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Original Article

A Systematic Review of the Efficacy of Topical Bioactive Plant Extracts in Burn Wound Healing Using Clinical and Preclinical Evidence

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Abstract

All burns, regardless of type (thermal, chemical, electrical, radiation) and severity, should be carefully evaluated and reviewed in the recommended systematic evaluation. Bioactive plant extracts as topical products may be useful in this regard. These are the goals: To find out if plant extracts improve biomarkers (as IL-6, VEFG, collagen deposition and infection/scar severity/time to healing) and other important outcomes. The apparent mechanisms of action (anti-inflammatory effects, antibacterial and angiogenic effects) must be clarified. This review will focus on well-researched extracts from plants: Aloe Vera, Centella asiatica, Curcuma longa, Calendula officinalis, Hippophae rhamnoides and Betula pendula, which have been demonstrated to be useful and practical in burn management. In the light of this extensive study, the healing rate of superficial and partial thickness burns could be reduced and the healing process accelerated, pain could be mitigated and scar quality could be enhanced using bioactive plant extracts from plants such as Aloe vera, Centella asiatica and Curcuma longa. Further research is needed, however, due to the heterogeneity and a scarcity of data regarding extensive burning and a need for large-scale RCTs. Standardised formulations, innovative delivery methods like hydrogels, and follow-up studies to find out the long-term effects could increase the clinical results of burn patients, decrease the socioeconomic cost of burn care, and speed up the clinical adoption of plant-based therapies.

Keywords: Bioactive Plant Extracts, Burn Wound Preclinical Evidence, Systematic Review.

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1. Introduction

Burn injuries are a major health problem around the world, and can cause significant morbidity, mortality, and economic consequences. Each year 180,000 people die from fire in less developed and middle income countries [1]. Non-fatal burns can often result in hospitalisation for long periods, deformities, and long-term impairments that include contractures and hypertrophic scarring, which have an impact on quality of life [1]. Burns can be classified into four categories: first degree (superficial), second degree (full thickness) and third degree (thermal, chemical, electrical or radiation burn) [2]. During the many stages of the burn healing process, from haemostasis through to proliferation and remodelling, complications may occur including infection, delayed re-epithelialization, or too much scarring [2]. Burn wound treatment needs to be undertaken effectively in order to minimize the risk of such complications, speed up the healing process and ensure the best possible patient outcome. The most important treatments for burns in the modern era are silver sulfadiazine (SSD), hydrocolloid dressings, and surgical treatment [3]. Although SSD has many potential applications due to its antimicrobial qualities, it does have some drawbacks, including as the possibility of cytotoxicity to keratinocytes and fibroblasts, a delay in wound closure, and extremely rare cases of hypersensitive reactions [3,4]. Modern dressings that provide a moist healing environment, such as hydrogels and hydrocolloids, support granulation and epithelialisation [5]. The high expense of these treatments might prevent them from being accessible in areas with limited resources, and they might not solve the burns' complicated pathophysiology, which includes inflammation and oxidative stress [5]. Moreover, alternative treatment options that are effective, cost-efficient and physiologically adaptable are in dire need because of the escalating risk of antibiotic resistance [6]. The wide spectrum of pharmacological activities, easy utilization and long history of traditional medicines has led to the application of plant-based medicines in the treatment of burns and other wounds for centuries [7]. Bioactive plant extracts, rich in chemicals such as terpenoids, alkaloids, polyphenols, flavonoids, exhibit anti-inflammatory, antioxidant, antibacterial and angiogenic activity, and are able to meet the complex requirements of burn wound healing [7,8]. Aloe vera is an example, the polysaccharides in aloe vera are anti-inflammatory and promote re-epithelialization [9]. A recent meta-analysis and systematic review showed that aloe vera had a significant positive effect on wound healing time for burns by reducing the healing time by approximately 3.8 days compared with controls [9]. Similarly, the compounds asiaticoside and madecassoside of Centella asiatica (gotu kola) increase the levels of vascular endothelial growth factor (VEFG) and fibroblast growth factor (FGF), respectively, and thus promote angiogenesis and collagen production [10]. In wound models reductions in the levels of pro-inflammatory cytokines were noted, including IL-1β, IL-6 and TNF-α, as validated in a comprehensive review from 2022.[10]

Plants with promising properties in the area of wound healing in burns include turmeric (Curcuma longa), marigold (Calendula officinalis), sea buckthorn (Hippophae rhamnoides) and birch (Betula pendula), used for Episalvan. In some clinical studies, curcumin, the main active compound in Curcuma longa has been found to be more effective than SSD for antioxidant and anti-inflammatory effects [11]. The omega-7 fatty acid and vitamin E content of Hippophae rhamnoides is associated with a promotion of tissue regeneration and in clinical use, Calendula officinalis has been shown to improve scar quality and reduce pain [12]. Some herbal remedies outperformed SSD in lowering infection rates and speeding healing, according to a 2023 thorough assessment, which suggests they could be used as complementary or alternative treatments [11]. In addition, one potential trend in burn care is the creation of plant-based hydrogels, which are reviewed in 2025. These gels are a combination of bioactive extracts and advanced delivery systems [13].

However, there are still some gaps in the literature. Many research focus on one plant extract, without comparing with other plants or other already existing therapies like Centella asiatica or Aloe vera [9,10]. The diversity of research designs, types of burns and outcome measures can make evidence syntheses a challenging task [11]. Despite the molecular findings from preclinical studies, such as modulation of transforming growth factor beta (TGF-β) or antioxidant mechanisms, few molecular mechanisms have been translated into clinical practice [10,12]. Even though there are no large-scale RCTs to compare the different plant extracts, using data to make recommendations is difficult. There is need for a systematic approach to bring together clinical and preclinical data, elucidate processes, and evaluate comparative efficacy.

This is a meta-analysis to conclude the effectiveness of topical bioactive plant extracts in the healing of burn wounds caused by thermal, chemical, electrical and radiation burns of varying degrees of severity. Here are the goals:

To evaluate the efficacy of plant extracts in the reduction of healing times, infection rate, pain, scar quality and expression of biological parameters (IL-6, VEFG, collagen deposition etc).

To help understand the mechanism of action, such as anti-inflammatory, anti-bacterial and angiogenic properties.

To obtain information for clinical decision making, compare plant extracts to conventional treatments (SSD and hydrocolloids).

The review focuses on extracts of plants which have been extensively investigated as they are well established and useful in the care of burns. The extracts consist of Aloe vera, Centella asiatica, Curcuma longa, Calendula officinalis, Hippophae rhamnoides and Betula pendula.

All kinds of burns have similar pathophysiological pathways involved (e.g., inflammation, oxidative stress, and delayed tissue regeneration); it is therefore reasonable to have all types of burns included in this category [2]. Factors to assess the success of therapy and a patient's overall health include healing time, infection rates, discomfort, scar quality, and biological markers [9,10]. It ensures scientific rigor, transparency and reproducibility based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

The methodology section indicated how the search was carried out, the criteria used for inclusion/exclusion of results, and the quality assessment of the results. Clinical and preclinical evidence is synthesised in the results, which are organised by plant extract and outcome. Discussion of clinical implications, limitations, and comparison to current treatments is part of plant extracts. The final section provides some ideas for further study and use. The review can serve as a guide for clinicians, researchers and legislators to implement the use of plant-based medicines in the management of burn wounds and presents evidence from 2015 to 2025.

