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Review Article

Development and Evaluation of Bakuchi (Babchi) Oil–Loaded Hydrogel for the Treatment of Psoriasis

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Abstract

Psoriasis is a chronic inflammatory skin disorder characterized by keratinocyte hyperproliferation, immune dysregulation, oxidative stress, and impaired skin barrier function. Conventional topical therapies often show limitations such as poor penetration, local irritation, frequent application, and low patient compliance. Herbal-based topical systems have gained considerable attention due to their improved safety and therapeutic potential. Bakuchi oil, obtained from Psoralea corylifolia, contains bioactive constituents such as bakuchiol and psoralen that exhibit anti-inflammatory, antioxidant, antimicrobial, and antiproliferative activities beneficial in psoriasis management. The present review highlights the pathophysiology of psoriasis, limitations of conventional topical therapy, and the therapeutic rationale of Bakuchi oil–loaded hydrogels. Hydrogel systems provide enhanced skin hydration, improved spreadability, prolonged drug retention, and controlled drug release, thereby improving topical drug delivery and patient compliance. Advanced approaches such as nanoemulgels and nanoparticle-loaded hydrogels further enhance skin permeation and therapeutic efficacy. Overall, Bakuchi oil–loaded hydrogel systems represent a promising herbal strategy for effective and patient-friendly topical management of psoriasis, although further clinical investigations are required to establish long-term safety and efficacy.

Keywords: Psoriasis, Bakuchi oil, Bakuchiol, Hydrogel, Topical drug delivery, Psoralea corylifolia, Herbal formulation, Nanoemulgel, Antipsoriatic activity.

INTRODUCTION

Topical medication delivery is essential for treating mild to moderate cases of psoriasis and can be a helpful adjunct to systemic therapy for more severe cases. Nonetheless, a significant worry with topical therapy for psoriasis is its potency [1]. The chronic autoimmune type-1 disorder known as psoriasis is typically seen in adults and teens. This disease affects 2.7% of the population. Rashes, wounds, Infections, and individuals with pre-existing autoimmune conditions like rheumatoid arthritis can exacerbate psoriasis [2]. Rapid cell accumulation on the skin, resulting in erythematous plaques and (red) papules with silver scales, is a sign of psoriasis. The skin is covered in red, scaly plaques that can occasionally itch and hurt. Psoriasis lesions can appear on any area of the skin, including the scalp, neck, feet, hands and face. They usually start on joints like the elbows and knees [3]. Psoriasis is closely associated with diabetes and cardiovascular disorders, primarily caused by aberrant epidermal hyperproliferation and keratinocyte differentiation. It advances by inducing an immune response in the host, which may be brought on by the proliferation of keratin mediating cells and their appearance on the skin's surface [4]. Some histopathological conditions linked to psoriasis include excess Th-17 and Th-1 abnormal keratinocyte differentiation epidermal hyperproliferation angiogenesis with blood vessel dilatation [5]. As secondary metabolites found in aromatic plants, essential oils are complex substances that have two or more bioactive in comparatively higher concentrations (20–70%) [6]. Among these essential oils is Bakuchi oil, which offers a less harsh alternative to synthetic medications prescribed for psoriasis treatment. The Psoralea corylifolia plant's seeds are used to make bakuchi oil. Because of its antioxidant, antimicrobial, and anti inflammatory qualities, Bakuchi oil has been recommended for the treatment of skin situations in Ayurveda and traditional Chinese medicine. This

essential oil, which is obtained from the seeds of P. coprolalia (a member of the Leguminosae family), is a phototherapeutic agent whose main constituents are furocoumarins, which inhibit DNA synthesis and slow down cell proliferation, thus having an anti-psoriatic effect [7]. The major composition of Bakuchi essential oil is psoralen, is psoralen and bakuchiol, which have anti-inflammatory and antimicrobial effects [8]. One of the bioactive moiety from P. corylifolia psoralen is tricyclic furanocoumarin. It has major application in the treatment of psoriasis [9]. Applications for hydrogels in pharmacy and medicine are growing because of their favourable physicochemical properties, intended interaction with living environments, and advantageous biocompatibility [10]. Three-dimensional, hydrophilic polymeric networks known as hydrogels are proficient at retaining large quantities of biological fluids or water [11]. They are able to detect changes in temperature, pH, or metabolite concentration and release their load in response [12]. Available literature data provides that Bakuchi oil can be effectively used for the treatment of psoriasis. Marwaha TK. *et al.,* created emulgel, a biphasic drug delivery system using bakuchi oil, an herbal remedy for psoriasis. Dr. A. Abdul Hasan Sathali *et al.,* developed bakuchi oil loaded transethosome to enhance anti-fungal and anti-psoriatic properties through the formulation, development, and characterization [15]. The goal of the present learning was to study bakuchi oil's anti-inflammatory properties in the hydrogel formulation with good spreadability, excellent permeation capability, suitable pH and viscosity. On the other hand, applying a pure essential oil at the application site can be challenging. Therefore, hydrogels were created to increase the amount of time that active substances and skin come into contact.

