate, geraniol, and nerolidol. Linalool, a major component of neroli oil, has been shown to enhance keratinocyte proliferation, leading to the formation of new skin cells. This process helps improve skin texture, reduce the appearance of fine lines and wrinkles, and promote a more youthful complexion (Ayaz *et al.,* 2017). It stimulates collagen production in fibroblast cells, the primary cells responsible for collagen synthesis. Neroli oil exhibits antioxidant properties due to its high content of limonene and other terpenes, which helps protect the skin from premature ageing, and maintains its youthful vitality. Inhalation of neroli oil aroma or topical application can help reduce stress levels, promote better sleep, and support overall skin wellness, contributing to antiageing efforts (Canday *et al.,* 2023). It possesses anti-inflammatory properties that help soothe inflamed skin and reduce redness and swelling.

4.6 *Rosa moschata* (Rosehip oil)

Rosehip oil, also known as rosehip seed oil, is extracted from the seeds of the fruit (hips) of various species of roses, primarily *Rosa canina*, *Rosa rubiginosa*, and *Rosa moschata*. These roses belong to the Rosaceae family. It is rich in bioactive compounds, including essential fatty acids, vitamins, antioxidants, and phenolic compounds.

Rosehip oil contains a high concentration of essential fatty acids, particularly linoleic acid (omega-6) and linolenic acid (omega-3). These fatty acids help maintain the skin's barrier function, improve moisture retention, and promote skin regeneration. It is an excellent source of vitamin A (retinol) and vitamin C (ascorbic acid), both of which are potent antioxidants. Vitamin A stimulates cell turnover and collagen production which helps reduce the appearance of fine lines, wrinkles, and sagging skin, resulting in a more youthful complexation. While vitamin C brightens the skin, reduces hyperpigmentation, and protects against UV damage (Kiralan and Yildirim, 2019).

4.7 *Punica granatum* (Pomegranate seed oil)

Pomegranate seed oil is derived from the seeds of the pomegranate fruit *Punica granatum*, which belongs to the family Lythraceae. It is extracted through cold-pressing the seeds and has been prized for its numerous health and skincare benefits.

The pomegranate seed oil contains a high proportion of punicic acid, a type of conjugated linolenic acid (CLA). Other fatty acids present include linoleic acid (omega-6), oleic acid (omega-9), and palmitic acid. It contains significant amounts of phytosterols (â-sitosterol), tocopherol (vitamin E), and phenolic compounds (ellagic acid, punicalagins, flavonoids). It contains a high content of tocopherols and phenolic compounds and shows antioxidant properties. They also possess anti-inflammatory properties, attributed to their phytosterols and phenolic compounds, help soothe irritated skin, and reduce redness (Boroushaki *et al.,* 2016; Drinic *et al.,* 2020). A List of herbal formulations for antiageing available in the market is listed in table 1.

Table 1: List of herbal formulations for antiageing available in the market

Herbal formulation	Dosage form	Category	Brand name	Mechanism of action	Active ingredients	References
Ginseng extract	Capsules	Herbal health	Ginsana	Antioxidant, anti-inflammatory effects	Ginsenosides, polysaccharides, flavonoids	Kim *et al.,* 2021
Ginkgo biloba	Tablets	Nature's bounty	*Ginkgo biloba*	Improves blood circulation, scavenges free radicals	Flavonoids (including flavone glycosides and terpene lactones), ginkgolides	Mahadevan and Park, 2008
Turmeric	Capsules	Organic India	Turmeric formula	Antioxidant, anti-inflammatory, protect against cellular ageing	Curcuminoids (including curcumin, demethoxycurcumin, and bisdemethoxy-curcumin)	Hewlings and Kalman, 2017
Ashwagandha	Powder	Himalaya	Ashwagandha powder	Adaptogenic, antioxidant, anti-inflammatory	Withanolides, sitoindo sides, alkaloids, flavonoids	Kulkarni and Dhir, 2008
Green tea extract	Tablets	NOW foods	Green tea extract	Antioxidant, anti-inflammatory, protects against UV damage	Epigallocatechin gallate (EGCG), catechins, flavonoids	Butt and Sultan, 2009
Rhodiola rosea	Capsules	Gaia herbs	*Rhodiola rosea*	Adaptogenic, enhances mitochondrial function	Rosavin, salidroside, tyrosol	Qu, *et al.,* 2012
Schisandra berry	Liquid	Swanson	Schisandra Extract	Adaptogenic, hepatoprotective, antioxidant	Schisandrins, lignans, polysaccharides	Chiu, *et al.,* 2008
Sandalwood oil, Neroli oil	Serum	Skincare	Ageless blend	Enhance collagen production, reduces signs of ageing	Sandalwood oil, Neroli oil	Canday *et al.,* 2023
Pomegranate seed oil	Serum	Skincare	Youthful essence	Rich in antioxidants, reduces oxidative stress	Pomegranate seed oil	Juhaimi *et al.,* 2017

5. Conclusion

In conclusion, understanding the intricacies of skin ageing mechanisms provides a foundation for exploring herbal interventions as potent tools in antiageing strategies. The theories of free radicals and oxidative stress, inflammation, and photoaging shed light on the complex molecular processes underlying skin ageing. The significance of protecting the skin from external stressors, such as UV radiation, becomes evident in the pursuit of youthful and resilient skin. These natural herbs, rich in bioactive compounds, present an opportunity to complement conventional skincare practices. Integrating these herbs into antiageing regimens may offer a harmonious balance between nature and science, promoting skin health and resilience. As research in herbal medicine advances, it opens avenues for personalized skincare approaches, enhancing the quest for ageless and vibrant skin. Embracing the wisdom of herbal remedies becomes not just a trend but a profound journey towards nurturing the skin's well-being and embracing the grace of ageing.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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