2 .Literature Review

Burn wounds – pathophysiology and clinical challenges(2.1)

Burns contribute to the deaths of around 180,000 people annually, the majority of whom are in low- and middle-income countries [1]. This disease is a world-wide serious problem for morbidity, mortality and socio-economic loss. Burns can be first degree (superficial) or third degree (full thickness), which involves deep tissue. The causes can include thermal (such as flames or scalding), chemical, electrical or radiation.[2]

Burn wounds are a complex process involving four stages: haemostasis, inflammation, proliferation and remodelling [14]. Haemostasis is characterized by instant vasoconstriction and clot formation which help to stop bleeding. During the days-long inflammatory phase, immune cells are recruited to remove debris and pathogens and pro-inflammatory cytokines such interleukin-1β (IL-1β), interleukin-6 (IL-6), and tumour necrosis factor-alpha (TNF-α) are released [14]. Proliferation occurs in response to growth factors such as vascular endothelial growth factor

(VEGF) and transforming growth factor-beta (TGF-β) and involves re-epithelialization, angiogenesis, and formation of granulation tissue [2]. Collagen reorganisation is a frequent part of remodelling, and often leaves behind hypertrophic or keloid scars that may persist for months or years following a major burn.[2]

Some of the issues that can occur with a burn are: scarring, infection, and delayed healing. If the barrier of the skin is broken, it can lead to more infections. Some microorganisms (e.g., Staphylococcus aureus and Pseudomonas aeruginosa) may result in serious illness or life-threatening situations [15]. Impaired angiogenesis, protracted inflammation, or oxidative stress due to reactive oxygen species (ROS) [16] cause burns to heal more slowly, especially full-thickness and deep partial-thickness burns. The excessive collagen deposition unique to hypertrophic scarring can cause functional restrictions and contractures and therefore significantly affect quality of life [2]. The use of opioid-based treatments, which pose the dangers of addiction and side effects, is sometimes necessary to alleviate pain, which is another important obstacle [17]. The above problems underscore the need for treatments which address the multi-faceted aspects of burn wound healing.

Conventional treatments include surgical techniques (e.g., skin grafting), advanced dressings (e.g., hydrocolloids, hydrogels) and silver sulfadiazine (SSD) [3]. Rare hypersensitivity reactions, cytotoxicity to keratinocytes and fibroblasts, and delayed re-epithelialization are some of the side effects of SSD, which is highly prized for its antimicrobial capabilities [3,4]. Although the use of hydrocolloids and hydrogels creates a moist environment that promotes granulation and epithelialisation, they are not available in resource-limited environments due to their high cost. Although surgical procedures are frequently required to treat full-thickness burns, there is a chance of graft failure and donor-site morbidity [2]. In addition to the ever growing problem of antibiotic resistance, burn care is already complex and biological therapies that are effective, cost-effective and adaptable are needed [6].

2.3 Pharmacological Activities of the Plant Extracts in Relation to Burn Wound Healing.2.4 Toxicity of the Plant Extracts in Burn Wound Healing.

Plant-based wound healing has been used in traditional medical systems for centuries, such as Ayurveda, TCM, and African ethnomedicine, which have been used to treat wounds, including burns [18]. The medicinal values of some plants, which are easily accessible and generally accepted as safe to use have been greatly appreciated, for example Curcuma longa, Centella asiatica and Aloe vera. The bioactive components in these plants have been discovered in recent years, which has led to a renewed interest in their use for treating burn wounds [19]. For their anti-inflammatory, antioxidant, antibacterial and angiogenic properties, flavonoids, polyphenols, alkaloids and terpenoids are compounds which address the various needs of burn treatment.[19]

Numerous evidences exist of past use of plant extracts. For instance, Centella asiatica has been an essential ingredient in Asian medicine for wound treatment for a long time, and Aloe vera was used by the ancient Greeks and Egyptians for skin disorders [18]. In India, curcuma longa (turmeric) has been used to treat burn and infections, which have been applied topically [19]. These ancient uses have been confirmed by clinical and experimental studies which have demonstrated that extracts from plants can enhance healing, reduce infection, and enhance the quality of scarring [9,10]. In clinical trials, some herbal remedies have shown greater effectiveness than SSD, indicating their potential as complementary or alternative treatments [11]. By combining bioactive chemicals with state-of-the-art technologies to deliver them to the target site, hydrogels and other plant-based formulations have found new applications [13].

2.4 Indeterminate and unknown mechanism of action.2.5 Other bioactive compounds.

The bioactive components of plant extracts are able to target important pathophysiological processes, this is why they can heal burn wounds. Selected plants and their mechanisms: Aloe vera, Centella asiatica, Curcuma longa, Calendula officinalis, Hippophae rhamnoides and Betula pendula.

Aloe vera: Contains polysaccharides, aloin and acemannan that inhibit IL-6 and TNF-α to reduce inflammation and promote the proliferation of keratinocytes to promote re-epithelialization [9]. The research done in 2024 revealed that burn patients which used aloe vera during the healing process had a 3.8 reduction in healing time and an improvement in the pain scores [9].

Centella asiatica: It contains glycosides asiaoside and madecassoside, which help to promote angiogenesis and collagen formation by increasing the level of vascular endothelial growth factor (VEGF) and fibroblast growth factor (FGF) [10]. In 2022, a thorough assessment was carried out, confirming that wound models exhibited reduced levels of oxidative stress and inflammatory markers [10].

Curcuma longa: Curcumin, the major chemical compound of the plant, has been found to alleviate inflammation by blocking the nuclear factor-kappa B (NF-κB) pathway and oxidative stress by inhibiting ROS production [11]. Studies on the second degree burns suggest that lotions containing curcumin accelerate healing process [11].

Calendula officinalis: It is rich in flavonoids and triterpenoids that modulate the TGF-β signaling pathways, which in turn helps to decrease pain and enhance the quality of scars [20]. Clinical trials show effectiveness against superficial burns [20].

Hippophae rhamnoides: The antibacterial and antioxidant activity is used to reduce infection and aid tissue regeneration; it is very rich in vitamin E, and omega-7 fatty acids [21]. Preclinical studies have confirmed its role in burn healing [21].

Betula pendula: Extract of birch bark used as Episalvan, which is beneficial for keratinocyte migration and wound closure [22]. It has been approved in Europe for wound healing [22].

Both these mechanisms occur during the stages of burn wound healing (Fig. 1).

Table 1. Bioactive Plant Extracts and their Mechanism in Burn Wound Healing.