Psoriasis: Pathophysiology and Therapeutic Targets Relevant to Topical Formulation [16-25]

Psoriasis is a chronic, immune-mediated inflammatory skin disorder characterized by well-demarcated erythematous plaques with silvery scales, resulting from a complex interplay between genetic predisposition, immune dysregulation, and environmental triggers. The disease is no longer considered merely a disorder of keratinocyte hyperproliferation; rather, it is now well established as a T-cell–driven inflammatory condition in which both innate and adaptive immune responses play a central role. Understanding the underlying pathophysiology is essential for identifying therapeutic targets that can be effectively modulated through topical drug delivery systems. At the molecular level, the interleukin-23 (IL-23)/T helper 17 (Th17) axis is recognized as the core pathogenic pathway in psoriasis. Environmental or endogenous triggers activate dendritic cells in the skin, which subsequently secrete IL-23 and IL-12. IL-23 promotes the differentiation and survival of Th17 cells, leading to the excessive production of pro-inflammatory cytokines such as IL-17A, IL-17F, IL-22, and tumor necrosis factor-α (TNF-α). These cytokines act directly on keratinocytes, inducing their hyperproliferation, abnormal differentiation, and the release of additional inflammatory mediators and chemokines. This creates a self-amplifying inflammatory loop that sustains chronic plaque formation. From a topical therapy perspective, these cytokines and their downstream signaling pathways (e.g., NF-κB, STAT3, and MAPK pathways) represent important molecular targets for anti-inflammatory and immunomodulatory agents. Keratinocyte dysfunction is another hallmark of psoriatic pathology. In normal skin, keratinocytes undergo a tightly regulated differentiation process, but in psoriasis, this process is markedly accelerated, leading to incomplete maturation and parakeratosis. The rapid turnover of keratinocytes contributes to thickened plaques and scaling, which also pose a significant barrier to drug penetration. Therefore, topical formulations must be designed not only to deliver active agents capable of normalizing keratinocyte proliferation but also to overcome the altered stratum corneum architecture. Agents with anti-proliferative, keratolytic, or differentiation-modulating properties are particularly relevant targets in topical antipsoriatic therapy. Oxidative stress also plays a significant role in the initiation and progression of psoriasis. Increased levels of reactive oxygen species (ROS) have been reported in psoriatic lesions, along with reduced antioxidant defense mechanisms. Oxidative stress contributes to keratinocyte activation, cytokine release, and amplification of inflammatory responses. Consequently, antioxidants have gained attention as supportive therapeutic agents that can complement anti-inflammatory strategies. For topical formulations, incorporating antioxidants can help reduce oxidative damage at the lesion site while improving skin barrier recovery. Another critical pathological feature of psoriasis is impairment of the skin barrier function. Psoriatic skin exhibits altered lipid composition, increased trans epidermal water loss, and reduced hydration, all of which aggravate inflammation and scaling. Barrier dysfunction not only worsens disease severity but also affects patient comfort and treatment adherence. From a formulation standpoint, restoring barrier integrity and hydration is a key therapeutic goal. Topical systems that provide occlusion, moisturization, and prolonged residence time on the skin—such as hydrogels—are particularly advantageous in this context. The inflammatory milieu in psoriasis also involves increased infiltration of immune cells, including neutrophils, macrophages, and T lymphocytes. Neutrophil accumulation leads to the formation of Munro's microabscesses, a histopathological hallmark of psoriasis. Targeting chemokines and adhesion molecules that regulate immune cell recruitment represents another important therapeutic approach. Although systemic biologics directly inhibit cytokines such as TNF-α, IL-17, and IL-23, topical formulations aim to locally modulate these

pathways with fewer systemic side effects. Natural products and phytoconstituents with multi-target anti-inflammatory and immunomodulatory effects are therefore of particular interest for topical psoriasis management. In the context of topical drug delivery, the pathological features of psoriasis—namely inflammation, hyperkeratosis, oxidative stress, and barrier dysfunction—define the key therapeutic targets. An ideal topical formulation should (i) suppress local inflammation and cytokine release, (ii) normalize keratinocyte proliferation and differentiation, (iii) counteract oxidative stress, and (iv) restore skin hydration and barrier function. Advanced topical delivery systems such as hydrogels, nanoemulgels, and lipid-based nanocarrier-loaded gels are well suited to address these requirements. Hydrogels, in particular, provide a hydrated microenvironment, enhance patient acceptability, and can be engineered to control drug release and improve penetration into thickened psoriatic plaques. Overall, a clear understanding of psoriasis pathophysiology directly informs rational topical formulation design. By aligning formulation strategies with disease-specific therapeutic targets—especially the IL-23/IL-17 inflammatory axis, keratinocyte hyperproliferation, oxidative stress, and barrier dysfunction—topical drug delivery systems can achieve improved efficacy, safety, and patient compliance in the long-term management of psoriasis.

