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SHORT REVIEW

Exploring the Bioactive and Herbal Approaches of *Saussurea lappa:* A Precious Phytoherb from the Himalayas

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Abstract

The *Saussurea* genus, particularly *Dolomiaea costus* (formerly *Saussurea lappa*), is a globally distributed perennial plant with significant medicinal usage, due to the unique biochemical composition. Despite advancements, comprehensive studies on its bioactivity remain limited. This review describes current knowledge on *S. lappa*, detailing its components, physiological effects, traditional uses, commercial challenges, and conservation issues. Drawing from botanical investigations and historical records, it explores *S. lappa's* traditional applications across 43 ailments and delves into scientific inquiries on its therapeutic properties and chemical constituents. Emphasizing structural features and potential mechanisms, the review advocates for further research to validate and expand its medicinal potential.

Keywords: Clinical Research, Herbal Potential, Phytochemicals, *Saussurea lappa*

1. Introduction

Saussurea lappa, recognised by its vernacular names costus or kuth, is a perennial botanical entity affiliated with the Asteraceae family. Indigenous to the elevated Himalayan terrain, encompassing regions such as India, Nepal, and Bhutan, this plant assumes significance within the extensive *Saussurea* genus, constituting approximately 350 distinct species, with *S. lappa* standing out as a noteworthy representative. From a biological perspective, the plant exhibits distinctive features, characterized by robust rhizomes and expansive leaves[1,2].

Renowned for its medicinal attributes, *S. lappa* finds application in various traditional healing systems, notably Ayurveda. Unfortunately, its prevalence in the wild is dwindling, primarily attributable to excessive utilization for medicinal and business objectives, leading to its classification as a critically endangered species. Somehow, it's signifying its precarious preservation status, and which is among the 37 Himalayan biological herbs facing endangerment[1].

Acknowledging the urgency of conservation measures, the Indian government, via Ministry of Commerce, has imposed restrictions on the export of 29 medicinal and fragrant plant varieties, involving *S. lappa*, whether in raw or processed forms. The Planning Commission, in collaboration with the NMPB (National Medicinal Plants Board), has formulated a policy manuscript focusing on terms of advertising and business aspects of such medicinal plants sector. In alignment with national priorities, the Planning Commission emphasizes an annual requirement of approximately 0.43 tonnes of *S. lappa*. The NMPB has identified 32 prioritized medicinal plant species, while the Planning Commission registered 24 for targeted exploration and innovation efforts, both of which include *S. lappa*[3].

The roots and root stalks of this botanical specimen are traditionally employed to address diverse ailments, such as toothaches, skin diseases, rheumatism, and asthma, particularly the areas of Himalaya, Kashmir and Punjab. According to *Unani* medicinal system, *S. lappa* roots are

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utilised for treating conditions such as inflammation, fever, cough, asthma, headache, and paralysis[2].

2. Unveiling the Herb's Botany

Saussurea lappa presents itself as an upright, sturdy, pubescent, and enduring herb with a robust, unbranched stem reaching heights of 1–2m. Its leaves, exhibiting a membranous texture, possess a scaberulous upper surface while appearing glabrate beneath, featuring auricles at the base and irregularly toothed margins. The basal leaves, expansive and ranging from 0.50 to 1.25m in length, showcase a prolonged, winged petiole. In contrast, the upper leaves, comparatively smaller, are either subsessile or possess short petioles, often with 2 minor projections close to the base, almost encircle the stem[4]. The flower heads, devoid of stalks, display hues ranging from purple-blue to partial black. These heads are compact, firm, and spherical, measuring 2.4–3.9 cm in diameter, frequently clustered in groups of 2–5 within the leaf axils or terminally. The numerous involucral bracts, ovate-lanceolate and distinctly pointed, exhibit a purple hue, presenting a rigid and hairless texture. Notably, the receptacle bristles are conspicuously lengthy. The corolla, approximately 2 cm in length, assumes a tubular form, showcasing shades of purple-blue or nearly black. Tails of another feature a fimbriate structure. The achenes, curved and compressed, measure around 8mm in length with narrowed tips and a single rib on each face. The pappus, in a distinctive brown hue, manifests as a double feathery arrangement. *S. lappa* roots are stout, displaying a dark brown or grey coloration, and can extend up to 40 cm in length[4,5].