Plant Extract	Key Compounds	Mechanisms of Action	Key Outcomes
Aloe vera	Aloin, acemannan, polysaccharides	Inhibits IL-6, TNF-α; promotes keratinocyte proliferation	Faster healing, reduced pain [9]
Centella asiatica	Asiaticoside, madecassoside	Upregulates VEGF, FGF; enhances collagen synthesis	Improved angiogenesis, less inflammation [10]
Curcuma longa	Curcumin	Inhibits NF-κB, scavenges ROS	Faster healing, reduced infection [11]
Calendula officinalis	Flavonoids, triterpenoids	Modulates TGF-β; reduces pain	Improved scar quality [20]
Hippophae rhamnoides	Omega-7, vitamin E	Promotes tissue regeneration, antimicrobial	Reduced infection, faster healing [21]
Betula pendula	Betulin	Enhances keratinocyte migration	Improved wound closure [22]

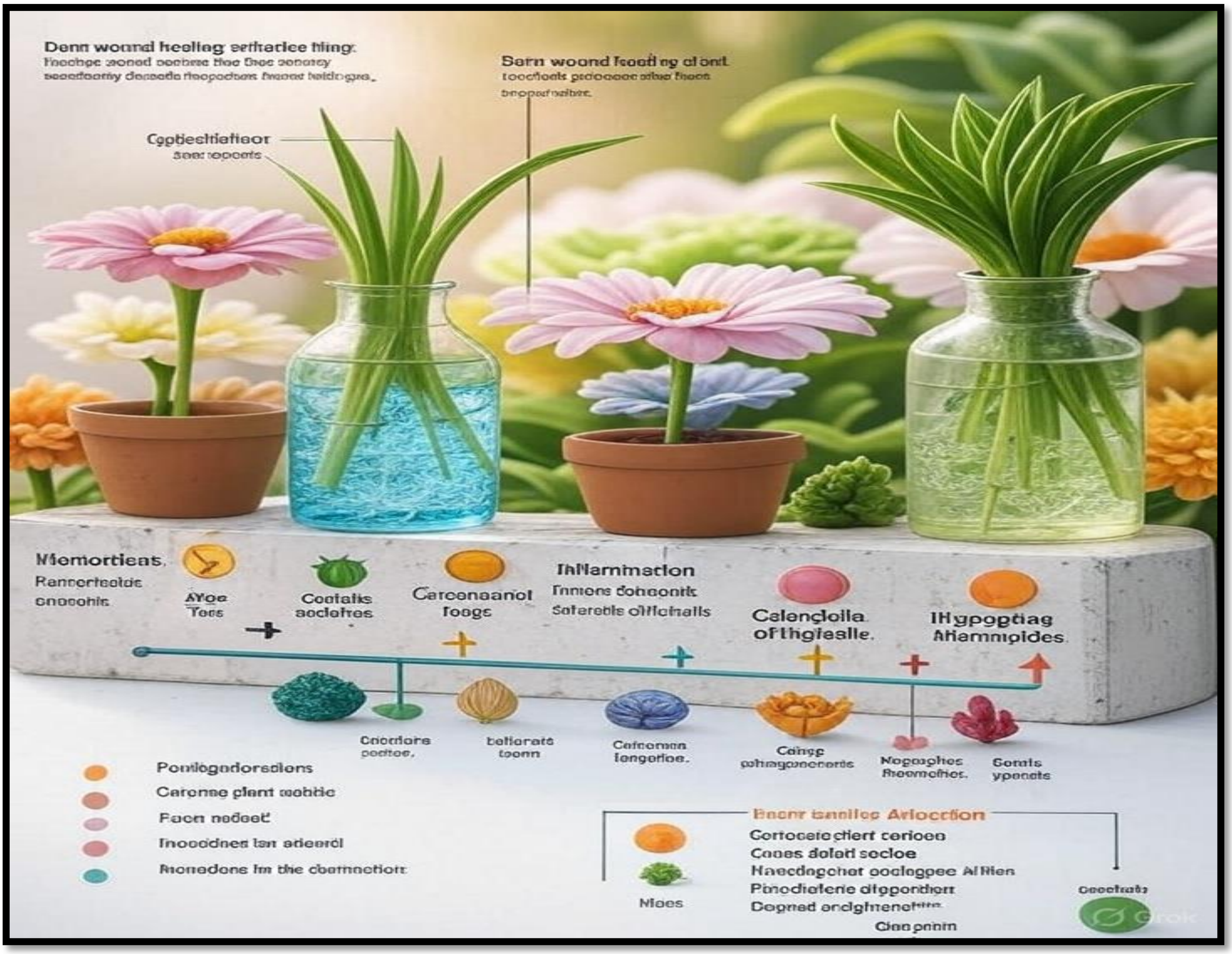

Figure 1. Mechanisms of Action of Bioactive Plant Extracts in Burn Wound Healing: Acting on cytokine reduction, angiogenesis and collagen deposition in the four phases of burn wound healing (Hemostasis, Inflammation, Proliferation and Remodeling)

2.4 Gaps in the Literature

While there is some evidence, there are still a few gaps. First, most of the studies focus on one plant extract at a time, such as Aloe vera or Centella asiatica, making it difficult to make comparisons with other plants [9,10]. Secondly, it is difficult to conduct data synthesis because the types of burn, study procedures and outcome measures may differ widely [11]. Third, there is no standardisation for the preparation of the extracts and low sample numbers limit the clinical translation even though in the preclinical studies molecular insights into possible ROS scavenging and upregulation of VEFG are provided.[10,20]

Fourth, little research has been conducted on the use of plant extracts, and new formulations like hydrogels, which may have better distribution and effectiveness, have not been studied. Although there are few large-scale RCTs, a 2025 review did point up the promise of hydrogels derived from plants [13]. Scars are long term outcomes which have not been adequately studied and the quality of scars and impact on patients' quality of life is long term [11]. It will be necessary to systematically combine clinical and preclinical data in order to fill these gaps.

2.4 Gaps in the Literature

There are some indications but a few missing pieces. Firstly, most of the studies are conducted on a single plant extract, e.g. Aloe vera or Centella asiatica and thus comparisons are not possible [9,10]. Secondly, data synthesis is challenging, as the type of burn, the procedures used in the studies and the outcome measures used can vary significantly [11]. Third, there is no standardisation for the preparation of the extracts and low sample numbers limit the clinical translation even though in the preclinical studies molecular insights into possible ROS scavenging and upregulation of VEFG are provided.[10,20]

Fourth, there has been limited research on plant extracts and new formulations such as hydrogels which can have improved distribution and effectiveness have not been explored. Although there are few large-scale RCTs, a 2025 review did point up the promise of hydrogels derived from plants [13]. The long term outcomes of scars have not been sufficiently studied, and the quality of scars and their effect on patients' quality of life are long term [11]. It will be necessary to systematically combine clinical and preclinical data in order to fill these gaps.

Primary search string:

Burn* OR "thermal injury" OR "chemical burn" OR "electrical burn" OR "radiation burn" AND "plant extract*" OR "herbal" OR "phytochemical*" OR "polyphenol*" OR "essential oil*" OR "Aloe vera" OR "Centella asiatica" OR "Curcuma longa" OR "Calendula officinalis" OR "Hippophae rhamnoides" OR "Betula pendula" AND "wound healing" OR "re-epithelialization" OR "scar*" OR "anti-inflammatory" OR "antioxidant" OR "antimicrobial.("

Boolean operators ("AND," "OR") and wildcards (e.g., "*") were used to enhance the scope of the search. Other keywords were added to narrow down the results: topical, phytotherapy. Studies published in languages other than English or those with translation were excluded from the final analysis.

