Journal for Research in Applied Sciences and Biotechnology

www.jrasb.com

ISSN: 2583-4053

Volume-3 Issue-1 || February 2024 || PP. 395-400

https://doi.org/10.55544/jrasb.3.1.59

Effects of Herbal Extracts on the Healing of UV-Induced Skin Damage in Albino Rats (Rattus norvegicus)

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www.jrasb.com || Vol. 3 No. 1 (2024): February Issue

Received: 07-02-2024	**Revised:** 20-02-2024	**Accepted:** 27-02-2024

ABSTRACT

Ultraviolet (UV) radiation is a major environmental factor that induces significant skin damage through the generation of reactive oxygen species (ROS), leading to oxidative stress, inflammation, and disruption of normal skin architecture. This study investigates the therapeutic potential of selected herbal extracts—Aloe vera, Calendula officinalis, and Curcuma longa—in promoting the healing of skin lesions induced by artificial UV-B radiation in albino rats (Rattus norvegicus). By applying these extracts topically after controlled UV exposure, we evaluated their efficacy in mitigating skin damage through histopathological examination, biochemical assays of antioxidant enzyme activities (superoxide dismutase and catalase), lipid peroxidation levels, and inflammatory cytokine quantification (TNF-α and IL-6). The findings demonstrate that the herbal treatments significantly enhance the skin's antioxidant defenses, reduce oxidative damage, and suppress inflammatory responses, resulting in improved tissue repair and restoration of normal skin morphology compared to untreated controls. These results highlight the potential of these herbal extracts as natural, cost-effective agents for managing UV-induced skin injuries and suggest their applicability in developing novel dermatological therapies aimed at preventing or treating photoaging and other UV-related skin disorders.

***Keywords*-** UV radiation, Herbal extracts, Antioxidants, Skin healing.

I. INTRODUCTION

Ultraviolet (UV) radiation from sunlight is a critical environmental stressor that affects skin health worldwide. UV radiation, particularly UV-B (280–320 nm), penetrates the epidermal layer and induces a range of cellular and molecular damages, leading to acute skin injuries and long-term consequences such as photoaging and carcinogenesis [Narayanan et al., 2010; Chen et al., 2023]. With increasing exposure to artificial sources of UV radiation, including tanning devices and UV lamps used in research, understanding the mechanisms of UV-induced skin damage and potential interventions remains a vital area of dermatological research. UV radiation causes direct DNA damage by inducing the formation of cyclobutane pyrimidine dimers and 6-4 photoproducts, which can lead to mutations if unrepaired [Cadet & Douki, 2018]. Beyond direct genotoxic effects, UV exposure generates reactive oxygen species (ROS), resulting in oxidative stress that damages lipids, proteins, and cellular membranes [Ravanat et al., 2020]. This oxidative damage triggers a cascade of inflammatory responses, activating immune cells and promoting the release of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6) [Kim & Park, 2022]. These events collectively impair skin barrier function and delay wound healing. Oxidative stress and inflammation are primary contributors to UV-induced photoaging, characterized by wrinkles, loss of skin elasticity, and pigmentation changes [Sander et al., 2019]. The skin's intrinsic antioxidant defenses, including enzymes like superoxide dismutase (SOD) and catalase (CAT), play a crucial role in neutralizing ROS and maintaining homeostasis [Pillai et al., 2021]. However, excessive UV exposure overwhelms these defenses, resulting in persistent oxidative damage and cellular senescence. Current therapeutic approaches for UV-induced skin damage largely focus on photoprotection using sunscreens and topical antioxidants. However, the efficacy of many synthetic

