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Review Article

Phytochemical Composition and Pharmacological Potential of *Sophora flavescens*: A Mini Review

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ABSTRACT

Sophora flavescens, commonly known as Kushen, is a perennial shrub extensively used in East Asian traditional medicine to treat various ailments. This review summarises its phytochemical composition and pharmacological activities, focusing on root-derived bioactive compounds. The key constituents, such as quinolizidine alkaloids (matrine and oxymatrine) and flavonoids (kurarinone and kushenol), have been linked to potent antimicrobial, antioxidant, anticancer, anti-inflammatory, hepatoprotective, and neuroprotective effects. A literature search using PubMed, ScienceDirect, and Google Scholar retrieved studies published between 2000 and 2025. The review highlights the major mechanisms of action, including the generation of reactive oxygen species, induction of apoptosis, and modulation of the mitogen-activated protein kinase (MAPK) and phosphoinositide 3-kinase/protein kinase B (PI3K/AKT) pathways. Despite these promising properties, challenges such as poor bioavailability, phytochemical variability, and potential toxicity limit its clinical application. Therefore, standardised formulations, integration of omics-based technologies, advanced delivery systems, and rigorous clinical trials are necessary to translate the traditional knowledge of *S. flavescens* into effective evidence-based therapeutics.

Keywords: *Sophora flavescens*, Phytochemical Composition, Alkaloids, Flavonoids, Pharmacological Properties, Ethnomedicinal Applications

Introduction

Medicinal plants have long played a central role in natural product research and continue to serve as valuable sources for drug discovery and therapeutic development.[1] Among various medicinal plants, *Sophora flavescens* (family Fabaceae), commonly known as Kushen in traditional Chinese medicine (TCM), has attracted increasing scientific interest due to its extensive ethnomedicinal use across East Asia, particularly in China, Korea, and Japan.[2,3] *S. flavescens* is a perennial shrub, indigenous to these regions and parts of Europe, where it has been traditionally used for centuries to treat various ailments. The dried root and flowering parts of *S. flavescens* serve as the primary medicinal source in traditional formulations, as depicted in Figure 1 to illustrate its key botanical features.[4,5] Phytochemical investigations have revealed that *S. flavescens* contains diverse bioactive compounds, especially flavonoids such as kurarinone and kushenol, and alkaloids including matrine, oxymatrine, and sophoridine.[6] These phytoconstituents have been linked to numerous pharmacological benefits, such as antibacterial, antioxidant, anticancer, anti-inflammatory, and neuroprotective effects.[7] Among its various activities, the antibacterial potential of *S. flavescens* has received considerable attention, primarily due to the synergistic effects of its abundant alkaloids and flavonoids.[8] Notably, flavonolylated flavonoids such as Sophoraflavanone G and kurarinone are among its most prevalent antibacterial compounds. Both have demonstrated potent antibacterial activity, with minimum inhibitory concentrations (MICs) or fractional inhibitory concentrations (FICs) < 10 mg/mL, often exhibiting synergistic effects with conventional antibiotics.[9] These compounds are believed to disrupt bacterial membrane permeability, thereby inhibiting growth and damaging cells.[10] In addition to its antibacterial properties, *S. flavescens* has also garnered attention for its hepatoprotective effects. Globally, liver diseases like cirrhosis, hepatic fibrosis, and liver failure represent a major public health burden.[11] Reportedly, various constituents, including oxymatrine, matrine, sophoridine, silymarin, glycyrrhizin, and schizandrin B, protect against liver damage.[12] Although most hepatoprotective studies have focused on the alkaloids matrine and sophoridine, there is a growing interest in the protective potential of its flavonoids, especially lavandulyl flavonoids like kushenol C.[13,14] Thus, the present review aimed to provide a concise and updated overview of the phytochemical composition and pharmacological properties of *S. flavescens*, with a particular focus on its root-derived bioactive compounds. This review emphasises the therapeutic relevance of underexplored flavonoids and the well-known alkaloids, as well as highlights their molecular mechanisms of action, including the modulation of oxidative stress, induction of apoptosis, and regulation of the TLR2/NF-κB pathway. In addition, it discusses formulation challenges and the potential of nanotechnology-based delivery systems to enhance bioavailability and clinical translation. Herein, a narrative review approach was adopted to facilitate the integration of diverse findings from recent literature and to assess the pharmacological evidence on traditional ethnomedicinal applications. This synthesis aims to support future research and promote the development of *S. flavescens* as a potential therapeutic agent.