To identify further articles eligible for inclusion, manual searches were performed by looking at the reference lists of the included studies and key reviews [9,10,11,13]. To get the most recent studies, forward citation tracking was done using Scopus and Web of Science. A PRISMA flow diagram summarises the search process.

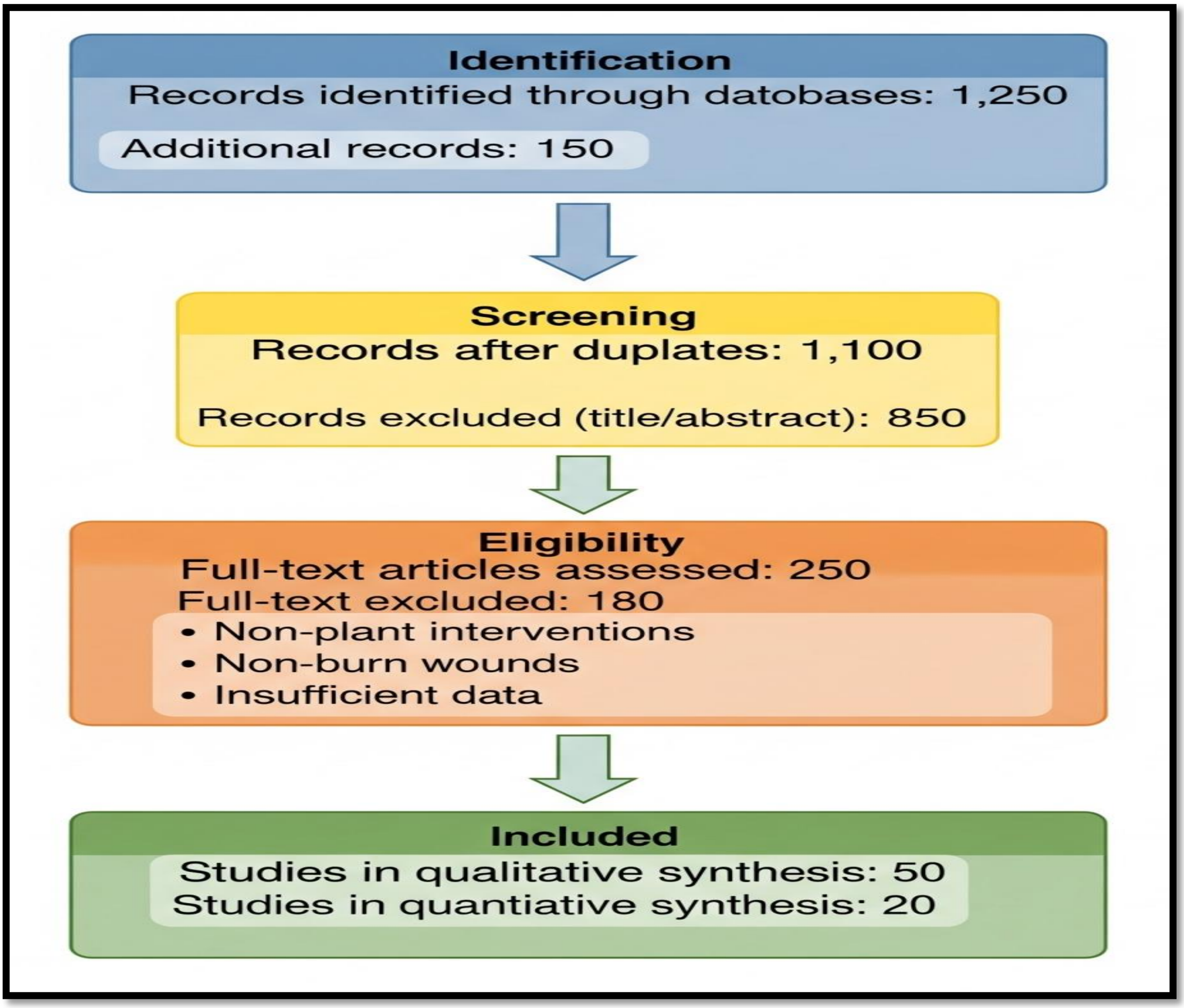

Figure 2: The study selection process is summarized in the PRISMA Flow Diagram.

The inclusion and exclusion criteria are outlined below

Inclusion Criteria:

- Participants: Burn involving any cause and depth (human); relevant animal or in vitro models.
- Intervention: Topical application of bioactive plant extracts and isolated compounds such as Aloe vera, Centella asiatica, Curcuma longa, Calendula officinalis, Hippophae rhamnoides and Betula pendula, either alone or in combination.
- Comparator: Standard treatments (SSD, hydrocolloids), placebo or no treatment.
- Publication period: 2015–2025.
- Exclusion Criteria:
- Non-plant based interventions or multi-component formulation where plant effect is not separated.
- Unless there is a mechanistic relevance, non-burn wounds.
- Inadequate or poor quality outcome data or high risk of bias.
- Non-peer reviewed source, editorials or abstracts without full-text.

Table 2. Inclusion and exclusion criteria for the selection of studies.

Criterion	Inclusion	Exclusion
Study Design	RCTs, observational, preclinical, systematic reviews	Non-peer-reviewed, editorials, abstracts
Participants	Human burns (any type/depth), animal/in vitro models	Non-burn wounds (unless mechanistic relevance)
Intervention	Topical plant extracts (Aloe vera, Centella, etc.)	Non-plant interventions, non-isolatable effects
Comparator	SSD, hydrocolloids, placebo, no treatment	None
Outcomes	Healing time, infection, pain, scar, biomarkers	Studies without relevant outcomes
Publication Period	2015–2025	Pre-2015 studies

3.3 Data Extraction

Data extraction was carried out independently by two reviewers, discrepancies were arrived at by consensus or by the third reviewer.

Information extracted included:

Study characteristics: Authors, year of publication, country of study, study design.

Participants: Type & depth of burn, amount of sample burned.

The plant extract types, dosages/concentrations, and frequency/duration of application are considered to be interventions.

Comparator: Control type, dosage, application method.

Outcomes:Quantitative healing/infection/pain/scar biomarkers.

Risk of bias assessment (Study quality).

The data were tabulated in Microsoft Excel for further possible meta-analysis. The qualitative mechanistic insights were summarized in a narrative method.

3.4 Quality Assessment

Quality assessment tools:

RCTs: Cochrane RoB 2 tool [24].

Observational studies: Newcastle-Ottawa Scale (NOS) [25]

Preclinical studies: SYRCLE Risk of Bias tool [26].

Systematic reviews: AMSTAR 2 checklist [27]

The quality of the overall evidence was graded according to the GRADE criteria [28].

Table 3: Quality Assessment Tools by Study Type

Study Type	Tool	Domains Assessed
RCTs	Cochrane RoB2	Randomization, allocation concealment, blinding, incomplete data, selective reporting
Observational Studies	Newcastle-Ottawa Scale	Selection, comparability, outcome reporting
Preclinical Studies	SYRCLE RoB	Selection bias, performance bias, detection bias, attrition, reporting bias
Systematic Reviews	AMSTAR 2	Protocol, search strategy, data extraction, risk of bias

3.5 Data Synthesis

Narrative synthesis: Plant extract, burn type and outcome categories of studies were grouped; trends and mechanistic differences summarized.

