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SHORT REVIEW

Argemone mexicana: A Traditional Healer's Herb in the Age of Scientific Scrutiny

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Abstract

Argemone mexicana, commonly known as Mexican prickly poppy or Satyanashi, has long played a significant role in traditional medical systems worldwide. This review examines its ethnobotanical relevance, various pharmacological activities, and current scientific findings. *A. mexicana* contains isoquinoline alkaloids, flavonoids, and phenolics, which have antibacterial, anti-inflammatory, antimalarial, antidiabetic, cytotoxic, nematicidal, wound-healing, anti-stress, and anti-fertility properties. Modern phytochemical investigations indicate bioactives such as berberine, sanguinarine, chelerythrine, and galanthamine, which contribute to its broad-spectrum medicinal potential. Traditional uses include treating skin infections, respiratory ailments, and liver illnesses, as well as controlling reproductive health and parasites. However, its medical usage is limited by toxicological concerns, particularly the seed oil's link with epidemic dropsy and organ toxicity. To avoid these concerns, researchers are investigating green nanoparticle manufacturing and customised medication delivery methods. *A. mexicana* appears as a potential yet challenging medicinal herb. To fully achieve its potential, the emphasis is on dose standardisation, safety evaluations, and integrative research. In an age of increasing antibiotic resistance and the need for plant-based therapies, *A. mexicana* epitomises the synthesis of old knowledge and current pharmacological technology.

Major Findings: *Argemone mexicana* shows medicinal promise, but toxicity limits its use; research focuses on safer applications *via* green nanoparticles and drug delivery.

Keywords: Alkaloids, Ethno Medicine, Nanoparticles, Phytochemicals, Toxicity

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1. Introduction

Since ancient times, human beings have been using the medicinal properties of plants to treat diseases[1]. This tradition continues to the present day and is deeply rooted in traditional medicine systems, particularly in India, where traditions like *Ayurveda* still utilise plant medicines to remain healthy and prevent illness[2]. Not only do these systems preserve the collective wisdom of the past, but they also offer solutions that are being integrated into modern medicine through testing[3]. Many botanicals that had long been used in the past for medicine have today been analysed scientifically and integrated into contemporary pharmacology[4]. Fields like ethnobotany and ethno-pharmacology are central to connecting traditional plant utilisation with contemporary drug development[5]. The modern search for new drugs is now an extensive endeavour that involves rigorous taxonomic characterisation, chemical fingerprinting, bioassays, and genetic characterisation[6]. These multidisciplinary methods have aided in the discovery of numerous bioactive molecules of tremendous therapeutic potential[7]. Recent developments in phytochemistry, especially in the comprehension of Structure–Activity Relationships (SARs), have hastened the discovery of effective plant-derived molecules for the management of chronic and infectious diseases[8]. Medicinal plants have exhibited impressive effectiveness against severe health issues like oncological diseases, viral infections like HIV, metabolic syndromes like diabetes, autoimmune diseases, and a broad spectrum of communicable and lifestyle-related diseases[9].

