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RHODIOLA ROSEA: A PHYTOCHEMICAL POWERHOUSE FOR COSMECEUTICAL AND THERAPEUTIC USES

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ABSTRACT

Rhodiola rosea, a well-known adaptogen traditionally used in various cultures, has gathered significant attention over the years for its potential as a cosmeceutical ingredient due to its multi-therapeutic properties. In the current review, we have carried out a comprehensive analysis of *R. rosea's* pharmacological activities, such as antioxidant, anti-inflammatory, antistress, and immunomodulatory, highlighting its relevance in cosmetic applications. In addition, this present review also covers the microscopic characters, cultivation, and collection of the plant. We have also summarized the primary bioactive constituents, including salidroside, rosavin, tyrosol, and various flavonoids, which are known for their potent medicinal and cosmetic applications. Despite the various medicinal and cosmetic applications, plants also exhibit some minor adverse effects, which have been highlighted in the article. In summary, *Rhodiola rosea* presents a valuable opportunity for developing advanced cosmeceutical products, offering natural solutions for enhancing skin health and appearance. Continued exploration and clinical validation will be essential in realizing its full potential in the cosmeceutical industry.

INTRODUCTION

Ayurveda, the ancient system of medicine in India, underlines several approaches to maintaining the health of mankind. Thousands of medicinal plants, their benefits, phytochemicals and formulations have been listed in the Ayurveda. This traditional system of medicine, which is officially recognized in India, documents the uses of various plants and plant parts for the treatment of various ailments, as well as for their cosmetic value, such as enhancing skin health, promoting hair growth, and maintaining overall beauty [1]. It describes the specific herbs, their preparation methods, and application techniques for different cosmetic purposes such as complexion improvement, wrinkles reduction, managing acne, and hair strengthening. These formulations often involve the combination of multiple plants, each chosen for its unique properties, to provide a natural and sustainable solution for beauty and skincare needs [2].

Plant *Rhodiola rosea* is one of the well-acknowledged plants of Ayurveda studied for various cosmetic and medicinal purposes. It is a perennial herbaceous plant that belongs to family Crassulaceae. Plant is also known as "golden root", "roseroot" or "arctic root" with synonyms *Sedum rhodiola* DC., *Sedum roseum* (L.) Scop). The plant is distributed throughout the arctic regions of Asia and Europe and coastal areas of North America [3,4]. Plant thrives at clefts of Rocky Mountains, and sandy soil of coastal regions. The common name of the plant roseroot is based on the yellow flowers that bear the essence of a rose. Roots of the plant exhibit huge medicinal properties and are hence exploited in many countries due to high demand. Industrial supply of the plant material is majorly met by harvesting wildly grown plant. Therefore, increased scarcity and lack of regulation has led to the adulteration, illegal marketing and habitat destruction of the species [4].

Rhodiola rosea exhibits distinctive anatomical features throughout its various parts, owing to its adaptation in the harsh environment. Roots and rhizomes exhibit a typical dicotyledonous structure, with an outer cork layer composed of 6-7 layers of thick-walled, rectangular cells that are suberized, providing protection against external stressors. Cortex comprises thin-walled parenchymatous cells filled with starch grains with calcium oxalate crystals frequently observed as prismatic crystals. The plant's stem consists of a single-layered epidermis covered by a thick cuticle with unicellular or multicellular non-glandular trichomes that provide a protective function. The cortex beneath consists of collenchymatous cells that offer mechanical support and parenchymatous cells containing chloroplasts, facilitating photosynthesis [5]. The leaf anatomy is marked by a single-layered epidermis covered with a thin cuticle, with stomata of the anomocytic type present on both surfaces, but more abundant on the lower side. The mesophyll is differentiated into a palisade layer of elongated chloroplast-rich cells, promoting efficient photosynthesis, and a spongy parenchyma with intercellular air spaces facilitating gas exchange. Altogether, these microscopic characteristics show *Rhodiola rosea's* anatomical adaptations, which are helpful to plants for survival in extreme conditions, supporting its pharmacological and medicinal properties [6].

Among the various species of the *Rhodiola*, *R. rosea* is massively studied for its medicinal uses. The earliest record of the *Rhodiola rosea* for medicinal purposes dates back to Dioscorides in 77 AD, where it was acknowledged for antifatigue, and antidepressant activity. Thereafter from 1969 to 1985 plant was listed as adaptogen by Health Ministry and medicinal agency of Russia, Sweden and Europe for its antistress properties. Apart from this *Rhodiola* has history to alleviate the mountain sickness in

Tibetan traditional system of medicine since ancient times. Some other species of *Rhodiola* such as *R. crenulata* and *R. kirilowii* can be also traced in the Chinese pharmacopeia dated 1977 to 1985 [4].

R. rosea has a long-standing traditional significance in various cultures, particularly in cold and mountainous regions such as Russia, Europe, and Tibet. Root of the plant has been prized as an adaptogen, which is believed to help the body adapt to the stress, enhance resilience and restore balance. Traditionally, people used *R. rosea* to combat fatigue, increase physical endurance, and improve mental clarity and concentration. It is also used to reduce anxiety and depression, elevate the mood, and promote the overall well-being of the person. The literature on the plant indicates that the root of the *R. rosea* is the most used part for its medicinal purposes and is reported to contain phenylpropanoids, flavonoids and their glycosides, lignans, terpenoids, coumarins, gallic acid and its derivatives. In addition to its folk medicine, recent and advanced research on *Rhodiola rosea* depicts its multiple pharmacological activities such as antioxidant, neuroprotective, antihypertensive, antidiabetic, antiinflammatory, and immunomodulatory [7].