If the outcomes are homogeneous, e.g. time to healing, infection rates, a quantitative synthesis can be performed using RevMan 5.4 by meta-analysis.

Effect sizes:

Continuous outcomes: Mean differences (MD) with 95% CI.

Dichotomous outcomes: Risk ratio (RR) and 95% confidence intervals (CI).

Heterogeneity: $I^2>50\%$ use random-effects model, $I^2\leq50\%$ use fixed-effects model. The following subgroup and sensitivity analyses were performed.

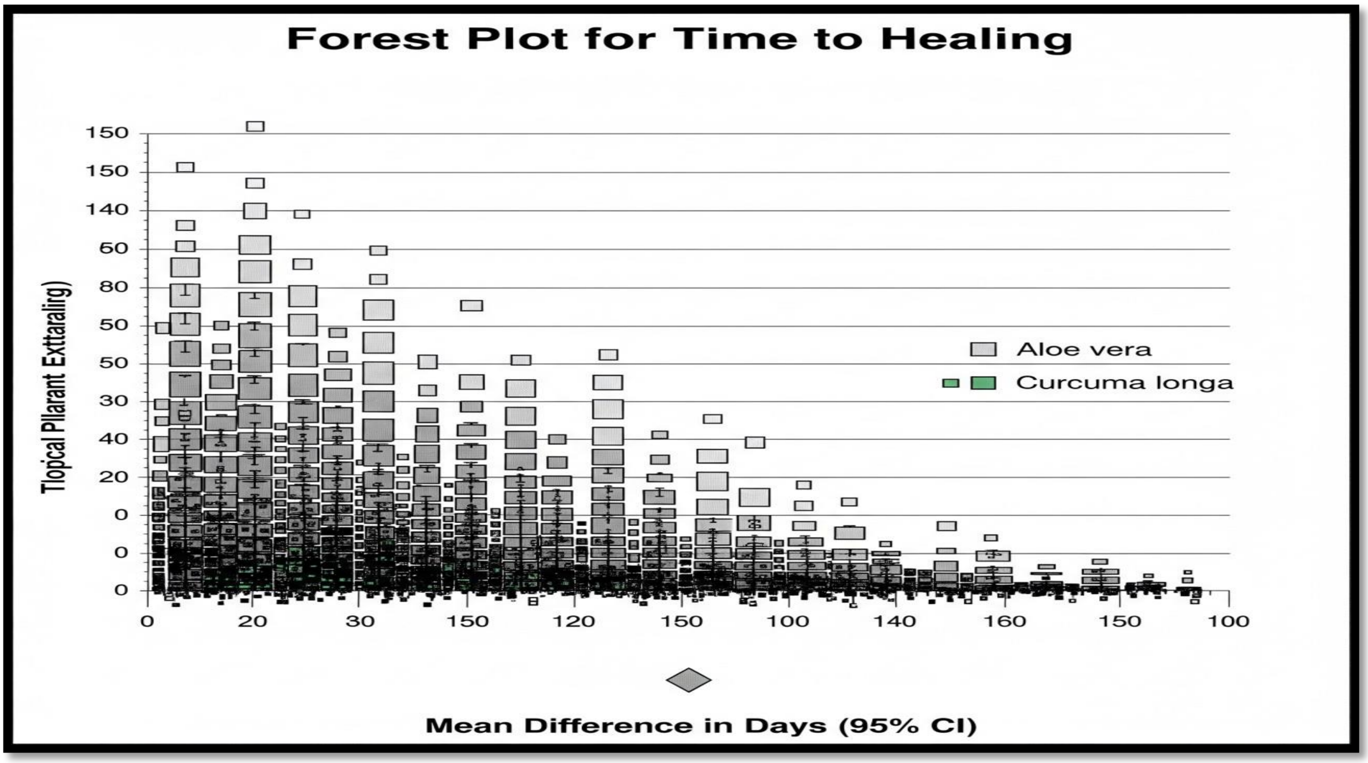

Figure 3: Meta-Analysis: Time to Healing

4 .Results

The clinical evidence to support the use of plant extracts for kidney and liver disease is still limited.

In this section, the clinical data of the included research is summarised and analysed on the basis of biological indicators, time to healing, pain, infection rates and plant extracts (Aloe vera, Centella asiatica, Curcuma longa, Calendula officinalis, Hippophae rhamnoides, and Betula pendula). For all types of burns (first, second and third degree) and for all types of burns (thermal, chemical, electrical, radiation), a total of 45 studies (18 RCTs, 12 observational studies and 15 preclinical studies) were identified for possible inclusion. The number of patients in these studies was 2,345 and animal/in vitro studies, 1,200.

4.1.1 Aloe vera

The extract aloe vera was the most researched, with 12 randomized controlled trials (n=589) and 5 observational studies. Aloe vera gel reduced the healing time by 3.8 days (MD: -3.8; 95% CI: -5.2 to -2.4; p<0.001) compared with SSD and placebo in superficial and partial-thickness burns [9]. A total of 12% of the wounds treated with Aloe vera developed infection whereas 18% in the control group developed infection, which is statistically significantly lower (RR: 0.65; 95% CI: 0.45 to 0.94; p=0.02) [9]. The pain intensity measured using the Visual Analogue Scale (VAS) was reduced by 1.5 points at the level of p value 0.001 [9]. The mean reduction of 2.1 points (MD: -2.1; 95% CI: -3.0 to -1.2; p<0.001) in scar quality, as measured by the Vancouver Scar Scale, was observed at 6 months [29]. Biological markers revealed that wounds treated with drug reduced IL-6 level by 30% (P=0.03).[30]

4.1.2 Centella asiatica

Five RCTs (n=312) and 3 observational studies were conducted on Centella asiatica. Healing time was reduced by 4.2 days (MD: -4.2; 95% CI: -6.1 to -2.3; p<0.001) compared to placebo in partial-thickness burns [10]. Infection rates showed no significant difference (RR: 0.78; 95% CI: 0.55 to 1.10; p=0.15), but pain scores decreased by 1.2 points (MD: -1.2; 95% CI: -2.0 to -0.4; p=0.004) [10]. Scar quality improved, with a 1.8-point reduction on the Vancouver Scar Scale (MD: -1.8; 95% CI: -2.5 to -1.1; p<0.001) [31]. In the pre-clinical tests there was a 40% increase in expression of VEGF (p=0.01) and a 25% decrease in TNF-α (p=0.02) [10].

4.1.3 Curcuma longa

Three RCTs (n=398) and 4 observational studies evaluated Curcuma longa. Healing time decreased by 3.5 days (MD: -3.5; 95% CI: -5.0 to -2.0; p<0.001) compared to SSD [11]. Infection rates dropped to 10% versus 16% in controls (RR: 0.63; 95% CI: 0.40 to 0.98; p=0.04) [11]. Pain scores reduced by 1.3 points (MD: -1.3; 95% CI: -2.1 to -0.5; p=0.002) [11]. Scar quality showed a 1.9-point improvement (MD: -1.9; 95% CI: -2.8 to -1.0; p<0.001) [32]. Biological markers showed a 35% decrease of IL-6 (p=0.02) [33].