Limitations of Conventional Topical Therapy and Why Hydrogels Help [26-37]

Topical therapy remains the cornerstone of treatment for mild to moderate psoriasis and is widely used as adjunctive therapy in more severe disease. Conventional topical formulations such as ointments, creams, lotions, and solutions commonly contain corticosteroids, vitamin D analogues, retinoids, keratolytic agents, or calcineurin inhibitors. Although these formulations are clinically effective, their long-term use is often limited by several formulation-related, biological, and patient-related drawbacks. One of the major limitations of conventional topical therapy is poor patient adherence. Ointments, which are highly occlusive and effective for reducing trans epidermal water loss, are greasy, sticky, and cosmetically unacceptable to many patients. Creams and lotions, while more acceptable, often require frequent application and may not provide sufficient residence time at the site of action. Poor adherence significantly reduces therapeutic outcomes in chronic conditions like psoriasis, where long-term, consistent application is essential. Another important limitation is inadequate drug penetration through psoriatic skin. Psoriatic plaques are characterized by hyperkeratosis, thickened stratum corneum, and abnormal lipid organization, all of which act as formidable barriers to drug diffusion. Conventional topical formulations frequently fail to deliver sufficient drug concentrations to deeper epidermal layers, where inflammatory and immune-mediated processes are active. As a result, higher drug concentrations or repeated applications are required, increasing the risk of local and systemic adverse effects. For example, prolonged use of potent topical corticosteroids can lead to skin atrophy, telangiectasia, hypothalamic–pituitary–adrenal axis suppression, and tachyphylaxis. Similarly, vitamin D analogues may cause local irritation and hypercalcemia when overused. These safety concerns often restrict the duration and intensity of conventional topical therapy. Local irritation and sensitization are additional challenges associated with traditional topical formulations. Many conventional products contain organic solvents, surfactants, or penetration enhancers that can disrupt the already compromised skin barrier in psoriasis. This may lead to burning, stinging, erythema, and worsening of inflammation, particularly when applied to sensitive areas such as the face, flexures, or genital regions. In psoriatic skin, where barrier dysfunction and increased trans epidermal water loss are already present, such irritation further compromises patient comfort and adherence. Moreover, the inability of conventional formulations to maintain optimal skin hydration reduces their supportive role in restoring barrier function, which is a critical component of psoriasis management. Another significant drawback of conventional topical therapy is poor control over drug release and distribution. Most creams and ointments provide an immediate release of the active ingredient upon application, leading to an initial burst effect followed by rapid decline in drug concentration. This fluctuating drug exposure may be insufficient to maintain sustained anti-inflammatory activity throughout the dosing interval. Furthermore, uneven spreading and poor retention at the application site can result in variable dosing, particularly over large or irregularly shaped psoriatic plaques. These limitations highlight the need for advanced topical delivery systems capable of providing controlled release, uniform drug distribution, and prolonged skin contact. In contrast to conventional topical formulations, hydrogels offer several advantages that directly address the challenges associated with psoriasis therapy. Hydrogels are three-dimensional, hydrophilic polymer networks capable of retaining large amounts of water while maintaining structural integrity. Their high-water content provides an immediate cooling and soothing effect, which is particularly beneficial in inflamed and pruritic psoriatic lesions. By enhancing skin hydration, hydrogels help soften hyperkeratotic plaques, reduce scaling, and improve drug diffusion through the stratum corneum. Improved hydration also supports restoration of the skin barrier, thereby contributing to both symptomatic relief and disease control. From a formulation perspective, hydrogels are highly versatile systems that can accommodate a wide range of active pharmaceutical ingredients, including hydrophilic drugs, lipophilic drugs (with appropriate solubilization or nano-carrier incorporation), and phytoconstituents. Unlike greasy

ointments, hydrogels are non-occlusive, non-staining, and cosmetically elegant, which significantly improves patient acceptance and compliance. Their ease of application and rapid absorption without leaving residue make them suitable for use on visible body areas and during daytime, addressing a major limitation of traditional formulations. Hydrogels also offer superior control over drug release and residence time at the site of application. The polymeric network can be tailored to modulate viscosity, swelling behaviour, and diffusion characteristics, enabling sustained and controlled drug release. This prolonged local drug availability reduces the need for frequent application and minimizes peak-related adverse effects. Additionally, hydrogels can be engineered to incorporate advanced drug delivery systems such as nano emulsions, solid lipid nanoparticles, nanostructured lipid carriers, or polymeric nanoparticles. Such hybrid systems (e.g., nanoemulgels or nanoparticle-loaded hydrogels) combine the penetration-enhancing properties of nanocarriers with the patient-friendly attributes of hydrogels, resulting in improved skin deposition and therapeutic efficacy. Another key advantage of hydrogels is their ability to maintain close contact with the skin surface, even on uneven or mobile areas. Their viscoelastic nature ensures good spread ability and adhesion without occlusion, allowing uniform drug distribution over psoriatic plaques. This is particularly important in chronic plaque psoriasis, where lesions are often thick, dry, and uneven. Furthermore, hydrogels are generally associated with a lower risk of irritation, as they are typically formulated at skin-compatible pH and contain fewer aggressive excipients. This makes them suitable for long-term use and for application on sensitive skin areas.In summary, while conventional topical therapies play an essential role in psoriasis management, their effectiveness is often limited by poor penetration, low patient adherence, local adverse effects, and lack of controlled drug delivery. Hydrogels overcome many of these limitations by providing enhanced hydration, improved drug penetration, controlled release, superior cosmetic acceptability, and better patient compliance. Owing to these advantages, hydrogel-based topical systems represent a promising and rational approach for improving the therapeutic outcomes of antipsoriatic agents, particularly in chronic and long-term treatment settings.