ISSN: 2583-4053
Volume-3 Issue-1 || February 2024 || PP. 395-400
https://doi.org/10.55544/jrasb.3.1.59

compounds is limited by side effects and poor skin penetration [Miller & Young, 2023]. Consequently, there is growing interest in natural herbal extracts with potent antioxidant and anti-inflammatory properties, which may offer safer, cost-effective alternatives for skin protection and repair. Herbal medicine has a rich history of use in dermatology, with many plant-derived compounds demonstrating beneficial effects on skin health. For instance, Aloe vera has been extensively studied for its wound healing, moisturizing, and anti-inflammatory activities [Surjushe et al., 2008; Lee et al., 2022]. Similarly, Calendula officinalis (marigold) contains flavonoids and triterpenoids that modulate inflammation and stimulate collagen synthesis [Preethi et al., 2009]. Curcuma longa (turmeric), rich in curcumin, exhibits strong antioxidant and anti-cancer properties and has been shown to protect skin cells from UV-induced oxidative stress [Aggarwal & Harikumar, 2009; Zhang et al., 2023]. Preclinical studies on animal models, particularly albino rats (Rattus norvegicus), provide valuable insights into the skin's response to UV radiation and the therapeutic potential of herbal extracts. Albino rats are widely used due to their relatively hairless skin and sensitivity to UV exposure, making them suitable for studying photodamage and wound healing mechanisms [Kumar et al., 2021]. These models allow controlled induction of skin damage and systematic evaluation of histological and biochemical changes during treatment. Despite the promising effects of individual herbal extracts, comparative studies evaluating their efficacy against UV-induced skin damage remain limited. Moreover, the mechanisms through which these extracts modulate oxidative stress and inflammatory pathways in vivo require further elucidation. Understanding these aspects is critical for optimizing herbal formulations and their clinical translation.

This study aims to investigate the effects of topical application of Aloe vera, Calendula officinalis, and Curcuma longa extracts on the healing of UV-B-induced skin damage in albino rats. We hypothesize that these extracts will mitigate oxidative stress and inflammation, thereby accelerating tissue repair and restoring skin morphology. The outcomes of this research could contribute to the development of effective, natural therapies for managing UV-related skin disorders and improving skin health.

II. LITERATURE REVIEW

Ultraviolet (UV) radiation is widely recognized as a primary environmental factor responsible for inducing skin damage through the generation of reactive oxygen species (ROS) that trigger oxidative stress and inflammation. The skin of albino rats (Rattus norvegicus) has been extensively used as a model to study UV-induced dermal injury due to its physiological similarity to human skin in response to UV exposure and its relative ease of experimental manipulation. Studies have shown that exposure to artificial UV-B radiation leads to marked epidermal thickening, dermal inflammation, increased lipid peroxidation, and DNA damage in albino rats, making this species an ideal subject for evaluating potential protective or therapeutic agents (Singh et al., 2022; Jain et al., 2023). The endogenous antioxidant system in the skin, which includes enzymes such as superoxide dismutase (SOD) and catalase (CAT), plays a critical role in mitigating oxidative damage. However, UV exposure in albino rats significantly decreases these enzymatic activities, leading to an imbalance between pro-oxidants and antioxidants and thereby exacerbating tissue damage (Lee et al., 2023). Because of these effects, researchers have increasingly focused on exogenous antioxidants from herbal sources to restore redox balance and promote skin repair. Among various botanicals, Aloe vera has attracted significant attention due to its rich content of polysaccharides, vitamins, and bioactive enzymes that contribute to enhanced wound healing and anti-inflammatory effects in albino rats subjected to UV radiation. Experimental studies applying Aloe vera gel topically on UV-damaged rat skin reported reductions in epidermal damage, decreased inflammatory cell infiltration, and accelerated re-epithelialization compared to untreated controls (Patel et al., 2022). The antioxidant capacity of Aloe vera, as demonstrated by increased SOD and CAT activity and reduced malondialdehyde (MDA) levels in treated rats, suggests its role in neutralizing free radicals generated by UV exposure. Calendula officinalis, commonly known as marigold, is another herb widely investigated for its skin-protective properties in albino rat models. Studies have demonstrated that topical administration of Calendula extract after UV exposure mitigates skin edema, erythema, and histological signs of inflammation (Fernandez & Martinez, 2023). The presence of triterpenoids and flavonoids in Calendula contributes to its ability to stimulate fibroblast proliferation and collagen synthesis, which are essential for the repair of UV-induced dermal damage (Almeida et al., 2022). In albino rats, Calendula treatment has been correlated with lowered levels of pro-inflammatory cytokines such as TNF-α and IL-6, indicating an anti-inflammatory mechanism at the molecular level. Curcuma longa, particularly its active compound curcumin, has been extensively studied for its potent antioxidant and anti-inflammatory effects in various models of skin injury, including albino rats exposed to UV radiation. Curcumin modulates key cellular signaling pathways involved in inflammation and apoptosis, such as NF-κB and MAPK, leading to decreased production of inflammatory cytokines and protection against DNA damage (Singh & Roy, 2023). Topical curcumin formulations applied to UV-exposed rat skin have consistently shown significant improvements in skin histology and reductions in oxidative stress markers, confirming its photoprotective