Materials and Methods

This narrative literature review followed a systematic search strategy to compile and evaluate peer-reviewed publications related to the phytochemical and pharmacological properties of *S. flavescens.*[15] A comprehensive literature search was performed across PubMed, ScienceDirect and Google Scholar using combinations of keywords such as '*Sophora flavescens*', 'phytochemistry', 'alkaloids', 'flavonoids', 'pharmacological activity' and 'nanodelivery systems'. Articles published in English between 2000 and 2025 were considered. The inclusion criteria encompassed *in vitro*, *in vivo*, or mechanistic studies that specifically addressed the phytochemical constituents or

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therapeutic applications of *S. flavescens*. Non-English language papers, reviews without experimental validation, and conference abstracts were excluded. Titles and abstracts were screened for relevance, and selected articles were assessed in full. This review strategy enabled the synthesis of recent evidence, highlighting the pharmacological significance and translational potential of *S. flavescens* in modern therapeutic research.

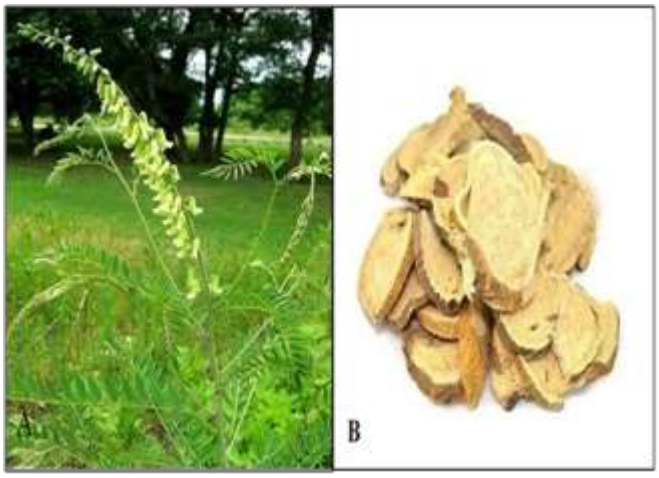


Figure 1: Morphological features of *S. flavescens*. (A) flowering plant of *S. flavescens*, (B) dried root slices of *S. flavescens*.

Results and Discussion

Phytochemical Composition of S. flavescens Root

The phytochemical screening of *S. flavescens* root identified many bioactive constituents, including alkaloids, flavonoids, saponins, terpenoids, polysaccharides, and glycosides, while tannins were notably absent (Table 1). These compounds are generally categorised into four major pharmacologically active classes, alkaloids, flavonoids, saponins, and polysaccharides, each contributing significantly to the plant's therapeutic potential.[4] Quinolizidine alkaloids, particularly matrine and its N-oxide derivative, oxymatrine, are the most abundant constituents, responsible for the root's characteristic bitterness, and have been extensively documented for their antiviral, anticancer, and anti-inflammatory properties.[16] Flavonoids, such as kurarinone, sophoraflavanone G, and maackiain, are major contributors to the antioxidant and anti-inflammatory effects of *S. flavescens*. Typically, these phenolic compounds are extracted using ethyl acetate or methanol and are characterised by hydroxyl and methoxy substitutions on the flavanone backbone, influencing their polarity and biological activity.[17] Triterpenoid saponins, including soyasaponin I and kaikasaponin III, also possess immunomodulatory and haemolytic effects. Due to their amphiphilic characteristic, these saponins interact with cellular membranes, potentially enhancing the absorption and bioavailability of co-administered compounds.[18] Notably, phytochemical content may vary due to environmental and cultivation factors, which should be considered in pharmacological evaluations.[19] These findings are consistent with previous reports on other *Sophora* species but highlight the unique flavonoid profile of *S. flavescens*, particularly its lavandulyl-type flavonoids, which are relatively uncommon in related genera.

Pharmacological Activities of S. flavescens Root

The pharmacological effects of *S. flavescens* root are primarily attributed to its abundant alkaloids and flavonoids. These bioactive compounds exhibit a wide range of therapeutic activities, including antimicrobial, antioxidant, anticancer, anti-inflammatory, hepatoprotective, and neuroprotective effects, as demonstrated by both *in vitro* and *in vivo* studies (Table 2 and Figure 2).