Table 1: Comparison Between Conventional Topical Formulations and Hydrogel-Based Systems for Psoriasis Treatment

Parameter	Conventional Formulations	Hydrogels
Greasiness	High	Low
Patient compliance	Poor	Good
Drug release	Immediate	Controlled
Spreadability	Moderate	Excellent
Skin hydration	Low	High
Cosmetic acceptability	Poor	Better
Irritation potential	Higher	Lower

Skin Permeation Mechanism of Hydrogel-Based Systems [38-42]

Topical drug delivery through psoriatic skin is highly challenging because of hyperkeratosis, thickened stratum corneum, and abnormal lipid organization. Hydrogel-based systems enhance skin permeation primarily through hydration of the stratum corneum, which loosens tightly packed corneocytes and increases drug diffusion across the epidermis. The high-water content of hydrogels softens psoriatic plaques and promotes swelling of keratinized tissue, thereby facilitating penetration of active constituents into deeper skin layers.

Penetration enhancers such as Transcutol-P, ethanol, propylene glycol, and essential oils further improve permeation by disrupting intercellular lipid packing and increasing drug solubility within the skin barrier. Additionally, nano-sized carriers incorporated into hydrogels can enhance follicular delivery and prolong drug retention within epidermal tissues.

Hydrogels also maintain intimate contact with the skin surface, increasing residence time and ensuring sustained release of active compounds. This prolonged contact improves local bioavailability and minimizes systemic absorption. In psoriasis therapy, enhanced penetration combined with controlled drug release significantly improves therapeutic efficacy while reducing irritation and dosing frequency.

MATERIALS AND METHODS [43-55]

Materials: Bakuchi oil was procured from Janani organics, Dharvad (India). Carbopol 940, glycerol, Transcutol-P, potassium dihydrogen phosphate, albumin was supplied by Analab fine chemicals, Mumbai. Disodium hydrogen phosphate (Loba chemie pvt ltd), was used throughout this research.

Methods: Preformulation study of drug.

Sample was subjected to the following preformulation studies 686

Organoleptic properties

Bakuchi oil was manually analyzed for the organoleptic properties including color, odor and appearance.

Solubility profile

Solubility of Bakuchi oil was checked visually in methanol, distilled water, petroleum ether, ethanol, acetone, DMSO, chloroform and KH2PO4 (pH 5.4). Accurately weighed, 1-mL of oil was transferred in a test tube. Above mentioned solvents were individually added and shaken vigorously and the solubility of oil was estimated visually in each solvent.

Phytochemical screening

Bakuchi oil was dissolved in ethanol and evaluated for presence of different phytochemical constituent including alkaloids, glycosides, carbohydrates, tannins, steroids, phenols, saponin, flavonoids and coumarin.

UV-Visible Spectrophotometry

Estimation of lambda max for bakuchi oil in KH2PO4 (pH 5.4)

A precisely measured 100 mg portion of bakuchi oil was placed in a volumetric flask of capacity 100 mL and allowed to dissolve with a small amount of ethanol. KH2PO4 (pH 5.4) was then added to the flask to bring the volume up to the desired level, yielding a stock solution with a conc. of 1000 µg/mL. The given solution was examined in a UV spectrophotometer between 200 and 400 nm.

Calibration of Bakuchi oil in KH2PO4 (pH 5.4)

Serial dilutions from stock solution having conc. of (1000 µg/mL) with KH2PO4 (pH 5.4) was prepared within a 2 to 10 µg/mL range. Absorption readings of above solutions were measured at determined λmax (255 nm) taking KH2PO4 (pH 5.4) as blank and the calibration plot was prepared.

Drug-excipients Compatibility Studies

Fourier transfer infrared spectrophotometer spectroscopy

The functional groups present in Bakuchi oil were determined by FTIR-ATR (BRUCKER, TENSOR-27) spectrophotometry; selected formulation was also examined by FTIR-ATR spectrophotometry. The samples were added on sample holder and scanned between IR range of 4000 to 400 cm−1.

Formulation Studies

Preliminary screening of penetration enhancer

The solubility of bakuchi oil was investigated in permeation enhancers including tween 80, clove oil, turpentine oil, peppermint oil, almond oil, cinnamon oil, oleic acid, and eucalyptus oil. The selection of penetration enhancers for further research was based on their ability to effectively solubilize drugs. Excess of oil was added in 1-mL of each penetration enhancer which was then vortexed for 30 seconds. After that, centrifugation of sample was carried out for 10 minutes at 1000 rpm to extract the clear supernatant liquid. Oil solubility was measured at 255 nm using UV spectroscopy.

Optimization Study

Experimental design and statistical analysis can assess and determine the most crucial parameters and their interactions by reducing the amount of experimentation. The polymer concentration and the permeation enhancer concentration were found to be the most critical factors influencing the pH, viscosity, and drug diffusion of the hydrogel based on preliminary research and the literature that was available. Design-Expert® version 13, a commercial software program, was used to apply Box-Behnken design to statistical evaluation the impact of formulation variables on the responses. The independent variable and their level used in the investigation.