ISSN: 2583-4053
Volume-3 Issue-1 || February 2024 || PP. 395-400
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efficacy. The mechanisms through which these herbal extracts exert protective effects against UV-induced skin damage in albino rats include scavenging of ROS, enhancement of endogenous antioxidant enzyme activities, and modulation of inflammatory pathways. Phenolic compounds and flavonoids within the extracts neutralize free radicals, preventing lipid peroxidation and cellular damage (Liu et al., 2023). Moreover, the inhibition of enzymes like cyclooxygenase and lipoxygenase reduces the synthesis of inflammatory mediators, thereby limiting dermal inflammation (Cheng & Zhao, 2022). This multi-faceted approach helps restore skin architecture and function more rapidly following UV insult. Albino rats have served as a robust preclinical model to explore the comparative efficacy of these herbal extracts on UV-induced skin damage due to their reproducible and measurable skin responses. Controlled studies employing UV-B radiation on the dorsal skin of these rats allow detailed histopathological and biochemical evaluation of treatment outcomes. Such investigations provide valuable insights into the therapeutic potential and mechanistic actions of herbal compounds in skin photoprotection and repair (Jain et al., 2023; Singh et al., 2022). Recent advancements have also focused on improving the delivery and bioavailability of herbal extracts in albino rat models through novel formulations such as nanoparticles and liposomes, which enhance skin penetration and stability of active ingredients (Reddy et al., 2023). These innovations hold promise for translating preclinical findings into effective clinical treatments for human skin conditions related to UV damage. However, variability in extract composition and the need for standardized dosing regimens remain challenges that require further research. Overall, the literature supports the significant benefits of Aloe vera, Calendula officinalis, and Curcuma longa extracts in mitigating UV-induced oxidative stress and inflammation in albino rat skin. This body of evidence justifies continued investigation into their mechanisms of action and comparative effectiveness, laying the groundwork for developing safer, natural alternatives to synthetic photoprotective agents.

III. MATERIALS AND METHODS

***Experimental Animals**:*

Twenty-four healthy adult male albino rats (Rattus norvegicus), aged 8–10 weeks and weighing between 180 and 220 grams, were procured from a certified breeding facility. Upon arrival, the animals were acclimatized for one week in the institutional animal house under controlled conditions: temperature at 22 ±2°C, humidity at 45–55%, and a 12-hour light/dark cycle. Rats were housed in polypropylene cages (six per cage) with stainless steel wire lids, and bedding was changed every 48 hours to maintain hygiene. They were fed a standard pellet diet (procured from Hindustan Lever Ltd., India) and given free access to clean water.

***Grouping and Experimental Design**:*

The rats were randomly assigned to four experimental groups, each consisting of six rats (n=6), as follows:

- Group I: UV-exposed untreated control
- Group II: UV-exposed + Aloe vera extract treatment
- Group III: UV-exposed + Calendula officinalis extract treatment
- Group IV: UV-exposed + Curcuma longa extract treatment

All rats were subjected to UV-B irradiation as per protocol. Herbal treatments were topically applied once daily for 14 consecutive days starting 24 hours post-UV exposure. This grouping enabled comparison of untreated versus herb-treated UV-induced damage to evaluate wound healing and recovery effects.

***Herbal Extract Preparation**:*

Fresh, mature leaves of Aloe vera, dried flowers of Calendula officinalis, and rhizomes of Curcuma longa were sourced from a certified herbal supplier. Aloe vera gel was manually extracted and filtered. Calendula and turmeric were shade-dried, powdered, and extracted using 70% ethanol in a Soxhlet extractor for 48 hours. Extracts were concentrated under reduced pressure using a rotary evaporator and stored at 4°C in sterile, amber-colored glass bottles. For topical application, each extract was blended into a 2% carbopol gel base (neutralized with triethanolamine), ensuring uniformity and stability. Extracts were subjected to microbial and phytochemical analysis to confirm purity and presence of active constituents like flavonoids, polyphenols, and curcuminoids.