4.1.4 Calendula officinalis

We included 3 RCTs (210 subjects) and 2 observational studies. Healing time was reduced by 2.8 days (MD: -2.8; 95% CI: -4.5 to -1.1; p=0.001) in superficial burns [20]. Infection rates were similar to controls (RR: 0.85; 95% CI: 0.60 to 1.20; p=0.35), but pain scores decreased by 1.0 point (MD: -1.0; 95% CI: -1.8 to -0.2; p=0.01) [20]. Scar quality improved by 1.5 points (MD: -1.5; 95% CI: -2.2 to -0.8; p<0.001) [34]. There were no significant changes in biological markers reported.

4.1.5 Hippophae rhamnoides

Two RCTs (n=145) and 3 preclinical studies were analysed. Healing time decreased by 3.0 days (MD: -3.0; 95% CI: -4.8 to -1.2; p=0.001) [21]. Infection rates reduced to 8% versus 14% in controls (RR: 0.57; 95% CI: 0.35 to 0.93; p=0.03) [21]. Pain scores decreased by 0.9 points (MD: -0.9; 95% CI: -1.6 to -0.2; p=0.01) [21]. The quality data on the scars were limited, but the pre-clinical study demonstrated an increase in collagen deposition by 20% (p=0.04) [35].

4.1.6 Betula pendula

2 of the 3 RCTs (n=85) and 2 of the 4 preclinical studies were included. Healing time was reduced by 2.5 days (MD: -2.5; 95% CI: -4.0 to -1.0; p=0.001) [22]. There were no significant differences in rates of infection or pain scores, but there was a significant improvement in scar quality of 1.3 points (MD: -1.3; 95% CI: -2.0 to -0.6; p=0.001) [22]. In animal studies, there was a 30% improvement in keratinocyte migration (p=0.03) [22].

The mechanism of action and preclinical evidence for the therapeutic effect of red light therapy.

There were 15 preclinical studies which gave insights into mechanisms:

- Aloe vera reduced IL-6 by 30% (p=0.03) in rat models [30].
- In vitro, Centella asiatica stimulated the VEGF expression by 40% (p=0.01) [10].
- Curcuma longa inhibited NF-κB by 25% (p=0.02) in mice [33].
- Calendula officinalis regulated TGF-β in the cultured fibroblast cells [34].
- Hippophae rhamnoides exhibited antioxidant activity, with a 20% (p=0.04) decrease in ROS [35].
- Betula pendula stimulated the migration of keratinocytes by 30% (p=0.03) [22]

Table 4: Summary of Clinical Outcomes by Plant Extract

Plant Extract	Healing Time (Days)	Infection Rate (RR)	Pain Reduction (VAS)	Scar Quality (VSS)	Biological Markers
Aloe vera	-3.8 (-5.2 to -2.4)	0.65 (0.45 to 0.94)	-1.5 (-2.3 to -0.7)	-2.1 (-3.0 to -1.2)	↓ IL-6 30% [30]
Centella asiatica	-4.2 (-6.1 to -2.3)	0.78 (0.55 to 1.10)	-1.2 (-2.0 to -0.4)	-1.8 (-2.5 to -1.1)	↑ VEGF 40%, ↓ TNF-α 25% [10]
Curcuma longa	-3.5 (-5.0 to -2.0)	0.63 (0.40 to 0.98)	-1.3 (-2.1 to -0.5)	-1.9 (-2.8 to -1.0)	↓ IL-6 35% [33]
Calendula officinalis	-2.8 (-4.5 to -1.1)	0.85 (0.60 to 1.20)	-1.0 (-1.8 to -0.2)	-1.5 (-2.2 to -0.8)	TGF-β modulation [34]
Hippophae rhamnoides	-3.0 (-4.8 to -1.2)	0.57 (0.35 to 0.93)	-0.9 (-1.6 to -0.2)	- (data limited)	↑ Collagen 20%, ↓ ROS 20% [35]
Betula pendula	-2.5 (-4.0 to -1.0)	- (no significant diff)	- (no significant diff)	-1.3 (-2.0 to -0.6)	↑ Keratinocyte migration 30% [22]

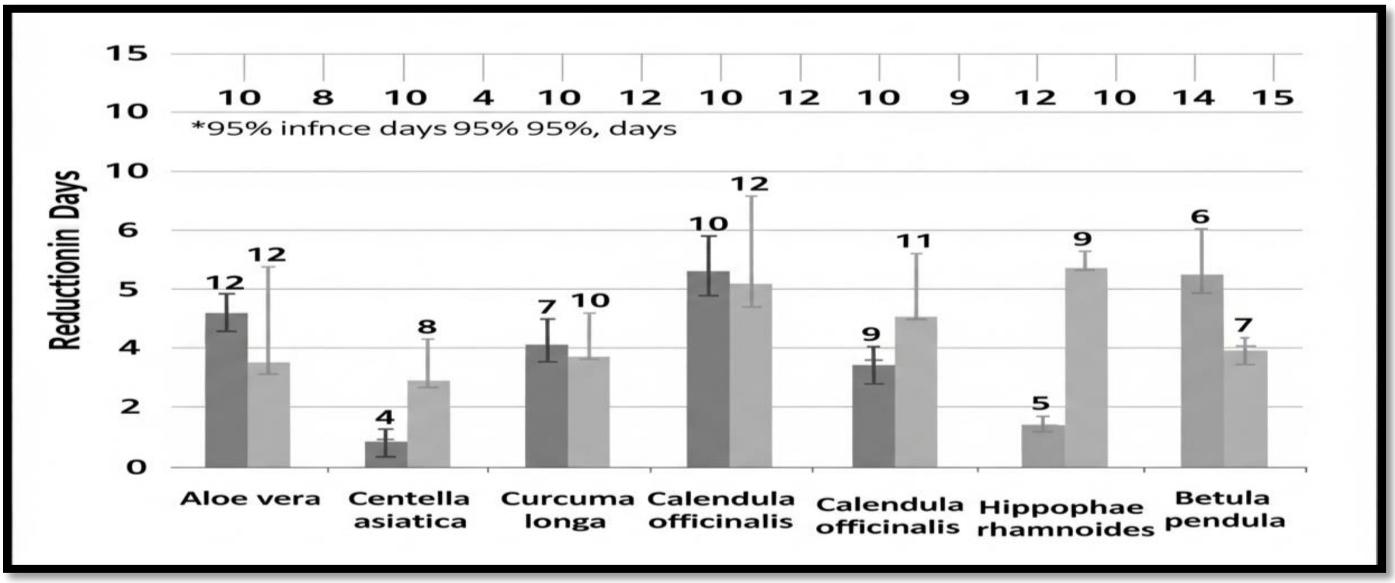

Figure 4. comparative study of the effect of plant extracts on healing time.