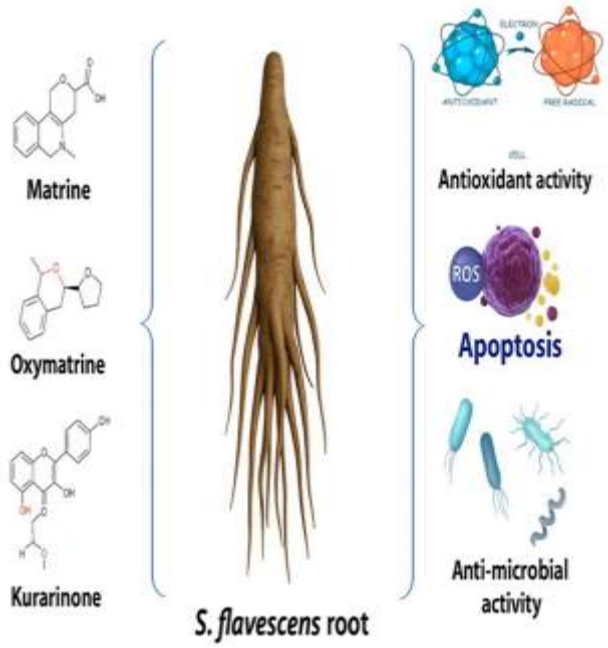


Figure 2: Summary of major pharmacological activities of *S. flavescens* root and its bioactive constituents

Mechanisms of Action

The pharmacological effects of *S. flavescens* root are mediated through multiple molecular pathways, including the generation of reactive oxygen species (ROS), the induction of apoptosis, and the inhibition of biofilm formation. Root extracts have been shown to induce ROS in microbial pathogens and cancer cells, leading to oxidative damage and cellular apoptosis.[64] Recent findings also confirm its antifungal activity via CYP51 enzyme inhibition and ROS-mediated fungal cell damage.[68] Both flavonoids and alkaloids modulate redox-sensitive pathways[69] and also regulate Bcl-2, Bax, and caspase proteins.[70] Matrine and oxymatrine increase the mitochondrial membrane permeability, facilitating cytochrome c release and caspase activation.[71] *S. flavescens* disrupts bacterial quorum-sensing, inhibiting biofilm formation and microbial resistance.[72] Kushenol C and D suppress the TLR2/NF-κB inflammatory pathway.[12] These multifaceted mechanisms, including ROS generation, apoptosis induction, anti-inflammatory signalling, and quorum-sensing inhibition, are summarised in Figure 3.

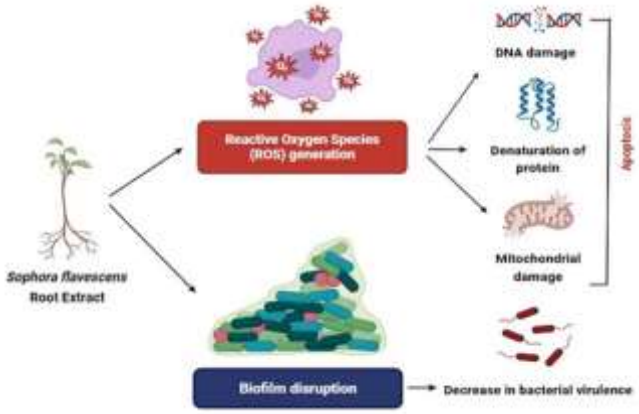
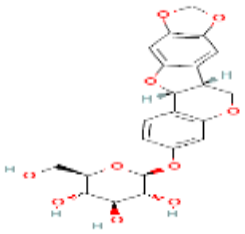
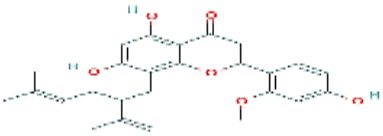
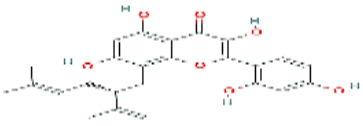
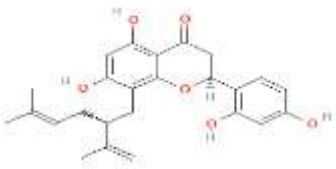


Figure 3: Mechanistic pathways of *S. flavescens* root extract

Table 1: Phytochemical screening of *S. flavescens* root

S/N	Phytochemical compounds	Structure	References
1	Oxymatrine		4, 12, 16
2	Sophoridine		13, 20
3	Matrine		16, 21, 22
4	Trifolirhizin		23, 24
5	Isokurarinone		6, 25
6	Kushenol C		14, 12, 26
7	Sophoraflavanone G		8, 27