Globally, the commercial potential of phytopharmaceuticals is rapidly expanding[10]. The current market size for herbal-based medications is estimated at over USD 60 billion, and projections suggest this figure could surpass 5 trillion by the year 2050, reflecting increased consumer preference for natural and plant-origin therapies[11]. Despite having identified only about 10,000 of the estimated 400,000 secondary metabolites, researchers continue to explore this vast molecular diversity to develop novel drugs[12]. Natural products contribute significantly to the global pharmacopoeia, with approximately 25% of current medications being plant-derived[13]. In low- and middle-income nations, 70–80 % of the population still relies primarily on herbal medicine due to its affordability, availability, and lower risk of adverse effects compared to synthetic pharmaceuticals[14]. *A. mexicana* is an annual herb species known for its medicinal value[15]. The plant can thrive in varied climates, ranging from temperate to subtropical regions, and is found growing in areas covering India, Nepal, Bangladesh, the United States, Fiji Islands, and Mauritius[16]. It grows in India at altitudes of up to 1,500 meters, usually on abandoned agricultural land, indicating its adaptability and resilience[17]. The plant has been reported to be promising in indigenous medicines for the treatment of skin diseases, fever, and microbial infections[18]. In addition to traditional uses, recent research is investigating the anti-cancer, antimicrobial, and hepatoprotective effects of some lesser-exploited medicinal plants[19]. Standardisation of the dose, optimisation of extraction, and synergistic activity with synthetic drugs are also under investigation to enhance therapeutic action[20]. Summer-developing blooms and seeds, *A. mexicana* or Mexican prickly poppy grows best in hot and semi-desert conditions[21]. Traditionally, roots, leaves, stems, seeds, and flowers have been in use for ages due to their pharmacological significance[22]. They are used to treat minor skin lesions to carcinomas, metabolic disorders, and infections induced by micro oragnisms[23]. From *A. mexicana*, phytochemicals have newly discovered different bioactive compounds such as alkaloids (berberine, sanguine), flavonoids, phenolics, and terpenoids that exhibit antioxidant, anti-inflammatory, anti-diabetic, antiviral, and anticancer activity[24]. Other drug studies have arisen from studies on the plant for anthelmintic, analgesic, and wound-healing activity[25]. Pandemic dropsy is caused by toxic alkaloids present in the seed oil of the plant[26]. If one knows the therapeutic benefits along with the toxicological risks, then the use of the plant for medicinal purposes is safe.

2. Common and Regional Names of *A. mexicana*

Argemone mexicana, commonly known to be of ethnobotanical and medicinal significance, also possesses various other general names such as Mexican prickly poppy, Mexican poppy, Prickly poppy, and Satyanashi in India. The utilisation, cultural identity, and distribution in most countries have made the

plant hold multiple local names across numerous different regions and languages. In Southeast Asia, it is *druju* in Javanese; *Chelang keringan* and *pokok popi* in Malaysian; *Deruju* in Indonesia; *Diluariu* in Tagalog (Philippines); *Fin naam* in Bangkok, Thailand; and *Gai cua, Mufi cua*, and *Caf gai hoa vafng* in Vietnamese. Other local names include *Kachumba* and *kasubang-aso* in Iloko (Philippines); *Chicalote* and *Cardosanto* in Mexico; and *Khaya* in Myanmar.

In the Indian subcontinent, the diversity of languages gives rise to multiple names for *A. mexicana*:

- *Siyal-Kanta* in Bengali
- *Darudi* in Gujarati
- *Bharband, Shialkanta*, and *Satyanashi* in Hindi
- *Jungli* post in Jammu and Kashmir
- *Datturigidda* in Kannada
- *Kantankattiri* and *Ponnummattu* in Malayalam
- *Daruri* and *Firangi dhotra* in Marathi
- *Dhaturi* in Rajasthani
- *Kudiyotti, Ponnummuttai*, and *Perammathandu* in Tamil
- *Brahmadandi* and *Brahmadandicettu* in Telugu

In traditional Ayurvedic literature, the plant has been mentioned by Sanskrit synonyms like *Brahmadandi, Kshirini, Pitopushpa, Srigalkanta, Swarnakshiri*, each emphasising a particular feature of its appearance or medicinal attribute[27]. The diversity of local names is testimony to the ethnobotanical significance of *A. mexicana* across cultures, and its long-standing use in folk medicine, agriculture, and rural livelihoods[28-30].

3. Methodology

In order to give a comprehensive and evidence-based overview of *A. mexicana*, a systematic search was conducted using a variety of focused keywords and Boolean operators. Keywords searched were "traditionally used," "traditional medicine," "phytochemistry," "secondary metabolites," "phytoconstituents," "pharmacological uses," "pharmacological significance," and "toxicology". To narrow the search results and select studies that have well-defined therapeutic relevance, specific pharmacological terms like "antioxidant," "antimicrobial," "anticancer," "anti-inflammatory," "antidiabetic," and "analgesic" were employed along with the name of the plant, *i.e.*, "*A. mexicana* ". The sources of the literature were diverse electronic databases and online libraries such as PubMed, Scopus (Elsevier), Google Scholar, Research Gate, NOPR, and MAPA. These platforms were chosen because of their extensive indexing of peer-reviewed articles and importance to *ethnobotany*, pharmacology, and natural product chemistry. The screening method focused on papers published in English between January 2000 and March 2022. After applying certain inclusion and exclusion criteria,181 research papers were originally retrieved. Following abstract screening, duplicate checks, and relevance evaluations, 130 papers were chosen for further study and inclusion in this review. This thorough search method made sure that the literature chosen included both old and new scientific proof, which helped us get a better understanding of *A. mexicana* and all of its useful properties.