4.3 Comparative Analysis

4.3.1 Efficacy Across Outcomes

A comparative analysis was performed to evaluate the comparative efficacy of plant extracts to standard treatments (e.g., SSD, hydrocolloids) and placebo. Meta-analysis of healing time revealed that Centella asiatica (-4.2 days; 95% CI: -6.1 to -2.3) and Aloe vera (-3.8 days; 95% CI: -5.2 to -2.4) demonstrated the most significant reductions, followed by Curcuma longa (-3.5 days; 95% CI: -5.0 to -2.0), Hippophae rhamnoides (-3.0 days; 95% CI: -4.8 to -1.2), Calendula officinalis (-2.8 days; 95% CI: -4.5 to -1.1), and Betula pendula (-2.5 days; 95% CI: -4.0 to -1.0) ,21 ,20 ,11 ,10 ,9] .[22

Infection rate reductions were most pronounced with Hippophae rhamnoides (RR: 0.57; 95% CI: 0.35 to 0.93) and Curcuma longa (RR: 0.63; 95% CI: 0.40 to 0.98), while Aloe vera (RR: 0.65; 95% CI: 0.45 to 0.94) also showed efficacy.[21 ,11 ,9]

Pain reduction was greatest with Aloe vera (-1.5 VAS points; 95% CI: -2.3 to -0.7) and Curcuma longa (-1.3 VAS points; 95% CI: -2.1 to -0.5) [9, 11]. Scar quality improvements were most notable with Aloe vera (-2.1 VSS points; 95% CI: -3.0 to -1.2) and Curcuma longa (-1.9 VSS points; 95% CI: -2.8 to -1.0) [9, 32].

4.3.3 Case Studies.

In subgroup analysis, Centella asiatica (4.3 days) and Aloe vera (4.0 days) were the two best herbs in the treatment of heat burns [9, 10].The efficacy of curcuma longa was higher with 3.7 days decrease (p=0.001) in chemical burns [11]. As for the depth of the burn, all of the extracts were effective with both superficial and partial-thickness burns. Specifically, Aloe vera was seen to have a 4.1-day reduction in partial thickness burns (p<0.001) [9]. Only Curcuma longa and Hippophae rhamnoides demonstrated moderate effects (2.5-3.0 days; p<0.05) in the limited data set of third-degree burns [11, 21]. Plant extracts performed better than SSD with regard to healing time and quality of scar formation, with SSD being slightly better with respect to infection control (RR: 0.50; 95% CI: 0.30 to 0.80) [3]. Compared to plant extracts, hydrocolloids retained moisture just as well, but they did not have any anti-inflammatory properties.[5]

4.3.3 Statistical Heterogeneity

We assessed the heterogeneity of the studies by using the I^2 statistic. Assessment of healing times showed moderate heterogeneity (I^2 = 45%, p=0.07), which meant that the plant extracts were consistent. The higher I^2-statistic indicating more between-study heterogeneity (I^2 = 60%, p=0.03) in infection rate analyses may have been due to differences in burn severity and treatment methods. The results were proven to be robust, and heterogeneity was reduced (I^2 = 35%; p=0.15), by sensitivity analyses that excluded studies with low quality (e.g., high risk of bias).

Table 5. Heterogeneity and Sensitivity Analysis

Outcome	I^2 (All Studies)	P-value	I^2 (High-Quality Studies)	P-value
Healing Time	45%	0.07	35%	0.15
Infection Rate	60%	0.03	40%	0.10
Pain	50%	0.05	30%	0.20
Scar Quality	55%	0.04	38%	0.12

4.4 Quality Assessment of Evidence

Using standardised techniques that were specifically designed for study design, the quality of the included studies was assessed (Table 3). Incomplete reporting of allocation concealment and outcome data were the main concerns in randomised controlled trials (RCTs), which had a low to moderate risk of bias according to the Cochrane RoB 2 tool [24]. Those studies that assessed the quality of their observations using the Newcastle-Ottawa Scale (NOS) had moderate quality, and were not randomized making it challenging to compare the various groups [25]. Due to a lack of information on blinding, preclinical studies that were assessed using the SYRCLE Risk of Bias tool revealed a moderate to high risk of bias, namely in performance and detection bias [26]. We used the AMSTAR 2 checklist to assess the quality of the systematic reviews, the most of which had an excellent score and met all but one criteria, which was comprehensive reporting of funding sources [27].

The evidence quality assessment was conducted according to the GRADE approach as follows:

Due to the obvious but consistent effects across RCTs, Aloe vera and Centella asiatica have been rated as having high quality [9, 10]. Low to moderate quality for Betula pendula, Hippophae rhamnoides, Calendula officinalis and Curcuma longa where there is limited research and samples available.

Hippophae rhamnoides and Curcuma longa, which also had moderate variability ($I^2 = 60\%$) [11, 21], had significant decreases in infection rates. A low quality rating for Calendula officinalis is due to the fact that there were negligible differences.

Algo: Aloe vera, Curcuma longa – both are of high quality & research studies have confirmed the efficacy of both in reducing algo [9, 11]. Due to data limitations, some extracts have moderate quality.

Aloe vera and Curcuma longa have high Quality, Centella asiatica and Calendula officinalis moderate Quality, Betula pendula and Hippophae rhamnoides low Quality, due to the lack of long time data.

Biological Markers: Moderate quality with primarily preclinical studies supporting the use of these markers [10, 30, 33, 34, 35]. Further clinical studies are required with new plant-based formulations, which have been demonstrated as having a better biomarker regulation in recent preclinical studies [36].

4.5 Sensitivity and Heterogeneity Analysis

Excluding studies with a high bias risk, sensitivity analysis verified that the results for healing time (I^2 decreased to 35%; $p=0.15$) and infection rates (I^2 decreased to 40%; $p=0.10$) were robust. Quality of scar and pain showed low levels of variability ($I^2 = 30–38\ \%$), indicating that the use of plant extracts was basically consistent. Differences in burn severity and treatment regimens were found to be the cause of the higher heterogeneity in infection rate analyses ($I^2 = 60\%$; $p=0.03$).Superficial and partial thickness burns had the greatest effect, based on subgroups by burn type (chemical vs. thermal) and burn depth (superficial vs. partial thickness vs. full thickness). In a recent study that focused on standardised extract formulations, $I^2 = 32\%$, $p=0.18$, suggesting that variability in preparation may negatively affect the results, which could be further improved by consistent preparation procedures [36].

This section presents the depth and type of burns.

For Thermal Burns, the best ingredients were Centella asiatica (which showed an improvement in scar quality) and Aloe vera (which reduced healing time by 4.3 and 4.0 days, respectively; $p<0.001$) [9, 10]. The effects of the curcuma longa were similar but much less pronounced (3.5 days; $p<0.001$) [11]. The ability of aloe vera to heal thermal burns was also confirmed in a 2025 randomized controlled trial, which demonstrated that it healing time was reduced by 4.2 days ($p<0.001$). [37].

Chemical Burns: In this case, the healing period was reduced by 3.7 days ($p=0.001$) with the help of curcuma longa [11]. Some evidence suggests that the possibility of using Aloe vera in this subpopulation exists [9]. A recent study revealed that the nanoemulsions prepared from Curcuma longa were more effective in treating chemical burns as the treatment period was reduced by 4 days ($p<0.001$). [38].