3. Glimpse of the Phytochemistry

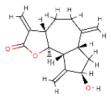
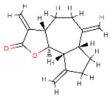
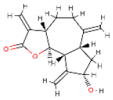
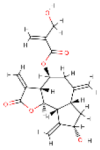
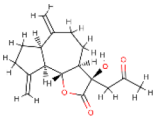
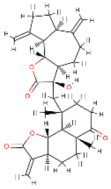
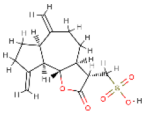
Phytochemical scrutiny of *S. lappa* roots unveiled the existence of monoterpenes, alkaloids, flavonoids, triterpenes, sesquiterpenoids, lignans, phytosterols, glycosides, anthraquinones, and other compounds[6,7]. The roots of *S. lappa* represent an abundant reservoir of sesquiterpenoids, particularly sesquiterpene lactones[8,9]. Notably, sesquiterpenes, flavonoids, and alkaloids emerge as the principal bioactive components, predominantly driving diverse pharmacological activities[10].

3.1 Sesquiterpenes

The root composition of *S. lappa* exhibits a substantial abundance of sesquiterpenes. These sesquiterpenes can be broadly classified into three distinct categories based on their carbocyclic skeleton, namely (i) Guaiane, (ii) Eudesmane, and (iii) Germacrene (Tables 1-3).

3.1.1 Guaianes

Table 1. Types of Guaianes in the root composition of *Saussurea lappa*[11-14]

S. No.	Name of the Phytoconstituent (Guaianes)	Structure of the compound
1	3-Epizaluzanin C	
2	Dehydrocostus Lactone	
3	Zaluzanin C	
4	Cynaropicrin	
5	Lappalone	
6	Lappadilactone	
7	Sulfocostunolide A	

3.1.2 Eudesmanes

Table 2. Types of Eudesmanes in the root composition of *Saussurea lappa*[15-17]

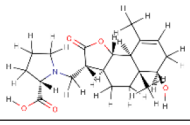
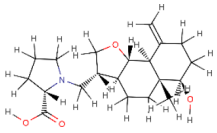
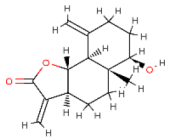
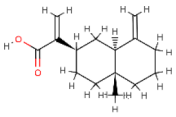
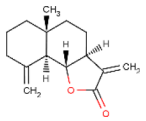
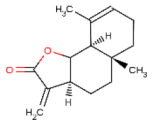
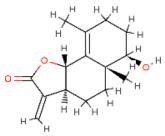
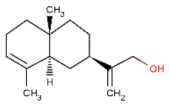
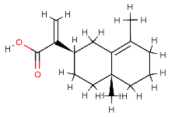
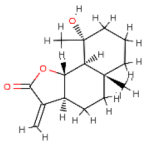
S. No.	Name of the Sesquiterpenes Phytoconstituents (Eudesmanes)	Structure of the compound
1	Saussureamine D	

Table 2. Continued...

S. No.	Name of the Sesquiterpenes Phytoconstituents (Eudesmanes)	Structure of the compound
2	Saussureamine E	
3	Reynosin	
4	β-costic acid	
5	β-cyclocostunolide	
6	α-Cyclocostunolide	
7	Magnolialide	
8	α-costol	
9	Isocostic acid	
10	Arbusculin	

3.1.3 Germacranes

Table 3. Types of Germacranes in the root composition of *Saussurea lappa*[18-20]

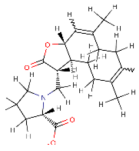
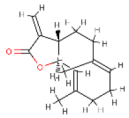
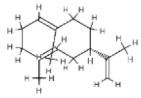
S. No.	Name of the Phytoconstituent (Germacranes)	Structure of the compound
1	Saussureamine A	

Table 3. Continued...