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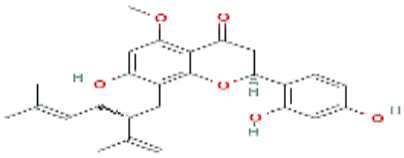
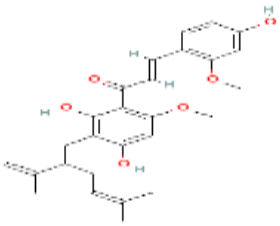
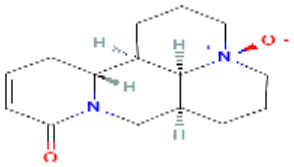
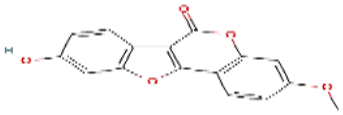
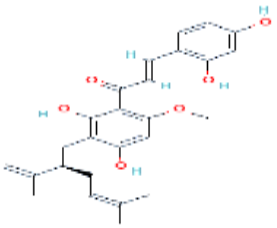
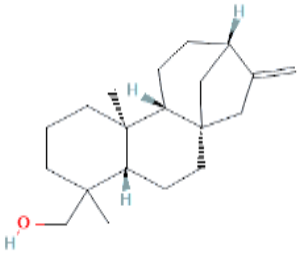
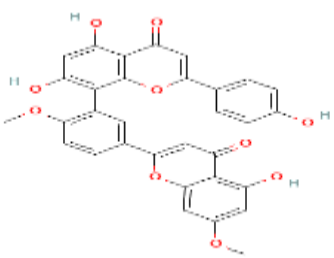
8	Kurarinone		12, 27
9	Kushenol D		14, 28
10	Sophocarpidine		14,29
11	3-O-Methylcoumestrol		30
12	Kuraridin		31,32
13	Kaur-16-en-19-ol		33
14	Ginkgetin		34,35

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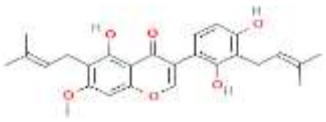
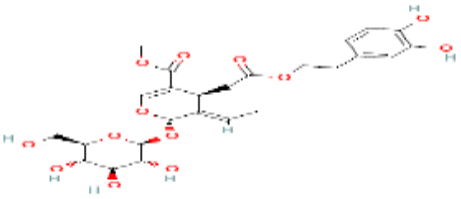
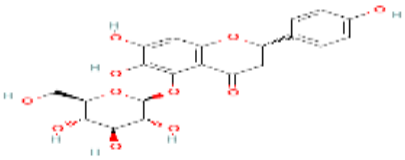
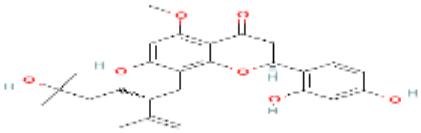
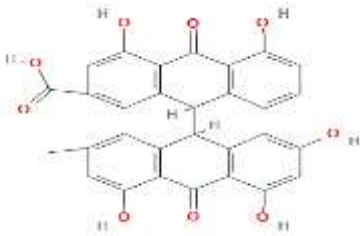
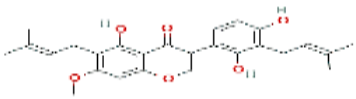
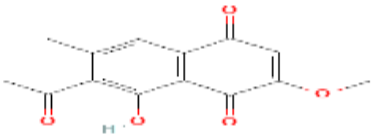
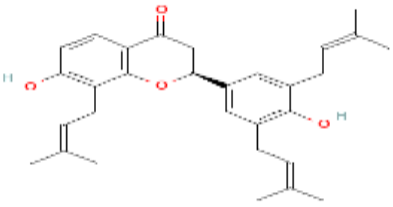
15	Kanzonol K		36
16	Oleuropein		37
17	Neocarthamin		38
18	Kurarinol		39
19	Rheidin A		40
20	Kanzonol G		41
21	Orientalone		42
22	Sophoranone		43