Rhodiola rosea is valued in cosmetics for its rich content of bioactive compounds, with various parts of the plant offering unique benefits. The roots are the most commonly used part in cosmetic formulations, primarily due to their high concentration of phenolic compounds like rosavin, salidroside, and tyrosol. These metabolites exhibit potent antioxidant properties, which help neutralize free radicals, reduce oxidative stress, and protect the skin from premature aging and environmental damage[8]. Root extracts are often incorporated into anti-aging creams, serums, and moisturizers to enhance skin elasticity, improve tone, and reduce the appearance of fine lines and wrinkles. The leaves of *R. rosea* are known to contain flavonoids and tannins, which have antiinflammatory and astringent properties. Leaf extracts can be used in formulations to soothing irritated skin, reducing redness, and improving skin texture. The stems also contain bioactive compounds that contribute to skin hydration and can be used in products targeting dry or sensitive skin types [9].

Despite its recognized benefits, *Rhodiola rosea* is often subject to adulteration due to high demand and limited supply. Common substitutes or adulterants include other *Rhodiola* species, such as *Rhodiola crenulata*, *Rhodiola quadrifida*, and *Rhodiola sachalinensis*. These species may resemble *R. rosea* but differ significantly in their phytochemical profiles, often lacking the characteristic compounds like rosavin and salidroside responsible for *R. rosea's* specific cosmetic benefits. Such adulteration can diminish the efficacy of cosmetic products, misleading consumers and potentially causing unwanted

side effects. Therefore, accurate identification and standardization of *R. rosea* extracts are crucial to ensuring product quality and maintaining consumer trust in cosmetic applications [10].

GEOGRAPHIC DISTRIBUTION, COLLECTION & CULTIVATION:

As discussed in the previous section, this herbaceous plant grows in cold mountain regions throughout the Northern hemisphere. It is distributed along the various continents, including Europe, Asia, and North America.

In Europe*, R. rosea* is found across the Arctic and mountainous regions of Scandinavia, Iceland, the British

Isles, and the Alps. In Russia, the plant is particularly present in the Ural Mountains, Siberia, and the Altai Mountains, where it thrives in the harsh, cold climates of high altitudes. In Asia*, R. rosea* is widely distributed across the Himalayas, including regions of Bhutan, Nepal, and parts of northern India, where it grows at an altitude of 3,000 to 5,000 meters from sea level. In North America, *R. rosea* is native to Alaska and the mountainous areas of Canada [11].

Rhodiola rosea is well grown in sandy or rocky soils, and is commonly found in alpine meadows, slopes, and along the riverbanks. Its ability to thrive in these extreme conditions is attributed to its extensive root system, which is the integral part of plant support and allows it to absorb nutrients efficiently from the scarce soil. The plant's distribution is influenced by its preference for cool temperatures, high altitudes, and areas with sufficient sunlight, which is on the main region why this plant is predominantly found in regions with long, harsh winters and short, cool summers [12].

The plant reaches full bloom in the summer from June to August, which is the peak time for its highest bioactive compound. Most plant is harvested for their roots, which are the primary source of their therapeutic and cosmetic benefits. The plant collection is mostly carried out manually, as the plant grows in remote and unreachable locations, which require careful extraction to avoid and minimize disturbing the fragile alpine ecosystem. In traditional practices, the roots are dug up using simple tools, and only mature plants that are several years old are harvested to ensure sustainability. Further, the roots or required part is washed, sliced, and dried at low temperatures to preserve their active phytometabolites [11,13] **Fig. 1** Shows the different parts of the plant [40].

Flower, leaves and stem **Whole plant in natural habitat** **Roots**

Fig 1: Images of different parts of *Rhodiola rosea* plant

Due to the massive medicinal and cosmetic applications, global demand for *Rhodiola rosea* has increased over the years, resulting in overharvesting, which has become a significant concern, particularly in areas where the plant is collected in the wild. In regions such as the Altai Mountains, the Himalayas, and parts of Russia, unregulated harvesting practices have led to a decline in wild populations, threatening the plant's natural habitats and biodiversity. Several countries have initiated significant conservation efforts to promote sustainable collection practices to avoid damaging the plant's natural habitat. These efforts include cultivating *R. rosea* under controlled conditions, implementing stricter regulations on wild harvesting, and developing guidelines for the fair and sustainable use of natural resources [13,14].

Cultivation of *Rhodiola rosea* is gaining importance as an alternative to wild collection, especially in countries like China, Russia, and Canada, where research is focused on developing high-yield, high-quality plant varieties. Cultivation practices typically involve selecting suitable altitudes and climatic conditions that mimic the plant's natural habitat, using organic farming techniques, and ensuring soil quality is optimized to maintain the concentration of active compounds in the roots. This controlled cultivation helps meet global demand and contributes to the conservation of wild populations [10].

While sustainable practices are necessary to prevent overexploitation, continued research and conservation efforts are essential to protect this valuable plant and ensure its availability for future generations.