S. No.	Name of the Phytoconstituent (Germacranes)	Structure of the compound
2	Costunolide	
3	Germacrene A	

3.2 Other Constituents

Phytosterols such as Pregnenolone, Lappasterol, Daucosterol, 3-Epilappasterol, Lappalanasterol and β-Sitosterol have been documented in the *S. lappa* roots. The roots of *S. lappa* also contain three compounds of anthraquinone, namely, Chrysophanol and Aloeemodin-8-O-β-d-glucopyranoside, Rhein-8-O-β-d-glucopyranoside, which exhibit inhibitory effects on the activity of protein tyrosine phosphatase (PTP-1B). Additionally, triterpenes such as 3-β-Acetoxy-9(11)-baccharene, α-Amyrin, and α-Amyrin eicosanoate have been identified in *S. lappa* roots[21,22]. Saussurine, found in *S. lappa*, alleviates spasms in smooth muscle in the gastrointestinal tract and bronchi. The *Shikiokiols*, present in the plant, demonstrate anti-tumor activity, while chlorogenic acid serves as an antioxidant by preventing oxidation and neutralizing free radicals[16,23-26].

4. Pharmacology

4.1 General Context of Pharmacology

A plethora of bioactive substances were extracted and observed from diverse segments of *S. lappa*, exhibiting a wide array of functionalities such as antidiabetic, hepatoprotective, anticancer, antimicrobial, antihepatotoxic, anthelmintic, immunostimulant, antifungal, antiulcer, pesticidal, antitumor, anti-inflammatory, etc. This exploration involved diverse *in vitro* and *in vivo* methodologies[25].

4.2 Anti-inflammatory Activity

The inflammatory properties of ethanolic infusion of SL (*Saussurea lappa)* were scrutinized in murine models, encompassing both short and long scenarios, as well as in rats. Doses ranged from 50-200 mg/kg administered

orally. The following extract demonstrated noteworthy anti-inflammatory effects, notably inhibiting paw edema provoked under the action of carrageenan at doses ranging from 50-200 mg/kg. Furthermore, it exhibited a preventive influence on the agglomeration of inflammatory leukocytes in carrageenan-induced peritonitis[26]. The anti-inflammatory action of costunolide, a bioactive constituent in SL, was also subjected to evaluation. The *in vitro* analysis of the activity of anti-inflammation involved the scrutiny of Nitric Oxide (NO) and TNF-α levels within mouse macrophage cells[27]. RAW - 264.2 murine macrophage cells nurtured in T25 flasks using Dulbecco's Modified Eagles Medium (DMEM) lacking phenol red, supplemented with 10% serum, i.e. heat in-activated, while maintaining a temperature of 37°C and 5% CO_2 with 90% relative humidity[28]. When the cells reached 85% confluence, they underwent trypsinization along with ethylene diamine tetra acetic acid and trypsin aqueous solution and were then seeded in 12-well plates at a density which will be (1x105) cells / well. The incubation persisted at 98.6°F for 24 hours, revealing that the experimental compound had a significant effect on TNF-α levels. Precisely, the experimental compound exhibited a substantial 33.76% inhibition of TNF-α[29].

4.3 Anti-cancer Activity

Lignin and β-peltatin derivatives obtained from acetone extractions of *S. lappa* demonstrate inhibitory effects on cancer cells of human pancreas, lungs, and squamous cells[30,31]. It's recognized that costunolide and dehydrocostus lactone exhibit a restraining influence on the activity of MDA.MB.453 and MCF.7 tumor cells of mammals[30]. An exploration of the *S. lappa* hexane extract investigated its chemo preventive potence in autonomous kind of androgen prostate cancer, coupled with programmed cell death initiation in DU145 cells. The results indicated that dehydrocostus-lactone, extracted out of extract of hexan, triggered apoptosis state in DU 145 human autonomous kind of androgen prostate cancer cell lines, restraining cell growth[32]. The examination of costunolide, derived from *S. lappa*, and its purported mechanisms of programmed cell death initiation in HL-60 human leukemia cells uncovered that constituent costunolide promotes ROS-mediated permeability transition, leading to the cytochrome-C release. This resulted for a determination that *S. lappa* extract hinders cell proliferation by initiating apoptosis[33].