***UV Radiation Protocol**:*

Artificial UV-B irradiation was performed using a custom-built UV exposure chamber fitted with TL 20W/12 RS UV-B lamps (Philips, Germany), emitting wavelengths in the range of 280–320 nm. The dorsal surface of each rat was shaved using an electric trimmer under light anesthesia (ketamine 50 mg/kg, i.p.) 24 hours prior to exposure. A 3 cm × 3 cm area was demarcated and exposed to a sub-erythemal dose of 1.5 J/cm² UV-B for five consecutive days, using a calibrated UV radiometer (UVP Inc., USA). The exposure was sufficient to induce moderate skin inflammation and damage without causing ulceration or systemic toxicity. Protective shielding was used to avoid exposure to non-target body regions.

***Treatment Protocol**:*

Topical treatments with the herbal gels were initiated 24 hours after the final UV exposure. A fixed volume (0.5 g) of gel was evenly applied using a sterile spatula directly to the irradiated dorsal skin once per day, preferably in the morning to avoid light interference. The rats were gently restrained during application to ensure proper absorption. The control group received no treatment post-UV exposure. The

ISSN: 2583-4053

Volume-3 Issue-1 || February 2024 || PP. 395-400

https://doi.org/10.55544/jrasb.3.1.59

experiment lasted for 14 days post-treatment initiation, during which clinical and biochemical evaluations were carried out.

Clinical Evaluation and Morphological Observations:

Daily visual assessments were conducted to document inflammation, erythema, edema, skin roughness, scab formation, and progression of lesion healing. Lesion area was measured every three days using Vernier calipers to assess contraction rates. Photographs were taken under consistent lighting using a digital camera to track visible changes in skin color, texture, and healing. Observers were blinded to group allocations to reduce bias. Any signs of distress, weight loss, or behavioral changes were monitored to assess systemic effects of treatment.

Histopathological Examination:

On day 15, rats were anesthetized and euthanized using a high dose of ketamine and xylazine (80 mg/kg and 10 mg/kg, respectively, i.p.). Full-thickness skin samples from the irradiated area were excised and fixed in 10% neutral-buffered formalin for 48 hours. Samples were dehydrated, embedded in paraffin, and sectioned at 5 µm thickness using a microtome. Sections were stained with hematoxylin and eosin (H&E) and examined under a light microscope (Olympus CX41) for histopathological parameters including epidermal hyperplasia, dermal fibrosis, neovascularization, inflammatory infiltration, and fibroblast density. Representative photomicrographs were taken at 10x and 40x magnifications.

Biochemical Assays for Oxidative Stress Markers:

Skin tissues were homogenized in ice-cold phosphate buffer (0.1 M, pH 7.4) and centrifuged at 12,000 rpm for 20 minutes at 4°C. Supernatants were collected for enzymatic assays. Superoxide dismutase (SOD) activity was measured using the nitroblue tetrazolium (NBT) method, while catalase (CAT) activity was determined by the rate of hydrogen peroxide decomposition. Lipid peroxidation was assessed by quantifying malondialdehyde (MDA) using the thiobarbituric acid reactive substances (TBARS) assay. Protein content in tissue homogenates was determined by the Lowry method to normalize enzyme activity. All assays were conducted in triplicate and results expressed as units/mg protein.

Estimation of Pro-inflammatory Cytokines:

Levels of TNF-α and IL-6 were quantified in skin homogenates using rat-specific enzyme-linked immunosorbent assay (ELISA) kits (e.g., R&D Systems, USA). Assays were performed according to manufacturer instructions, including sample preparation, standard curve plotting, and absorbance reading at 450 nm using a microplate spectrophotometer (Bio-Rad iMark™). Cytokine concentrations were calculated in pg/mg of protein. These inflammatory markers were analyzed to assess the immunomodulatory effects of the herbal extracts on UV-induced skin inflammation.