PHYTOCONSTITUENTS:

R. rosea exhibits complex and rich phytochemistry that have been reported by researchers all over the globe. Till date around 120 compounds have been reported from the different parts of plant. These

phytoconstituents belongs to different classes of compounds such as phenylpropanoids, lignans, terpenoids, flavonoids and their glycosides and gallic acid derivatives. Compounds such as salidroside, rosavin, rosin and rhodiolosides are the common biomarkers found in *R. rosea* that are reported for many pharmacological activities. **Fig. 2** depicts the phytochemical profile of the *R. rosea.* In this review, we have discussed different classes of compounds present in the plant reported till date [15].

Flavonoids and flavonoids glycosides

Flavonoids are a large class of polyphenolic compounds which are characterized by their basic structural skeleton, the flavone nucleus. The basic skeleton of flavonoids consists of 15 carbon units arranged in a C6-C3C6 configuration, forming two aromatic rings (A and B) connected by a three-carbon bridge that usually forms a heterocyclic ring (C). Numbers of flavonoids have been reported form the *R. rosea.* These are the crucial class of secondary metabolites widely accepted for their several pharmacological activities. These secondary metabolites are further divided into subclasses, based on additional functional groups on the basic skeleton [16]. For example compounds of subclass flavonols (hydroxyl group at 3-C position) such as Kaempferol **1**, Herbacetin **2**, Kaempferol-3-*O*-α-L-rhammopyranoside **3**, Astragalin **4**, Kaempferol 7-*O*-α-L- rhamnopyranoside **5**, Rhodionin **6**, Rhodalin **7**, Herbacetin-8-glucoside **8**, Leucoside **9**,
Kaempferol-3-xylosylglucoside **10**, Quercetin **11** and Quercitrin **12** are reported from the different parts of *R. rosea* plant [16–18]. Another important class of flavonoids are flavones (3-hydroxy is absent), which also contribute significant number of molecules in *R. rosea*. Compounds such as Tricin **13,** tricin 5-*O*-glucoside **14** and tricin-7-*O*-β-D-glucoside **15** are the flavones reported from the *R. rosea*. Apart from this, Flavanones (saturated C ring) and flavanonoles like 5,7,3′,5′-tetrahydroxy-flavanone **16,** dihydrokaempferol **17** have been reported till date [4]. Further catachins like Epicatechin, epigallocatechin and epicatechin-3-*O*-gallate are also reported from the roots of *R. rosea* [19].

Coumarins and their derivatives

Coumarins are the benzopyrone structure, specifically a 1,2-benzopyrone. The basic building blocks of these compounds are a benzene ring (ring A) fused with a pyrone ring (a six-membered heterocyclic ring containing one oxygen atom and a carbonyl group at the 2-position). The lactone ring present in the structure is considered critical for chemical reactivity as well as for the biological activity. In our literature studies we found only one coumarin reported from the *R. rosea*, that is crenulatin **18.** It is derivative of umbelliferon having substitution at position C-6 and C-7 [20].

Cinnamaldehyde and Lignin derivatives

Cinnamaldehyde consist of an aromatic ring and a propenal side chain that is made up of *α, β*-unsaturated aldehyde. Based upon the presence of oxygen at the terminal carbon these compounds are further divided into cinnamyl alcohol-type and cinnamic acid-type. Compounds like cinnamyl alcohol **19** and trans-cinnamic alcohol **20,** and their glycoside derivatives such as rosavin **21**, rosin **22** and rosarin **23** are reported from the plant [21]. Addition to this, cinnamyl alcohol such as 3-phenyl-2-propenyl 6-*O*-β-D-xylopyranosyl-β-D-glucopyranoside **24,** and (2E)-3-phenyl-2-propen-1-yl 6-*O*-β-D-xylopyranosyl-β-D-glucopyranoside **25** are also found in the plant**.** Apart from this**,** triandrin **26**, vimalin **27,** sachaliside 1 **28**, (2E)-3-(4-methoxyphenyl)-2-propen-1-yl β-D-glucopyranoside **29**, and (2E)-3-(4-methoxyphenyl)-2-propen-1-yl
6-*O*-α-L-arabinopyranosyl-β-D-glucopyranoside **30.** *p*-Coumaric acid **31**, trans-*p*-hydroxycinnamic acid **32**, caffeic acid **33** and trans-caffeic acid **34,** are the derivatives of cinnamic acid found in the plant. Lignins are the complex, high-molecular-weight polymers of Cinnamaldehyde found in the cell walls of plants. The basic skelton of tses compounds are made up of three primary monolignols which are *p*-coumaryl alcohol (no methoxy group), coniferyl alcohol (one methoxy) and sinapyl alcohol (two methoxy). These compound provides rigidity and strength to the plant cell wall and protect against the pathogen. Where different lignin are found in the other species of Rhodiola, till date no lignin has been reported from the *R. rosea* [22].