The cytotoxic effectiveness of the *S. lappa* chloroformic extract on cancer cell lines of breast (MDA-MB) exhibited similarity to the reference compound, doxorubicin[34]. Costunolide derived from *S. lappa* exhibited growth suppression of tumor and metastasis in MDA-MB-231, a highly metastatic breast cancer in humans, by suppressing the activation TNF-α-induced NF-kB[35]. *S. lappa* extract demonstrated restraint of proliferation of cells via the programmed cell death pathway on κB oral cancer cells of humans[36]. Cynaropicrin, extracted from *S. lappa* for the immunomodulatory impacts on exposure of cytokin, inhibiting effect of immune system, and production of nitric oxide, inhibited U937, Jukart T cell lines and Eol-1 in a manner of dose-dependency. The findings suggested that cynaropicrin exhibited greater cytotoxicity towards cancer cells derived from leukocytes compared to fibroblasts[37].

The derivative of ethyl acetate from *S. lappa*, when administered orally to rats, suppressed production of gastric acid, free acid, and total acid by 53.53%, 52.55%, and 30.30%, respectively, supporting its efficacy in treating gastric cancer with *S. lappa*[38]. Dehydrocostus - lactone, extracted from *S. lappa*, was subjected to *in- vitro* assays for hepatocellular carcinoma activity, confirming its anticancer efficacy at IC50 values of 16.7 and 18.8 µmol/L[39]. It was obtained, that compounds, that are of eight types demonstrating activity of cytotoxicity on cancer cells of humans. *S. lappa* phytocompounds dehydrocostus lactone, costunolide and dilactone exhibited non-specificity in cytotoxicity, with comparable effects on HeLa, HepG2, OVCAR-3, etc. Investigations into the function-structure relationship underscored that γ-lactone and α-methylene are essential for the activity of cytotoxicity, while the hydroxide radical's presence diminishes this activity[40,41].

4.4 Hepatoprotective Activity

The *S. lappa* acetone extract and costunolide display an effect of choleretic influence and possess the ability to hinder ulcer formation in mice[42]. Dehydrocostus-lactone and costunolide, derived from *S. lappa*, showed negligible influence on cell viability. Nonetheless, they

exhibited inhibitory effects on human hematoma the hepatitis B surface antigen (HBsAg) and Hep3-B cells expression. The study demonstrated that these substances impede HBsAg production in Hep3-B cells, exhibiting IC_{50} numeric measures of 1 and 2 μmol/L, respectively. The results suggest the prospective development of dehydrocostus-lactone and costunolide as robust anti-HBV medications in the coming years[43].

The extract (aqueous-methanolic) from *S. lappa* roots was assessed in opposition to lipopolysaccharide and D-galactosamine-initiated hepatitis in mice. Prior administration of varying *S. lappa* extract doses (150.0, 300.0, and 600.0 mg/kg) significantly alleviated the increase in AST and ALT levels in a manner of dose-dependency. Subsequent remedy with *Saussurea lappa* (600.0 mg/kg) notably restrained the advancement of damage in liver, as evidenced by histopathology indicating enhanced architectural detail in the liver, absence of parenchymal congestion, diminished swelling of cells, and a reduced number of apoptotic cells. This supports the traditional applications of *S. lappa* in addressing liver disorders[43]. An experiment carried out a comparative evaluation of the influences of the ethanolic-extract on flow of bile pre- and post-rat medication. The findings indicated that the ethanolic-extract enhances flow of bile and imparts an of effect of choleretic influence[44]. Additionally, it was explored that the influence on gall bladder movement due to *S. lappa* and the mechanism in dogs, elucidating that the *S. lappa* solution prompts gall bladder contraction in dogs without influencing plasma cholecystokinin[45].