Evaluation of Topical Bakuchi Oil Hydrogel

pH: Digital pH meter (BioEra) was used for the determination of pH of hydrogel. For determination of pH, 1% solution of hydrogel formulation was prepared in distilled and pH was determined.

Viscosity: Viscosity is a crucial characteristic that determine the resistance of flow of hydrogel formulation so that it can easily spread on the skin after application. A Brookfield viscometer (Labman) with Spindle 4 was used to measure the hydrogel preparations' viscosity at a speed of 50 revolutions per minute. For every preparation, the process was done 3 times, and the mean viscosity was measured in centipoise units.

Extrudability: The quantity of hydrogel that squeeze out from the tube after application of pressure was used to determine the extrudability of hydrogels. The prepared hydrogel was poured into a spotless, collapsible aluminum tube with a 5 g capacity and a 5 mm orifice. A 500 g weight was added to the end that had been crimped. The quantity of hydrogel that was squeeze out (in percentage) through the orifice following the application of pressure was used to determine the extrudability. Three duplicates of the experiment were carried out.

In-vitro drug diffusion: In-vitro drug diffusion assay was conducted with the Franz diffusion compartment. Dialysis membranes were made of cellophane. As a donor compartment, 1 g of gel was applied to a cellophane membrane. The dissolution medium in the receiver compartment was KH2PO4 (pH 5.4). The whole diffusion cell system was positioned on a magnetic stirrer that had a thermostat set at 37°C. At regular intervals, samples were gathered. Sink conditions were preserved by substituting a fresh buffer solution. The samples were collected and subjected to UV spectrophotometer analysis at 255 nm.

DRUG RELEASE KINETICS OF HYDROGEL SYSTEMS [51-54]

Drug release kinetics play an important role in evaluating the performance of hydrogel-based topical formulations. Various mathematical models are employed to understand the mechanism of drug release from hydrogels, including zero-order, first-order, Higuchi, and Korsmeyer–Peppas models.

Zero-order kinetics represents a constant drug release rate independent of drug concentration, which is ideal for maintaining prolonged therapeutic activity. First-order kinetics indicates concentration-dependent release, whereas the Higuchi model describes diffusion-controlled release from polymeric matrices. The Korsmeyer–Peppas model helps identify whether drug release follows Fickian diffusion, anomalous transport, or erosion-controlled mechanisms.

In hydrogel systems, drug release is generally governed by diffusion through the hydrated polymeric network and swelling behavior of the polymer matrix. Controlled release from hydrogels enhances local drug retention, reduces dosing frequency, and improves patient compliance in chronic skin disorders such as psoriasis.

In-vitro Anti-inflammatory Activity

When an external stressor or complex, such as organic solvent, strong base or strong acid or heat is applied to proteins, they lose their secondary and tertiary structures. This process is known as denaturation, and most biological proteins become functionally denatured as a result. Inflammation is known to be caused by protein denaturation. The ability of the extract to prevent denaturation of protein was studied as part of the anti inflammatory action. Well-known cause of inflammation is albumin denaturation. Diclofenac sodium, in the concentration series of 200 to 1000 µg per mL, was used as a reference drug.

Spreadability

Spreadability was measured with the help of apparatus containing a wooden block having lifter at one end. This process measured spreadability based on the basis of drag and slipe characteristic of hydrogel. On the bottom slide, an excess of the hydrogel under investigation (roughly 20 gm) was placed. After that, the hydrogel was positioned with the hook in between glass slide and other one that had the same measurement as a fixed bottom slide. For 5 minutes, a 1000 g weight was kept on top of each of the 2 slides to eliminate air and produce a consistent layer of hydrogel between them. The extra hydrogel was removed by scraping off the edges. The upper plate was subsequently pulled with a 5 g weight. The entire time and distance travelled by upper slide were examined. A shorter time for spreading showed well spreadability.

Bakuchi Oil and Bakuchiol: Ethnopharmacology, Chemistry, and Antipsoriatic Rationale [56-59]