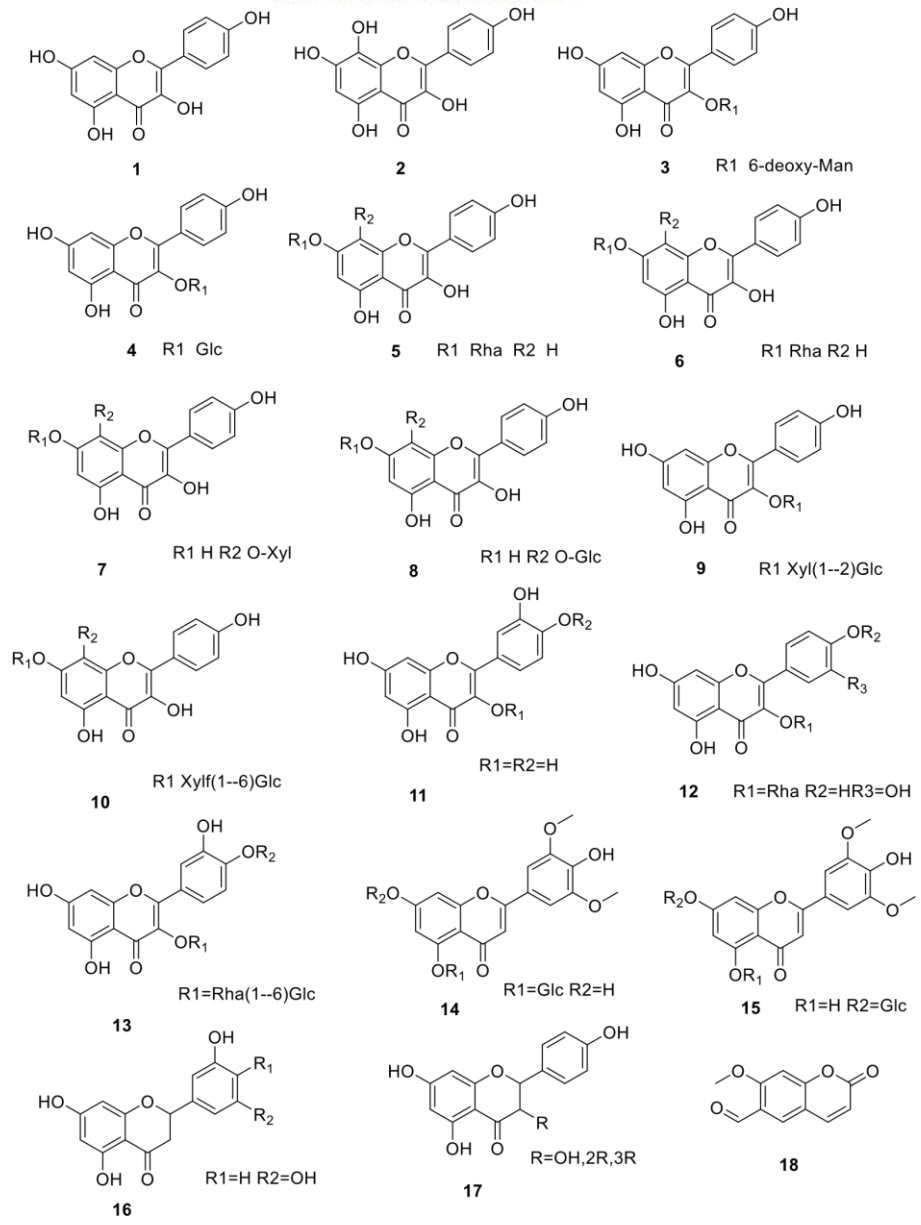

Fig. 2: Chemical structures of the phytoconstituents present in *Rhodiola rosea* Cont.

Gallic acid derivatives

Gallic acid derivatives are known for their strong antioxidant activity. Gallic acid **35** is the most abundant form of this class found in *R. rosea* plant. Till date five gallic acid derivative were reported form this plant which includes methyl gallate **36**, 1,2,6-tri-*O*-galloyl-β-D- glucoside **37**, 1,2,3,6-tetra-*O*-galloyl-β-D-glucopyranose **38**,

1,2,3,6-tetra-*O*-galloyl- 4-*O*-p-hydroxybenzoyl-β-D-glucopyranoside **39,** and 6-*O*-galloylsalidroside **40.** These naturally occurring polyphenol compounds, has a basic skeleton consisting of a six-membered benzene ring decorated with three hydroxyl groups at the 3, 4, and 5 positions, and a

carboxylic acid group at the 1 position. A large variety of gallic acid derivatives are formed by modifying their hydroxyl, carboxylic and even aromatic ring resulting in the wide and potent chemical properties and biological activities [23].

Phenyl ethane derivatives

This is one of the chief class of secondary metabolites of *R. rosea.* Phenylethylglycosides named Phenethanol βvicianoside **41** and 2-phenylethyl 6-*O*-α-L-arabinofuranosyl-β-D-glucopyranoside **42** have been isolated from the *R. rosea.* Two of the major studied compounds of this class are tyrosol **43** and salidroside **44.** These both compounds have been studied for various pharmacological activity and can be marked as biomarker of this plant. These compounds exhibit a pleasant fragrance of flowers. 4-hydroxypheny-2-ethyl β-D-glucopyranoside2-(4-methoxyphenyl)-1-ethanol **45**, icariside D2 **46**, viridoside **47**, and mongrhoside **48** are other tyrosol derivative isolated from the plant *R. rosea.* Apart from these, several other phytoconstituents have also been reported from the plant, which can be found in the comprehensive literature [4,16,20]. **Fig. 2** shows the chemical structure of major compounds found in the *Rhodiola rosea*.