4.5 Anti-ulcer Activity

Saussurea lappa stands as a primary constituent in UL-409, a medication renowned for its ulcer depleting properties, attributed to the enhancement of defensive factors that fortify gastric cyto-protection[46,47]. Infusion of *S. lappa* herbal infusion into the stomachs of individuals with chronic superficial gastritis showcased an augmentation in endogenous motilin release and accelerated stomach evacuation[48,49]. *S. lappa*'s acetone extract and costunolide exhibited both inhibitory and cholagogic effects on gastric ulcer development in mice. The anti-ulcer potential of a plant medication containing the plant, assessed in the animal male pigs and Wistar rats through mouth administration of dosage of 600 mg/kg. The formulation demonstrated particular efficacy in reducing stomach ulcers caused by aspirin and alcohol, as well as resistant to cold and ulcer models of duodenum. It notably augmented mucus association in all cases, solidifying its status as an antiulcer agent[50]. The ethyl acetate extract of *Saussurea lappa* exhibited efficacy in varying systems of duodenal and gastric ulceration activity in rats[51]. *Saussurea lappa* extract demonstrated apparent protective changes in opposition to short injury to rat gastric mucosa caused by reserpoid and hydrochloric acid-ethanol[52]. The 3 active components, namely Saussure amines A, B, and C, of *S. lappa*, notably shielded in opposition to damage induces stomach damage by hydrochloric acid and ethanol. Saussure amine A further exhibited inhibitory effects on stress-induced gastric ulcers in mice[53]. Beyond Saussure amines A, B, and C, both dehydrocostus lactone and costunolide significantly ameliorated stomach ulcers in rats[54].

4.6 Immunomodulator Action

The extract of hydroalcoholic solvent of *Saussurea lappa* roots manifested its immuno-modulatory impact on the doses of 200.00 and 100.00 mg/kg. Remarkably, at 250.00 mg/kg, no discernible changes were observed on antibody-mediated immune system/the total of manufacturing cells of anti-body in the graveyard of RBCs i.e. spleen. This outcome suggests that *S. lappa*, under short-term treatment, does not influence such responses significantly. However, when administered at higher doses, the *S. lappa* extract exhibited a potential of activity of immunomodulation in both the T and B cells facets of the immunity system[55].

Dehydrocostus and costunolide act as supressors of the cytotoxic-T lymphocytes (CTL) killing activity. By hindering the elevation in the levels of constituent, costunolide, phosphorylation of tyrosine inhibits the CTL activity of killing action in action to the T-cell receptors crosslinking. Dehydrocostus lactone from *S. lappa* and other guaianolides, serving as inhibitors of CTL function of killing action and inducers of intercellular adhesion molecules-1, were investigated for their activity-structure relation. It was verified the structure of guaianolide demonstrates significant restraining effects on the initiation of IAM-1 (Intercellular Adhesion Molecule-1) and the task of killing of CTL[56,57].

4.7 Bronchitis Treatment

Experiments were undertaken to investigate the impact of various *S. lappa* extracts on asthma and chronic bronchitis[58,59]. The fraction of alkaloids, determined to be non-toxic, exhibited minimal influence on the respiration and blood pressure of both rabbits and cats. Notably, it demonstrated a pronounced spasmolytic effect over the tracheal and smooth (intestinal) muscles of Guinea pigs when invigorated by the neurotransmitter, histamine, along with an influence of antispasmodic action on the isolated perfused lungs of guinea pig[58]. Further examinations were conducted on *Saussurea* tincture, ether extract of petroleum, *Saussurea* tincture derived from skimmed roots, and extracts acquired through consecutive extraction of *S. lappa* roots were tested. The outcomes indicated that essence of *Saussurea* and Petroleum-ether concentrate caused bronchial-narrowing in the animal guinea pigs, whereas *Saussurea* concentrate prepared from defatted roots and other extracts did not exhibit such an effect. This implies that *Saussurea* concentrate, without the fraction of soluble Petroleum-ether, could function as a beneficial therapeutic remedy for asthma and prolonged bronchitis[59].