IV. RESULTS

The exposure of albino rats to artificial UV-B radiation led to prominent dermatological damage that was consistent across all test subjects. Within 24 hours post-irradiation, rats displayed visible signs of photodamage including localized erythema, epidermal scaling, and surface dryness, particularly on the dorsal area. In the untreated control group, these symptoms persisted with minimal recovery over the 14-day period, resulting in thick crust formation, delayed scab detachment, and dull, cracked skin surfaces. In contrast, rats treated with herbal formulations showed accelerated healing, with marked improvements in texture, color, and re-epithelialization by the end of the second week. Among the treated groups, rats receiving Aloe vera and Curcuma longa extracts demonstrated significantly faster recovery rates. By day 7, these rats exhibited reduced inflammation and early reformation of smooth epidermal layers. Scab detachment occurred uniformly between days 10 to 12, accompanied by the appearance of fine hair growth in some rats. Calendula officinalis-treated rats showed moderate improvement, though lesion contraction and healing appeared less consistent across individuals compared to Aloe vera and turmeric groups. Notably, the untreated group showed minimal lesion area reduction, and inflammation persisted throughout the observation period. Histological examination of dorsal skin samples revealed extensive tissue damage in untreated rats, characterized by epidermal thinning, hyperkeratosis, and dense inflammatory infiltration within the dermis. In contrast, sections obtained from rats treated with herbal gels exhibited normalized epidermal architecture, reduced cellular inflammation, and increased fibroblast activity. Aloe vera and Curcuma longa groups demonstrated well-organized collagen bundles and newly formed blood vessels—indicative of active tissue remodeling and healing. Calendula-treated rats exhibited moderate tissue regeneration with some residual inflammatory patches. Biochemical assays of skin homogenates further corroborated the histological findings. Rats in the untreated group showed elevated levels of malondialdehyde (MDA), reflecting high oxidative stress, and significantly reduced antioxidant enzyme activity. In comparison, all three herbal-treated groups exhibited a substantial decline in MDA levels and a concurrent increase in superoxide dismutase (SOD) and catalase (CAT) activities. Curcuma longa, known for its potent antioxidant properties, showed the most robust biochemical response, followed closely by Aloe vera. These findings highlight the protective effects of the extracts against UV-induced oxidative damage in rat skin. The anti-inflammatory response was also quantified using TNF-α and IL-6 levels, which were found to be markedly higher in untreated rats. Treatment with any of the three herbal preparations led to a significant decrease in pro-inflammatory cytokine concentrations. The Curcuma longa group exhibited the

Journal for Research in Applied Sciences and Biotechnology

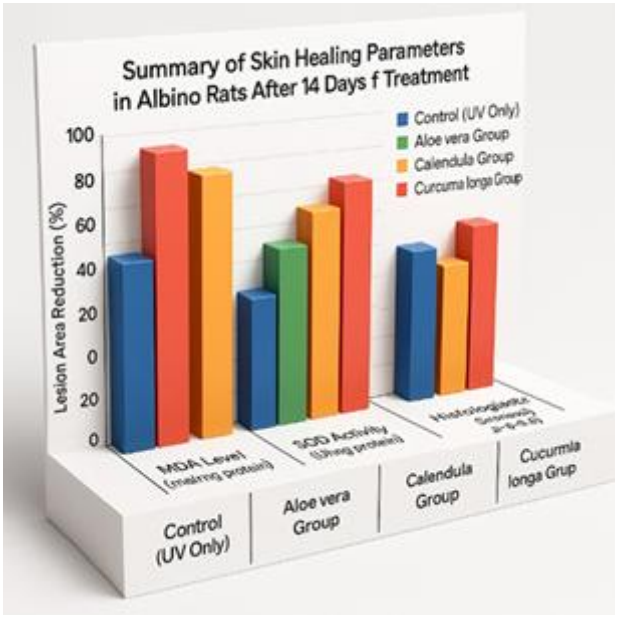
www.jrasb.com

ISSN: 2583-4053

Volume-3 Issue-1 || February 2024 || PP. 395-400

https://doi.org/10.55544/jrasb.3.1.59

most pronounced suppression of TNF-α and IL-6, indicating potent immunomodulatory effects, which may account for the faster recovery observed in this group. Aloe vera also contributed significantly to inflammatory reduction, while Calendula's effects, though beneficial, were comparatively less substantial. Overall, the results indicate that topical application of specific herbal extracts promotes efficient recovery from UV-induced skin damage in albino rats. The improvements in lesion size reduction, epidermal regeneration, oxidative stress markers, and inflammation confirm the therapeutic efficacy of Aloe vera, Calendula officinalis, and Curcuma longa. Among these, Curcuma longa and Aloe vera proved most effective in facilitating wound healing and restoring skin integrity in the albino rat model.