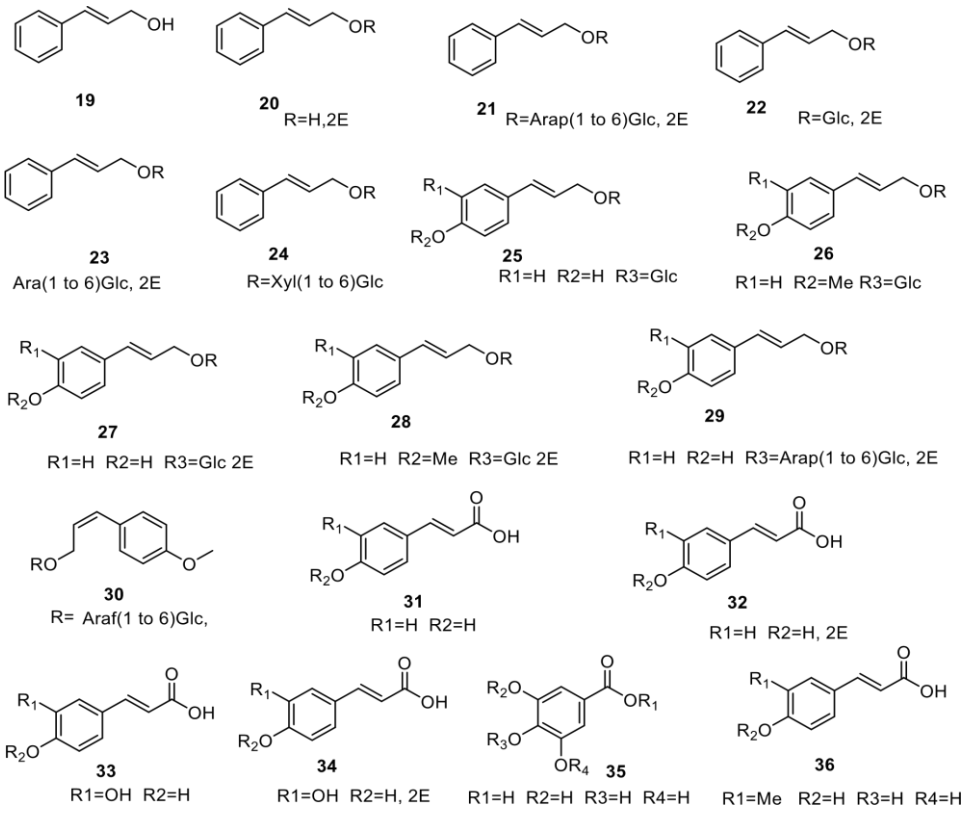

Fig. 2: Chemical structures of the phytoconstituents present in *Rhodiola rosea* Cont.

COSMETIC USES AND PHARMACOLOGICAL ACTIVITIES:

The rich phytochemical profile, particularly its roots, leaves, and stems, offers a wide range of benefits in skin health and cosmetic applications. Various parts of the *Rhodiola rosea* plant are utilized in cosmeceutical formulations due to their unique bioactive compounds that provide protective, rejuvenating, and healing effects to the skin [7].

Roots: Antioxidants and skin protectants

The roots of *Rhodiola rosea* are the most widely used part of the plant in cosmetics, owing to their high concentration of phenolic compounds such as rosavin, salidroside, and tyrosol. These compounds are wellknown for their potent antioxidant properties, which help neutralize free radicals and protect the skin from oxidative stress caused by environmental factors like UV radiation and pollution. This antioxidant activity reduces the damage to collagen and elastin fibers, thereby preventing premature aging and maintaining skin elasticity and firmness [24].

1. **Anti-aging formulations:** Root extracts can be utilized in anti-aging creams, serums, and lotions. The presence of rosavin and salidroside helps to enhance skin elasticity, reduce the appearance of fine lines and wrinkles, and promote a youthful glow. These compounds stimulate the production of fibroblasts, which are responsible for collagen synthesis, thereby improving skin structure and reducing signs of aging [25].

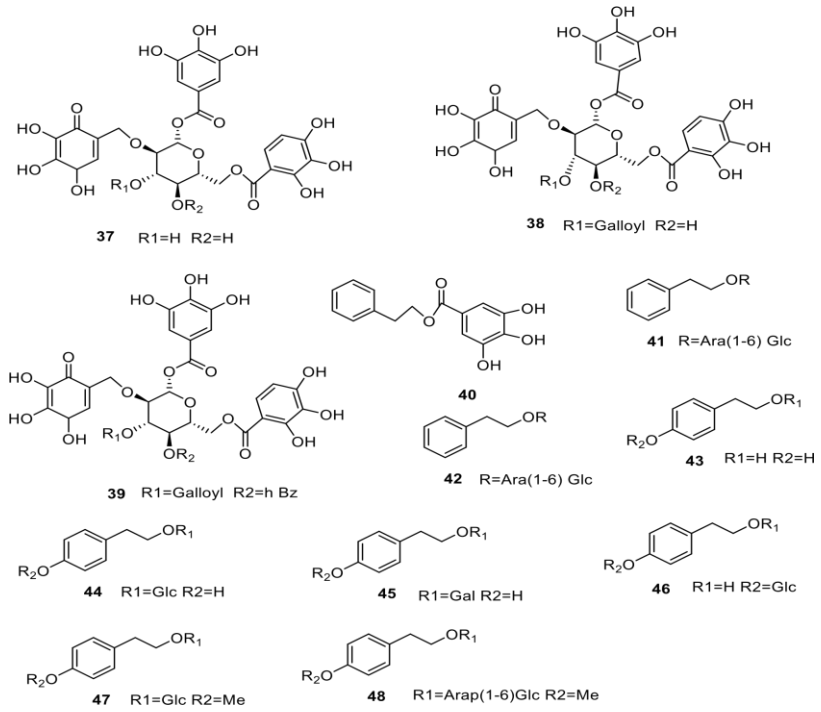

Fig. 2: Chemical structures of the phytoconstituents present in *Rhodiola rosea* cont.