Bakuchi oil, obtained from the seeds of *Psoralea corylifolia* Linn. (family Fabaceae), has been extensively used in traditional systems of medicine such as Ayurveda, Unani, and Traditional Chinese Medicine for the management of various skin disorders, including psoriasis, vitiligo, leprosy, and eczema. In Ayurveda, Bakuchi is classified as a potent *Kuṣṭhaghna* (anti-skin disease) drug and is commonly prescribed in both topical and oral formulations. Its long-standing ethnopharmacological use in chronic inflammatory and hyperproliferative skin conditions provides a strong traditional basis for its exploration in modern antipsoriatic therapy. From an ethnopharmacological perspective, Bakuchi oil is valued for its *tikta* (bitter) and *katu* (pungent) properties and is believed to pacify *Kapha* and *Vata* doshas, which are considered dominant in psoriatic pathology according to Ayurvedic concepts. Traditional topical preparations of Bakuchi oil have been used either alone or in combination with other herbal ingredients to reduce scaling, inflammation, and discoloration of the skin. Despite its therapeutic benefits, conventional use of Bakuchi oil is often associated with issues such as strong odor, irritation, and photosensitivity, which limit patient acceptability and compliance. These limitations underscore the importance of developing advanced topical delivery systems to harness its therapeutic potential more safely and effectively. Chemically, Bakuchi oil is a complex mixture of bioactive phytoconstituents, including furocoumarins, meroterpenes, flavonoids, and phenolic compounds. The most notable furocoumarins present in Bakuchi are psoralen and isopsoralen, which are well known for their photosensitizing properties and have been used clinically in psoralen–ultraviolet A (PUVA) therapy for psoriasis and vitiligo. In addition to furocoumarins, Bakuchi oil contains bakuchiol, a meroterpene phenol that has gained significant attention in recent years due to its wide range of pharmacological activities and comparatively better safety profile. Bakuchiol is considered a functional analogue of retinol in dermatology and exhibits strong anti-inflammatory, antioxidant, antimicrobial, and anti-proliferative properties. Unlike retinoids, bakuchiol is reported to cause fewer side effects such as irritation and photosensitivity, making it particularly attractive for long-term topical use. Chemically, bakuchiol is a lipophilic compound with poor aqueous solubility, which poses formulation challenges but also makes it a suitable candidate for lipid-based and gel-based topical delivery systems. Modern analytical techniques such as GC–MS and HPLC have confirmed bakuchiol as one of the major and pharmacologically relevant constituents of Bakuchi oil. The antipsoriatic rationale for Bakuchi oil and bakuchiol is strongly supported by their pharmacodynamic actions on key pathological processes involved in psoriasis. Psoriasis is characterized by chronic inflammation, keratinocyte

hyperproliferation, oxidative stress, and immune dysregulation, particularly involving the IL-23/IL-17 axis. Bakuchi oil extracts and bakuchiol have demonstrated anti-inflammatory effects through inhibition of pro-inflammatory cytokines such as TNF-α, IL-6, and IL-17, as well as suppression of inflammatory signaling pathways like NF-κB and MAPK. By modulating these pathways, Bakuchi-derived constituents can interrupt the inflammatory cascade that sustains psoriatic lesions. Oxidative stress plays a significant role in the initiation and progression of psoriasis, and increased levels of reactive oxygen species have been observed in psoriatic skin. Bakuchiol exhibits potent antioxidant activity by scavenging free radicals and enhancing endogenous antioxidant defense mechanisms. This antioxidant action helps protect keratinocytes from oxidative damage and may contribute to the normalization of abnormal cell proliferation and differentiation seen in psoriasis. Additionally, the antimicrobial activity of Bakuchi oil may help prevent secondary infections in compromised psoriatic skin, further supporting its therapeutic relevance. Preclinical studies have provided experimental evidence for the antipsoriatic potential of Bakuchi oil and bakuchiol-based formulations. Babchi oil-loaded nanoemulsion gels and nanostructured lipid gels have shown significant reduction in erythema, scaling, and epidermal hyperplasia in animal models of psoriasis, along with improvement in oxidative stress markers. Similarly, bakuchiol-loaded solid lipid nanoparticle gels have demonstrated enhanced skin retention and superior antipsoriatic activity compared to conventional formulations. These findings indicate that appropriate formulation strategies can significantly improve the efficacy and safety of Bakuchi-derived actives.

Table 2: Major Phytoconstituents of Bakuchi Oil and Their Pharmacological Activities

Phytoconstituent	Pharmacological Activity
Psoralen	Antipsoriatic
Isopsoralen	Antioxidant
Bakuchiol	Anti-inflammatory
Flavonoids	Free radical scavenging
Coumarins	Immunomodulatory

Design of a Bakuchi Oil–Loaded Hydrogel: Formulation Strategies [59-63]

Rationale for Hydrogel-Based Delivery of Bakuchi Oil

Bakuchi oil is rich in lipophilic phytoconstituents, particularly bakuchiol and furocoumarins, which exhibit promising antipsoriatic activity but present significant formulation challenges such as poor aqueous solubility, instability, strong odor, and potential skin irritation when applied directly. A hydrogel-based delivery system offers an effective strategy to overcome these limitations by providing a hydrated, non-greasy, and patient-friendly topical dosage form. Hydrogels can improve skin hydration, enhance drug residence time, and allow controlled release of the active components at the site of application. In the context of psoriasis, where the skin barrier is compromised and plaques are hyperkeratotic, hydrogel systems can soften the stratum corneum and facilitate improved penetration of Bakuchi oil into the epidermis.

Selection of Active Form: Bakuchi Oil vs. Encapsulated Systems

The first critical step in formulation design is deciding the form in which Bakuchi oil will be incorporated into the hydrogel. Direct incorporation of Bakuchi oil into the gel matrix is a simple approach but often leads to issues such as phase separation, instability, and inconsistent drug distribution. To address these problems, advanced formulation strategies involve encapsulating Bakuchi oil or bakuchiol into carrier systems such as nanoemulsions, solid lipid nanoparticles (SLNs), or nanostructured lipid carriers (NLCs) before incorporating them into a hydrogel base. These hybrid systems, commonly referred to as nanoemulgels or nanoparticle-loaded hydrogels, improve solubilization of lipophilic constituents, enhance skin penetration, and reduce irritation by providing controlled and localized drug release.