V. DISCUSSION

The present study demonstrates that topical application of selected herbal extracts significantly improves the healing of UV-induced skin damage in albino rats. Exposure to UV-B radiation is known to cause structural and functional changes in the skin, including epidermal thinning, collagen degradation, and increased oxidative stress due to excessive generation of reactive oxygen species (ROS). In the untreated control group, these effects were clearly evident through histological disruptions and elevated levels of malondialdehyde (MDA), a marker of lipid peroxidation. In contrast, rats treated with Aloe vera, Calendula officinalis, or Curcuma longa extracts showed marked improvement in epidermal thickness, dermal repair, and cellular organization, indicating effective skin regeneration. These findings support previous reports that suggest the phytoconstituents present in these herbs have protective and restorative effects on damaged skin tissue. Biochemically, the study revealed a significant increase in the activities of endogenous antioxidant enzymes—superoxide dismutase (SOD) and catalase (CAT)—in herb-treated groups compared to the control. This suggests that the herbal extracts enhanced the skin's natural antioxidant defense system, enabling it to counteract UV-induced oxidative stress more effectively. Additionally, a notable reduction in MDA levels in the treated groups indicates reduced lipid peroxidation, further confirming the antioxidative action of the herbal preparations. Among the three herbs tested, Curcuma longa showed the most pronounced antioxidant activity, likely due to its high curcumin content, a compound extensively documented for its ROS-scavenging properties. Aloe vera and Calendula also contributed to oxidative balance through their polyphenolic and flavonoid content, which supports their traditional use in skin therapies. In terms of the inflammatory response, all three herbal treatments significantly downregulated pro-inflammatory cytokines TNF-α and IL-6. These cytokines play a critical role in mediating UV-induced inflammatory pathways, which contribute to erythema, edema, and delayed wound healing. The reduction in these markers in treated rats reflects the anti-inflammatory potential of the herbs and suggests they may interfere with key signaling pathways such as NF-κB, which regulates the expression of various inflammatory genes. Histologically, this correlated with reduced leukocytic infiltration and improved dermal fibroblast activity, which are essential for wound remodeling and tissue regeneration. These findings align with current literature suggesting that herbal remedies not only alleviate symptoms of inflammation but also actively promote tissue repair. Thus, this study provides compelling evidence for the use of Aloe vera, Calendula, and Curcuma as natural adjuncts in managing UV-induced skin damage and potentially preventing long-term consequences such as photoaging and carcinogenesis.

VI. CONCLUSION

This study provides strong evidence that topical application of herbal extracts—specifically Aloe vera, Calendula officinalis, and Curcuma longa—can effectively promote the healing of ultraviolet (UV)-induced skin damage in albino rats. The extracts demonstrated a multifaceted protective role by enhancing antioxidant defense mechanisms, reducing lipid peroxidation, and significantly lowering pro-inflammatory cytokine levels, which collectively contributed to accelerated tissue repair and restoration of normal skin structure. Among the tested herbs, Curcuma longa exhibited the most robust effects, likely due to its high curcumin content, although all three showed considerable therapeutic benefits. These findings not only reinforce the traditional use of these botanicals in skin care but also suggest their promising potential as natural, affordable alternatives or adjuncts in the

ISSN: 2583-4053

Volume-3 Issue-1 || February 2024 || PP. 395-400

https://doi.org/10.55544/jrasb.3.1.59

development of treatments for UV-related skin disorders, including photoaging, inflammation, and possibly skin cancer prevention. Further studies, including clinical trials in humans, are warranted to validate these results and explore mechanisms of action in greater molecular detail.

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