2. **Moisturizers and hydrating products:** the root extracts also contain gallic acid derivatives and flavonoids that exhibit astringent properties, helping to tighten pores and improve skin texture. Additionally, these compounds' moisturizing effects help retain skin hydration, making *Rhodiola rosea* a valuable ingredient in hydrating products designed for dry and sensitive skin types [26].

3. **Sun protection products:** *Rhodiola rosea* root is a well-accepted adaptogen described in the many traditional systems of medicines. It has the ability to reduce stress, and protect the skin against harsh conditions. Plant extract has been studied for anti UV properties. It provides an additional layer of protection against UVinduced damage, reducing erythema (skin redness) and photodamage [27].

4. **Brightening and skin tone enhancement:** The root extracts are also known to help in skin brightening by reducing melanin production and fading hyperpigmentation, by fighting the reactive oxygen species (ROS). This makes them ideal for use in products targeting pigmentation disorders or to achieve a more even complexion [28].

Leaves: soothing, anti-inflammatory, and healing properties

As mentioned in the previous sections, the leaves of *Rhodiola rosea* are rich in flavonoids, gallic acid derivates, and various polyphenols that provide significant benefits for skin health. These bioactive compounds exhibit strong anti-inflammatory and soothing properties, which are crucial in managing skin conditions characterized by redness, irritation, and inflammation [29].

1. **Soothing creams and lotions:** leaf extracts are frequently used in formulations aimed at calming irritated skin, reducing redness, and soothing inflammation. Their anti-inflammatory action helps alleviate symptoms of conditions like eczema, rosacea, and dermatitis, making them suitable for use in creams and lotions designed for sensitive or reactive skin [23].

2. **Acne treatment products:** The leaves also contain compounds with mild antibacterial properties that can help manage acne. They reduce inflammation around acne lesions and prevent bacterial colonization on the skin, reducing the frequency and severity of breakouts [29].

3. **Wound healing and repair creams:** Due to bioactive compounds that promote tissue regeneration, leaf extracts are used in wound healing and skin repair products. They help accelerate the skin’s natural healing process, making them effective in formulations for post-surgery or post-treatment recovery creams, particularly after dermatological procedures like chemical peels,

microdermabrasion, or laser therapy [30]. **Fig. 3** shows the cosmetic benefits of the phytochemicals and extract of the plant.

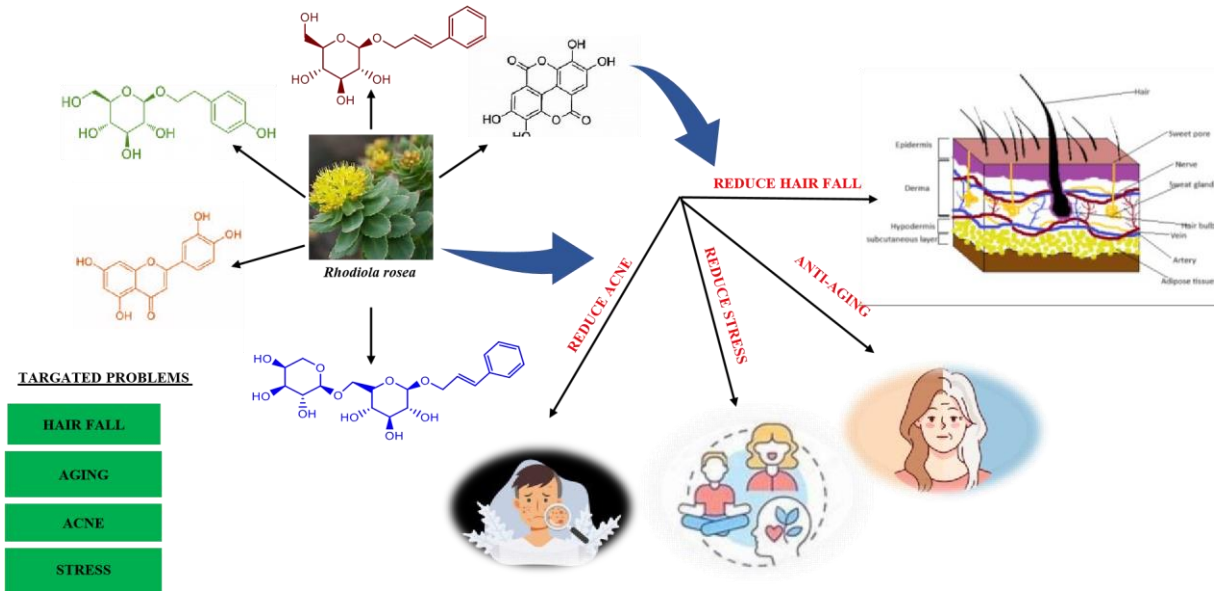

Fig. 3: Cosmetic uses of *Rhodiola rosea* plant and its chemical compounds

Flowers: Aromatic and antimicrobial applications

Although the flowers of *Rhodiola rosea* are less commonly used in cosmetics, they do have potential applications due to their aromatic properties and mild antimicrobial effects. The flowers contain volatile compounds that can be used to impart a natural fragrance to cosmetic products. Additionally, the antimicrobial properties of these compounds can contribute to formulations designed to maintain skin hygiene and prevent infections [31].