4.8 Cardiotonic Treatment

The exploration into cardioprotective adequacy of fluid extract derived from the *S. lappa* roots, administered in opposition to isoproterenol-induced myocardial lesion in the animal rats with a dosage of 85 mg /kg, unveiled substantial defense from myocardial injury. Rats were pre-treated with the *S. lappa* aqueous extract at three distinct doses (300.0, 200.0 and 100.0 mg/kg) via the oral administration route. Notably, the consumption of AESL at 200.0 mg/kg demonstrated a particular diminishment of oxidative stress, while higher (300 mg) or lower (100 mg) doses failed to provide safety from oxidative stress. The potential mechanism underlying this protective effect, achieved through chronic oral administration of AESL, may involve adaptation of myocardium, with oxidative stress mediation through a reduction in TBARS levels. The cardiac effects of roots of *S. lappa* were scrutinized in the perfused secluded rabbit heart utilizing Langendorff's process. Contractility, coronary flow and heart rate were assessed due to the existence of varying compositions of the *S. lappa* methanolic extract, alongside diltiazem and digoxin. The outcomes indicated that the *S. lappa* methanolic extract exhibited cardiotonic effects, potentially attributed to the availability of calcium channel blockers, sesquiterpene lactones and flavonoids[60,61].

4.9 Miscellaneous

4.9.1 Spasmolytic Activity

It was noted that *S. lappa* effectively induced relaxation in contraction triggered by Carbachol (30.0 µmol/L). The antioxidative properties of *S. lappa* were likely attributed because of the presence of sesquiterpene lactones. The sesquiterpenes have been acknowledged for their ability to activate Sgc, which, in turn, stimulates the expulsion of ions of K, consequently diminishing inherent ions of Ca across the initiation of PKG and cyclic CMP pathways. This cascade of events leads to the relaxation of smooth muscles[62].

4.9.2 Angiogenesis Effect

The proliferation of endothelial cells is subdued by the constituent costunolide, extracted from *S. lappa* roots[63]. Research substantiates; the directional movement initiated by the growth factor of vascular endothelial in human umbilical vein endothelial cells of umbilical vein of human encounters significant hindrance with an IC_{50} of 3.4 µmol/L of *S. lappa*. Similarly, in live experiments, the development of new blood vessels in the mouse cornea prompted by growth factor of vascular endothelial was documented to be restrained at a dose of 100 mg/kg/day[60,64].

4.9.3 Anti-diarrheal Activity

The anti-diarrheal potence of methanolic- extract derived from *S. lappa* roots was analyzed in the species Wistar rats. Hence, it was noticed that the consumption of doses at 100.0, 300.0, and 500.0mg/kg of body weight exhibited inhibitions of diarrhea by 26.33 %, 32.28 %, and 66.77 %, respectively. The drug (standard) loperamide demonstrated a substantial depression (68.02 %) in stool of diarrheal condition at a dose of 5.0mg/kg of body weight. Following study's outcome concluded that the root extract at a dose of 500 mg/kg body's weight exhibited effects akin to the drug (standard) loperamide mitigating diarrhea stool. The *S. lappa* roots methanolic extract displayed a 32.28% restriction of diarrhea at dose of 300 mg/kg body

weight. Thus, these points unequivocally establish the significant anti-diarrheal action of *S. lappa* methanolic extract[65]. Moreover, the *S. lappa* methanolic extract demonstrated substantial protection from diarrhea induced by castor oil in a manner of dose-dependency[66].

4.9.4 Anti-convulsant Activity

The extract of petroleum derived from roots of *S. lappa* exhibits robust anticonvulsant activity in opposition to pentylenetetrazol and convulsions induced by picrotoxin in the animal mice. This effect is achieved by heightening the threshold of the seizure through GABA ergic receptors[67]. The alcoholic extract obtained from *S. lappa* roots has been documented to exhibit noteworthy anti-epileptic activity. Various *S. lappa* root extracts were estimated for their anti-convulsant potential using picrotoxin-initiated convulsion, pentylenetetrazol, and maximal electroshock tests conducted on the animal mice. It was substantiated that the *S. lappa* roots (extract of petroleum) displayed potent anti-convulsant activity at doses of 100 and 300 mg/kg[68].

4.9.5 Anti-hyperlipidemic Activity

The alcoholic extract of *S. lappa* diminished the levels of triglycerides while markedly elevating the levels of HDL-C, both the tissues and serum[61].