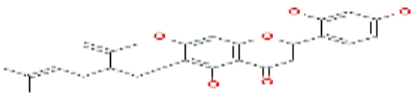
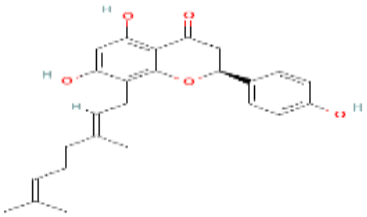
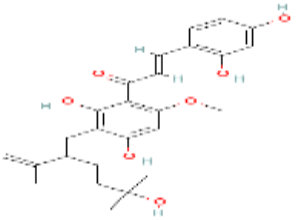
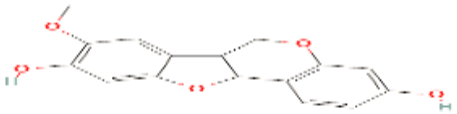
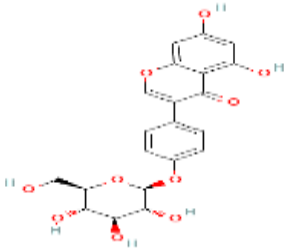
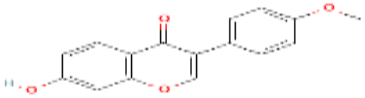
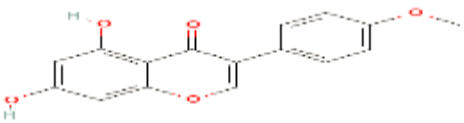
	Kurarinol		
23	Kushenol F		39 44
24	Kushenol E		45
25	Sophoraflavanone A		46
26	Kuraridinol		47
27	Kushenin		48
28	Sophoricoside		49
29	Formononetin		50
30	Biochanin A		51

Table 2: Pharmacological activities of major bioactive compounds from *S. flavescens* root

S/N	Pharmacological Activity	Bioactive Compounds	Mechanism of Action	Model/Assay	References
1	Antimicrobial	Sophoraflavanone G, matrine, oxymatrine	Membrane disruption, ROS generation, DNA gyrase inhibition	*In vitro* (*MRSA*, *E. coli*)	52,53,54,55
2	Antioxidant	Kurarinone, kushenol C, kuraridin, isoxanthohumol	DPPH/ABTS scavenging, upregulation of antioxidant enzymes	*In vitro* antioxidant assays	56,57,58,59
3	Anticancer	Matrine, oxymatrine, trifolirhizin, kurarinone, sophoranone	Apoptosis induction, NF-κB and PI3K/Akt/mTOR inhibition, mitochondrial disruption	A549, A2780, HCT116, colorectal models	14, 20, 60, 61,62,63
4	Anti-inflammatory	Kushenol C, kurarinone	TLR2/NF-κB inhibition, cytokine suppression (TNF-α, IL-6, COX-2)	LPS-activated macrophages	12, 64, 65
5	Hepatoprotective	Matrine, sophoridine	Antioxidant effects, stabilization of liver enzymes	CCl_4-induced hepatotoxicity	11, 12, 26
6	Neuroprotective	Kurarinone, matrine	Amyloid-β inhibition, ROS suppression, anti-inflammatory signaling	Neuronal cells, AD models	21, 66, 67

Abbreviations: ROS, reactive oxygen species; DPPH, 2,2-diphenyl-1-picrylhydrazyl; ABTS, 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); NF-κB, nuclear factor kappa-light-chain-enhancer of activated B cells; PI3K/Akt/mTOR, phosphatidylinositol 3-kinase/protein kinase B/mammalian target of rapamycin; TLR2, toll-like receptor 2; TNF-α, tumor necrosis factor-alpha; IL-6, interleukin-6; COX-2, cyclooxygenase-2

Challenges in Drug Development and Clinical Applications

Despite the promising pharmacological effects, the clinical translation of *S. flavescens* is limited due to the poor bioavailability of matrine and oxymatrine, which have short half-lives (1.5-4.7 h).[73] A previous study has reported hepatotoxicity, neurotoxicity, and environmental risks.[74] Herb-drug interactions may reduce the efficacy of co-administered agents such as indinavir via cytochrome P450 family 3 subfamily A (CYP3A) and P-glycoprotein induction.[75] Phytochemical variability across sources complicates standardisation, with matrine levels differing by up to 40%.[76] Owing primarily to preclinical evidence, rigorous clinical trials are essential. Nanocarrier systems and standardised formulations are critical to ensure therapeutic translation. Addressing these challenges requires future research to focus on innovative delivery systems, omics-based standardisation, and well-designed clinical trials.

Conclusion

S. flavescens root possesses significant pharmacological potential, supported by a diverse profile of bioactive compounds, particularly alkaloids and flavonoids. These constituents contribute to various therapeutic activities, including antimicrobial, antioxidant, anticancer, anti-inflammatory, hepatoprotective, and neuroprotective effects, through mechanisms such as oxidative stress modulation, apoptosis induction, and inflammatory pathway regulation. However, limitations such as poor bioavailability, toxicity concerns, and insufficient clinical validation currently hinder its clinical application. Thus, future research should focus on developing standardised formulations, improving delivery through nanotechnology-based systems, and conducting rigorous clinical trials. Integrating omics technologies and sustainable sourcing approaches will further support the safe and effective translation of *S. flavescens* into modern therapeutic use.

Conflict of Interest

The author`s declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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