Antioxidant activity

Compounds such as tyrosol, salidroside, gallic acid, and a range of flavonoids serve as the key components responsible for the antioxidant properties of *Rhodiola rosea* plant. Water extract of the plant have been studied for its antioxidant activity in various cell lines such as NCTC 2544 cells, IMR-32 cells, and mouse C2C12 myotubes. Results of the study indicated that protective effects of extract against oxidative stress could be due to a pro-oxidant hormetic mechanism. In C2C12 myotubes, the antioxidant effect of the *R. rosea* extract was associated with the modulation of the molecular chaperone HSP70. The extract showed no potential activity in the rest of the cell lines [32].

Antidiabetic activity

Different ethanol extracts (12%) in water were evaluated for their α-amylase, α-glucosidase, and ACE inhibitory activities. Extract with the highest tyrosol content inhibited the α-glucosidase and ACE at maximum percentage. This indicates the dose-dependent inhibition of tyrosol against these two enzymes. The study further reported that extracts containing the highest percentage of gallic acid and coumaric acid exhibit higher inhibition against the α-amylase enzyme. The author reports that these studies indicate that inhibition of different therapeutic targets depends upon the presence of phytochemical compounds in an extract. Another study showed that 95% ethanol extract can lessen the glucose generation in HepG2 cell lines. Another research reported that in diabetic rats induced by streptozotocin (STZ), a 70% plant ethanol extract could reduce formalin-induced hyperalgesia, indicating its potential use in treating diabetic hyperalgesia. It is evident from the several animal-based studies that *R. rosea* bears the potential antidiabetic activity [33,34].

Immunomodulatory activity

R. rosea has been widely explored for its immunity-enhancing properties. As a natural adaptogen, the plant is well-acknowledged as an immunomodulator. According to a study, 50 % ethanol extract stimulated the production of splenic lymphocytes in mice. Another study showed that a 70% ethanol extract from the plant could inhibit apoptosis of thymus T-lymphocytes and elevate Th1 cytokine levels by downregulating TIPE2. Extract of the *R. rosea* and one of its major components, salidroside, has also been reported to increase the section of interleukin-2 (Th-1), interferon γ, and Th-2 in mice models in a dose-dependent manner [35]. **Antifatigue activity**

Scientific studies have provided robust evidence for these antifatigue properties. Research has shown that extracts of *R. rosea* can significantly increase physical performance and reduce mental fatigue by modulating key pathways associated with energy metabolism and oxidative stress. For example, salidroside, one of the major active constituents, has been shown to enhance mitochondrial ATP production, thereby increasing cellular energy availability. Studies conducted on animal models have demonstrated that administration of *R. rosea* extract leads to increased endurance capacity, as evidenced by prolonged swimming times in mice subjected to forced swimming tests. This endurance enhancement is believed to be due to the plant's ability to reduce lactate levels and serum urea nitrogen, markers commonly associated with muscle fatigue. Moreover, the antioxidant properties of *R. rosea* play a crucial role in its antifatigue activity[36].

Anti-inflammatory activity

Inflammation is a complex biological response involving multiple signaling pathways and mediators such as cytokines, chemokines, and inflammatory enzymes. *R. rosea* extracts have been shown to exert antiinflammatory effects by modulating these key pathways. Salidroside, in particular, has been identified as a potent anti-inflammatory agent. It has been shown to inhibit the production of pro-inflammatory cytokines such as TNF-α, IL-6, and IL-1β, which are involved in the pathogenesis of various inflammatory diseases. Studies on macrophages have demonstrated that salidroside suppresses the activation of NF-κB, a critical transcription factor that regulates the expression of inflammatory genes. Furthermore, it has been observed that *R. rosea* extracts can downregulate the expression of inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2), which are key enzymes in the inflammatory response. Additionally, rosavins have been reported to exhibit significant anti-inflammatory effects by attenuating oxidative stress and reducing the activation of inflammatory pathways. Experimental studies have shown that rosavin can inhibit the activation of MAPK (mitogen-activated protein kinase) signalling pathways, which are crucial in the inflammatory response cascade[37].

ADVERSE EFFECTS:

While *Rhodiola rosea* is widely recognized for its beneficial properties, the literature also indicates that its consumption may be associated with certain adverse effects, particularly when taken in high doses or over extended periods. Although *R. rosea* is generally considered safe for most users, a few studies have reported mild to moderate side effects linked to its use. Some of the most commonly reported adverse effects of *R. rosea* and its compounds are gastrointestinal-related adverse effects. These effects include symptoms like nausea, dry mouth, and stomach upset. In clinical trials, these gastrointestinal disturbances were generally mild and selflimiting, occurring more frequently at higher doses of the plant extract. The symptoms resolve quickly upon discontinuation or reduction of the dose, indicating a dose-dependent response [38]. Adverse effects related to the central nervous system have also been noted, though they are relatively rare. Some users have reported symptoms such as dizziness, restlessness, agitation, or difficulty sleeping, which may be attributed to the stimulating properties of *R. rosea*. These effects are believed to arise from the modulation of neurotransmitter systems, particularly dopamine and serotonin, which play a role in mood regulation and alertness. However, these symptoms are typically mild and diminish with continued use or dose adjustment [37].