5. Navigating Conservation Challenges for the Long-term Sustainable Use of *Saussurea lappa*

Phototherapeutic flora is consistently fixated as a pivotal avenue for pharmaceutical advancement. Indigenous recognition of the therapeutic attributes of medicinal plants tends to be overlooked locally, prompting research endeavours aimed at unravelling diverse bioactive constituents within extracts and comprehending their precise modes of operation. Notably, cardiovascular research stands out as a domain where botanical compounds have made substantial and efficacious contributions. *S. lappa*, indigenous to Pakistan, has predominantly served in the alleviation of diverse ailments[69].

Saussurea lappa is a vital botanical entity extensively employed in both traditional and herbal medicinal practices, as well as medicines of modern times. Owing to heightened demand, the indigenous communities of this species are predominantly either eradicated or subjected to detrimental harvesting practices, thereby leading to the gradual depletion of accessibility to this crucial plant in its natural habitat. Indigenous to a geologically confined sector of the Himalayas, *S. lappa* thrives on damp slopes at elevations ranging from 2600 to 4000 meters[70]. Beyond the restricted dispersion, the collection of the entire plant for local utilization is a primary factor contributing to its endangered status. This critically imperilled species holds a position in the Appendix I – (CITES) Convention on International Trade in Endangered Species of Wild Fauna and Flora. *S. lappa* is recognized as one among the 37 Himalayan endangered medicinal plants targeted for both *in-situ* and *ex-situ* initiatives of conservation[70].

6. Future Perspectives

In 2021, a team of scientists conducted an *in vitro* investigation wherein ZnO nanoparticles were synthesized utilizing the *S. lappa* roots (rhizome) methanolic extract through the coprecipitate method. The antibacterial results indicate superior inhibitory activity against gram-negative strains compared to n gram-positive strains[71,72].

In 2020, a team of distinguished researchers explored the efficacy of wound healing of botanical medications (in situ gels and emulgels) incorporating root extract of *S. lappa* through the introduction of excision wounds in albino rats. In situ gels and emulgels were formulated with varying compositions of SLRE and evaluated for their physical and organoleptic characteristics. The outcomes reveal that the in-situ gel containing SLRE demonstrates noteworthy wound healing in the rats. Consequently, the results propose an approach for developing gel-based products with enhanced wound healing capabilities[73].

In 2021, a different group of researchers delved into the exploration of *S. lappa* CB. Clarke (SL), considering its extensively documented medicinal properties. Their primary goal was to offer insights into novel polymethyl methacrylate-based nano capsules designed to carry *S. lappa* essential oil and elucidate their biological functionalities. Respective nanoparticles were created through the technique of nanoprecipitation, thoroughly examined for characteristics, and assessed for their cytotoxic anti-diabetic, anti-inflammatory and anti-Alzheimer properties[74].

7. Conclusion

Conclusively, scientific exploration has unveiled *S. lappa*'s multitude of bioactive compounds, showcasing properties ranging from antidiabetic and hepatoprotective to anticancer and anti-inflammatory. This underscores its versatility as a botanical source with profound implications for medicinal and therapeutic applications. It emerges as a botanical entity of paramount importance, boasting diverse pharmacological activities extending to spasmolytic effects, anti-angiogenesis, anti-diarrheal, anti-convulsant, and anti-hyperlipidemic activities. These findings position it as a promising candidate for exploration across various therapeutic areas. *S. lappa*, historically is significant in traditional practices in Pakistan, confronts conservation challenges amid heightened demand and detrimental harvesting practices, leading to critical endangerment.

Ongoing scientific investigations, such as antibacterial activity in ZnO nanoparticles and potential wound-healing capabilities, emphasize the importance of sustainable practices for preserving and harnessing *S. lappa*'s therapeutic potential. The holistic approach of conservation efforts and innovative research is crucial for ensuring the sustainable utilisation of this invaluable botanical resource.

8. Author Contribution

AG conducted the literature search and compiled relevant studies. AM and SD analysed the data, interpreted the findings and drafted the initial manuscript, while AM critically revised it for intellectual content. All authors read and approved the final manuscript.

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