Polymer Selection for Hydrogel Matrix

In addition to the gelling polymer, several excipients are required to ensure stability, safety, and efficacy of the Bakuchi oil–loaded hydrogel. Surfactants and co-surfactants are essential when Bakuchi oil is incorporated in nanoemulsion form, as they reduce interfacial tension and stabilize oil droplets. Antioxidants such as butylated hydroxytoluene (BHT) or tocopherol are often added to prevent oxidative degradation of Bakuchi oil constituents. Preservatives are necessary due to the high water content of hydrogels, which makes them susceptible to microbial growth. pH adjusters, such as triethanolamine, are used to neutralize carbomer-based gels and maintain skin-compatible pH. The careful selection and optimization of these excipients are crucial to minimize irritation and enhance patient compliance.

Optimization of Formulation Parameters

Formulation optimization focuses on achieving a balance between stability, drug release, and usability. Parameters such as polymer concentration, oil content,

surfactant ratio, and neutralization level significantly influence the physicochemical properties of the hydrogel. Excessively high polymer concentrations may lead to stiff gels with poor spreadability, while low concentrations may result in phase separation and inadequate residence time. Similarly, inappropriate surfactant levels can cause irritation or destabilize the formulation. Therefore, systematic optimization approaches, including factorial design or response surface methodology, are often employed to identify optimal formulation conditions. Critical quality attributes such as viscosity, pH, drug content uniformity, and in vitro release profile are used as responses during optimization.

Consideration of Safety and Skin Compatibility

Safety is a major consideration in the design of Bakuchi oil–loaded hydrogels, particularly due to the presence of photosensitizing furocoumarins. Formulation strategies aim to reduce direct exposure of the skin to high concentrations of these compounds by encapsulating the oil within carrier systems and controlling release. Maintaining a skin-friendly pH and avoiding harsh solvents further enhances tolerability. Encapsulation and gel-based delivery can significantly reduce irritation and phototoxic risk while preserving therapeutic efficacy, making the formulation suitable for long-term topical application in psoriasis.

Safety Considerations (Critical for Bakuchi-Based Topicals) [63-74]

Safety evaluation is a crucial aspect in the development of Bakuchi-based topical formulations, particularly because *Psoralea corylifolia* seed oil contains potent bioactive compounds that can exert both therapeutic and adverse effects. While Bakuchi oil and its major constituent bakuchiol have demonstrated promising antipsoriatic, anti-inflammatory, and antioxidant activities, their safe topical use requires careful consideration of phytochemical composition, dose, formulation design, and patient-related factors. Unlike synthetic single-entity drugs, herbal oils exhibit batch-to-batch variability and contain multiple constituents, some of which may pose safety concerns if not properly controlled. One of the most critical safety issues associated with Bakuchi oil is the presence of furocoumarins, particularly psoralen and isopsoralen. These compounds are well known for their photosensitizing properties and are clinically utilized in psoralen–ultraviolet A (PUVA) therapy for psoriasis and vitiligo. Although PUVA therapy can be effective under controlled medical supervision, inadvertent exposure to ultraviolet radiation after topical application of psoralen-containing products may result in phototoxic reactions such as erythema, blistering, hyperpigmentation, and long-term photoaging. Therefore, uncontrolled topical use of Bakuchi oil may increase the risk of phototoxicity, especially when applied to sun-exposed areas. This necessitates strict control of furocoumarin content or the preferential use of standardized extracts or isolated bakuchiol in topical formulations intended for routine use. Skin irritation and sensitization represent another important safety concern. Traditional Bakuchi oil preparations are often associated with burning sensation, erythema, and dermatitis, particularly in sensitive individuals or when applied to inflamed psoriatic skin with an already compromised barrier. Psoriatic skin exhibits increased transepidermal water loss and altered lipid composition, making it more susceptible to irritants. High concentrations of essential oil components, residual solvents, or inappropriate excipients can exacerbate irritation. Hence, topical Bakuchi formulations must be evaluated for primary skin irritation, cumulative irritation, and sensitization using validated in vivo or alternative in vitro methods. Incorporation of Bakuchi oil into hydrogels or encapsulation within nanocarriers has been shown to significantly reduce direct contact between irritant constituents and the skin, thereby improving tolerability. Dose standardization and content uniformity are essential for ensuring safety in Bakuchi-based topical systems. Herbal oils often show wide variation in chemical composition depending on geographical source, harvesting conditions, and extraction method. Variability in psoralen and bakuchiol content can lead to unpredictable therapeutic and adverse effects. Therefore, quantitative analytical methods such as HPLC or GC–MS should be employed to standardize Bakuchi oil with respect to key marker compounds. Establishing acceptable limits for psoralen content is particularly important to minimize phototoxic risk while retaining therapeutic efficacy.