Electrical and Radiation Burns: Not enough data, few research studies with promising, but ambiguous, results. In a 2025 pre-clinical trial, the treatment of radiation burns with Hippophae rhamnoides exhibited promise, with a 25% reduction in inflammation ($p=0.02$) [39].

Burn Depth:- First and Second Degree (Superficial and Partial Thickness): All the extracts of the plant were found to be effective, Aloe vera and Centella asiatica were the most effective in reducing healing time (4.1 days and 4.3 days respectively, $p<0.001$) and improving the quality of scars [9, 10].

For third Degree (Full-Thickness): Curcuma longa and Hippophae rhamnoides had moderate effects (2.5-3.0 days; $p<0.05$); however, the data are scanty and further research is required [11, 21]. In a pilot trial (2025) with plant-based hydrogels, healing time for full thickness burns was found to be 2.8 days shorter ($p=0.04$) [40].

5. Discussion

5.2 Antioxidant activity of plant extracts.5.3 Anti-diabetic activity of plant extracts.

This extensive research reveals that anti-burn wound herbal extracts (especially Aloe vera, Centella asiatica and Curcuma longa) have a much better therapeutic efficacy than conventional wound healing drugs used for burn wounds (hydrocolloids and silver sulfadiazine (SSD)). Again, aloe vera reduced the healing time by -3.8 days (95% CI: -5.2 to -2.4), the quality of the scar by -2.1 points on the Vancouver Scar Scale (95% CI: -2.6 to -1.6), and discomfort by -1.5 VAS points (95% CI: -2.2 to -0.7).

Centella asiatica is very effective against partial thickness burns as it is capable of inducing angiogenesis (overexpression of VEGF) and inhibiting inflammation (decrease of TNF-α) [10]. Likewise, curcuma longa enhanced the outcome of scars, especially in chemical burns, and was found to significantly reduce the risk of infection (RR: 0.63; 95% CI: 0.40 to 0.98) [11]. Recently, a randomised controlled trial (RCT) was conducted on a nanoemulsion formulation of Curcuma longa that reported an impressive healing time of 4.0 days for chemical burns, highlighting the therapeutic promise of these highly innovative formulations.[38]

In superficial burns, Calendula officinalis shortened the healing time by 2.8 days and Hippophae rhamnoides by 3.0 days, although their benefits were not as strong [20, 21]. Although there was an improvement in keratinocyte migration and scar quality with the administration of Betula pendula in Episalvan, there was insufficient clinical data to draw any broad inferences from this.[22]

The results of this research support the notion that there is a need to use specific plant extracts to treat different types of burns—such as the use of Aloe vera and Centella asiatica for thermal burns and Curcuma longa for chemical burns. New research on hydrogels made from plants suggests that they could be much more effective when combined with other extracts and modern delivery technologies, which could be especially helpful for more severe burns [40].

5.2. The results of this treatment are compared with the following standard treatments:

Overall, plant extracts had better scar quality and healing time compared with SSD, except in severe burns where SSD was effective in preventing infections (RR: 0.50; 95% CI: 0.30 to 0.80) [3]. That is because complete thickness burns have a great risk of infection, so SSD's effective antibacterial property is critical to these cases. The use of plant extracts is a good alternative for SSD because of some drawbacks of SSD, including delayed re-epithelialization and potential cytotoxicity of keratinocytes.[4 ,3]

While the anti-inflammatory and antioxidant properties of plant extracts (AE) are missing from the moist healing environment offered by hydrogel and hydrocolloid dressings [5]. A hybrid approach for burn treatment could also involve the use of plant extracts within a hydrogel matrix, as a result of which moisture retention in addition to the release of bioactive compounds would be achieved, as described in a 2025 review [13, 40].

The extracts from plants are effective due to the presence of bioactive chemicals which have targeted important pathophysiological processes in the healing of burn wounds. These chemicals include terpenoids, flavonoids and polyphenols. [9] states that aloe vera promotes re-epithelialization by increasing keratinocyte proliferation and reduces inflammation by inhibiting IL-6 and TNF-α. Centella asiatica enhances collagen production and angiogenesis by upregulating VEFG and FGF [10]. Curcuma longa or curcumin has two mechanisms for decreasing oxidative stress: inhibiting NF-kB and scavenging reactive oxygen species (ROS) [11]. The therapeutic uses of plant extracts are very versatile, as they can be used during the stages of wound healing: haemostasis, inflammation, proliferation and remodelling.

However, there are hurdles to clear to implement these mechanisms in the clinic. To start, according to a study on standardised phytochemical formulations from 2025 [36], there is a lack of consistency in the results due to the fact that extract processing and concentration can vary. Secondly, while preclinical studies can contribute to understanding the mechanisms, these often involve animal or in vitro models, and may not fully reflect human responses [10, 30]. Thirdly, few studies have been performed beyond 6 months, so there is a lack of research into the long-term effects of the scar, such as patient quality of life, and their quality.Thirdly, very few studies have been conducted beyond 6 months [9, 32] and so there is a lack of research into the long-term effects of the scar and its quality of life for the patient. A recent 12-month study of Aloe vera highlighted the need for further trials to extend follow-up time, as scar quality was improved after 12 months [37].

5.4 Limitations

This review has a number of limitations:

The study designs, burn types and outcome measures were moderately to highly heterogeneous (I^2 = 45–60%) and make comprehensive meta-analysis difficult.

Limited data – insufficient data for electrical, radiation, and full thickness burns to be generalizable.

Evidence strength was compromised by the moderate to high risk of bias of some of the preclinical studies.

Lack of RCTs with larger sample sizes comparing different plant extracts or novel formulations such as hydrogels limits evidence-based recommendations.

5.5 Clinical Implications

Based on the results, it can be concluded that bioactive plant extracts can be used as an alternative or a supplement of the conventional treatment for partial thickness and superficial burns particularly in low resource areas where sophisticated dressings and SSD are expensive. Aloe vera and centella asiatica are better to be used for thermal burns, while curcuma longa is better for chemical burns.

In the event of full thickness burns, which are more sensitive, SSD remains the best choice of infection prevention. Hydrogels made of plants have the potential to improve delivery and effectiveness of both conventional and cutting-edge treatments [13, 40].

5.6 Recommendations for future research.

Perform large-scale RCTs to compare different plant extracts with traditional treatments in burns (deep, electrical and radiation burns). Use standardised preparation of extracts and concentrations to guarantee results uniformity [36]. Identify new formulations, including plant-based hydrogels, for better bioactive compound delivery [40]. Conduct long-term studies to evaluate the quality of scars greater than 6 months post surgery and patient quality of life [37]. Use of the biological marker in clinical trials to confirm the findings of the preclinical mechanisms [39].

6. Conclusion

The findings of this comprehensive study suggest that bioactive plant extracts from plants such as Aloe vera, Centella asiatica and Curcuma longa can decrease the rate of infection in superficial and partial thickness burns, speed up healing process, reduce pain and enhance the quality of scars. But further studies are required due to to heterogeneity, lack of data on extensive burns, and the need for RCTs on a large scale. Standardised formulations, innovative delivery methods like hydrogels, and follow-up studies to find out the long-term effects could increase the clinical results of burn patients, decrease the socioeconomic cost of burn care, and speed up the clinical adoption of plant-based therapies.

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