Although uncommon, allergic reactions to *R. rosea* have been reported in some cases. These may present as skin rashes, itching, or swelling, and are thought to result from hypersensitivity to one or more of the plant's components. There is limited evidence in the literature on the prevalence or severity of such allergic reactions, but individuals with known allergies to plants in the Crassulaceae family should exercise caution when using *R. rosea* extracts [40]. Evidence suggests that *R. rosea* may influence hormonal balance, particularly concerning the thyroid gland. Animal studies have indicated that high doses of *R. rosea* extracts may affect thyroid hormone levels, potentially leading to hyperthyroid-like symptoms such as palpitations, anxiety, and weight loss. While these effects have not been widely documented in human studies, individuals with thyroid disorders should be cautious and consult a healthcare provider before using *R. rosea* supplements [39].

Overall, while *Rhodiola rosea* is generally considered safe for most individuals, it is not without potential adverse effects. These effects are typically mild and dose-dependent, but they warrant attention, especially for individuals with pre-existing health conditions, those taking medications, or those using the herb in high doses over long periods.

MARKETED FORMULATION:

A number of *Rhodiola rosea* root extracts have been marked mostly for immunomodulatory and adaptogenic benefits. Cosmetic formulations available in the market are given in the **fig. 4.**

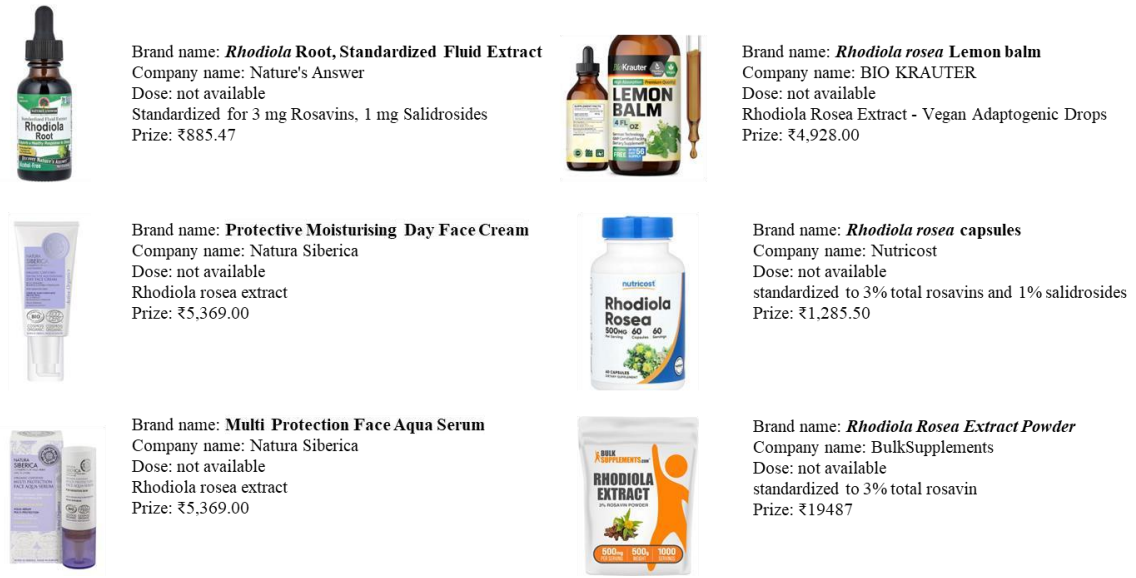

Fig. 4: Marketed formulations of the plant *Rhodiola rosea*

CONCLUSION:

Rhodiola rosea, a renowned adaptogen, has emerged as a promising candidate for cosmeceutical applications, owing to its multi-therapeutic properties and rich phytochemical profile. This review has explored the extensive scientific literature on *R. rosea*, highlighting its antifatigue, anti-inflammatory, and antioxidant activities, particularly relevant for cosmetic and dermatological use. The plant's bioactive constituents, including salidroside, rosavin, tyrosol, and various flavonoids, play a crucial role in its efficacy. Furthermore, *R. rosea* exhibits notable antioxidant, anti-inflammatory, antistress, and adaptogenic properties, which can be harnessed in cosmetic formulations aimed at revitalizing and rejuvenating the skin. The plant's ability to enhance cellular energy production and reduce mental and physical exhaustion complements its use in products that promote a more vibrant youthfulness.

Altogether, *Rhodiola rosea* holds considerable promise as a cosmeceutical ingredient due to its extensive range of therapeutic properties. Its ability to combat oxidative stress, enhance energy levels, and reduce inflammation positions it as a valuable asset in skincare and cosmetic formulations. Continued research and clinical trials will be crucial in optimizing its use and ensuring its safety and efficacy in cosmeceutical applications. As the demand for natural and effective skincare solutions grows, *R. rosea* offers a compelling option for developing advanced and beneficial cosmeceutical products.

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