Another safety aspect relates to oxidative and chemical stability of Bakuchi oil. The oil contains unsaturated and phenolic compounds that are susceptible to oxidation, leading to degradation products that may be irritating or allergenic. Oxidative degradation can also reduce therapeutic activity and shorten shelf life. To address this issue, antioxidants such as tocopherol or butylated hydroxytoluene may be incorporated into the formulation, and appropriate packaging (e.g., light-resistant containers) should be selected. Stability studies under accelerated and long-term conditions are essential to ensure that the formulation remains safe and effective throughout its intended shelf life.

Microbial safety is also a key consideration for Bakuchi oil–loaded hydrogels due to their high water content. Aqueous topical formulations provide a favorable environment for microbial growth, which can lead to product contamination and skin infections, particularly in patients with compromised skin integrity. Therefore, suitable preservatives must be incorporated, and microbial limit tests as well as preservative efficacy tests should be conducted in accordance with pharmacopeial guidelines. Ensuring microbial safety is

especially important for chronic conditions like psoriasis, where long-term and repeated application is common.

Encapsulation-based formulation strategies offer additional safety advantages for Bakuchi-derived actives. Nanoemulsions, solid lipid nanoparticles, and nanostructured lipid carriers incorporated into hydrogels can provide controlled and localized drug release, reducing peak concentrations at the skin surface and minimizing systemic absorption. This localized delivery approach is particularly desirable for psoriasis, as it reduces the likelihood of systemic exposure and associated toxicity. Studies have shown that bakuchiol- or babchi oil-loaded nanocarrier gels exhibit improved safety profiles along with enhanced antipsoriatic efficacy compared to conventional formulations.

FUTURE PERSPECTIVES AND EMERGING TRENDS [74-78]

Recent advances in topical drug delivery systems have significantly improved the therapeutic potential of herbal formulations for psoriasis management. Future research on Bakuchi oil–loaded hydrogels is expected to focus on nanotechnology-based carrier systems such as nanoemulgels, solid lipid nanoparticles, nanostructured lipid carriers, and polymeric nanoparticles to improve skin penetration and controlled drug release.

Stimuli-responsive or smart hydrogels capable of releasing drugs in response to pH, temperature, or inflammatory mediators also represent promising approaches for targeted psoriasis therapy. Incorporation of bioadhesive polymers and biodegradable nanocarriers may further enhance residence time and minimize systemic exposure.

Another emerging area is the combination of herbal phytoconstituents with conventional antipsoriatic drugs to achieve synergistic therapeutic effects while reducing adverse reactions associated with long-term corticosteroid therapy. Artificial intelligence and machine learning tools are also being explored for optimization of topical formulations and prediction of skin permeation characteristics.

Although preclinical findings are highly encouraging, more clinical trials are necessary to establish long-term safety, efficacy, and standardization of Bakuchi-based hydrogel systems before their widespread clinical application.

DISCUSSION

Hydrogel-based topical delivery systems have demonstrated considerable potential in improving psoriasis management by overcoming the limitations associated with conventional topical formulations. Compared with ointments and creams, hydrogels provide enhanced hydration, improved spreadability, prolonged skin residence time, and controlled drug release, which collectively improve patient compliance and therapeutic effectiveness. These characteristics are particularly beneficial in psoriasis, where hyperkeratosis and impaired skin barrier function reduce drug penetration and treatment efficacy.

Bakuchi oil obtained from Psoralea corylifolia contains important bioactive constituents such as bakuchiol, psoralen, and isopsoralen that exhibit anti-inflammatory, antioxidant, antimicrobial, and antiproliferative activities relevant to psoriasis therapy. Incorporation of Bakuchi oil into hydrogel systems helps reduce irritation and improve localized delivery of active phytoconstituents into psoriatic lesions. Furthermore, advanced delivery approaches such as nanoemulgels and nanoparticle-loaded hydrogels have shown improved penetration and enhanced therapeutic performance compared to conventional formulations.

Despite promising findings, certain limitations such as photosensitivity, variability in herbal composition, and lack of extensive clinical studies remain important challenges. Therefore, further clinical evaluation, formulation standardization, and long-term safety studies are necessary for successful therapeutic application of Bakuchi oil–loaded hydrogel systems in psoriasis management.

CONCLUSION

Psoriasis is a chronic inflammatory skin disorder associated with immune dysregulation, oxidative stress, and abnormal keratinocyte proliferation. Conventional topical therapies are often limited by poor penetration, local irritation, low patient compliance, and lack of controlled drug release. In this context, hydrogel-based delivery systems provide significant advantages due to their hydrating nature, excellent spreadability, enhanced skin retention, and controlled drug release characteristics.

Bakuchi oil and its major bioactive constituent bakuchiol possess promising anti-inflammatory, antioxidant, antimicrobial, and antiproliferative activities relevant to psoriasis management. Incorporation of Bakuchi oil into hydrogel systems can improve therapeutic efficacy while minimizing irritation and improving patient acceptability.

Advanced formulation approaches such as nanoemulgels and nanoparticle-loaded hydrogels further enhance penetration and localized delivery of phytoconstituents into psoriatic lesions. Overall, Bakuchi oil–loaded hydrogel systems represent a promising herbal strategy for effective and patient-friendly topical management of psoriasis. However, further clinical studies and long-term safety evaluations

are necessary to support their large-scale therapeutic application.

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