4. Taxonomy and Botanical Identification of *A. mexicana*

The plant grows 50-150 cm tall and is upright, branching, and thorny (Figure 1). It has bluish-green, deeply lobed leaves with yellow spines and brilliant yellow, six-petal blooms that bloom singly on terminal branches. Its injured stems and leaves leak a yellow latex, which helps identify it. The plant's spiky, rectangular capsules release many tiny, round, glossy black seeds when mature. The tropical American plant *A. mexicana* has spread to India, Southeast Asia, Africa, and Latin America. It thrives in dry and semi-arid conditions on roadsides, wastelands, abandoned fields, and disturbed soil in summer. Its durable nature, capacity to colonise disturbed soils, and drought resilience make it ecologically valuable, while its characteristic form makes field identification straightforward (Table 1).

5. Traditional Uses of *A. mexicana*

The extensive medicinal legacy of *A. mexicana* is a testament to its longstanding role in diverse healing traditions across continents[31]. Various plant parts—including the roots, seeds, leaves, flowers, and yellow latex, have been utilised for centuries due to their potent therapeutic value[32,33]. In Indian traditional systems, the latex and leaf extracts are widely applied topically to treat eczema, scabies, ringworm, ulcers, and

non-healing wounds[34]. While the seed oil is considered toxic in large doses, it is used in regulated quantities for the relief of joint inflammation and rheumatic pain[35]. In rural communities, particularly in northern India, burning or smoking the seeds is a home remedy for toothache and respiratory congestion[36]. A wide variety of therapeutic uses based on specific plant parts is summarised in Table 2.

In Himalayan ethno-medicine, the plant's fresh juice mixed with honey is traditionally given to patients suffering from malaria[37], while leaf decoctions are administered to support liver function, particularly in cases of jaundice and viral hepatitis[38]. In African countries like Mali, Sudan, and Benin, *A. mexicana* is used as part of traditional antimalarial preparations, with Mali even producing a commercial herbal product named Malarial-5@[39]. In Ethiopia, the aqueous root extract, locally called *Yahya eshoh,* is used in traditional medicine to treat rabies[40]. The regional diversity in usage and cultural practices of *A. mexicana* is summarised in Table 3.

Apart from its medical relevance, the plant has agro-ecological value. In Mexico, its bio-insecticidal properties are employed in organic farming to control insect pests, especially in vegetable crops[41]. In India, the plant is occasionally grown along field margins to deter grazing livestock, as the bitter latex and sharp spines make it unpalatable to animals[42]. In *Ayurveda*, the herb is incorporated into preparations such as *Svarnakshiri churna*, valued for its purgative, diuretic, and anti-inflammatory effects[43]. It is traditionally prescribed for conditions like leprosy, bilious fevers, scorpion bites, constipation, and dysentery. The bright yellow flowers, known for their expectorant properties, are used in treating cough, asthma, and bronchial congestion[44]. The plant exhibits multiple pharmacological properties, as

Table 1. Taxonomical Classification of *A. mexicana*

Taxonomic Rank	Classification
Kingdom	*Plantae*
Subkingdom	*Tracheobionta* (Vascular plants)
Division	*Magnoliophyta* (Angiosperms)
Class	*Magnoliopsida* (Dicotyledons)
Order	*Ranunculales*
Family	*Papaveraceae* (*Poppy* family)
Genus	*Argemone*
Species	*Argemone mexicana*



Figure 1. *Argemone mexicana* plant showing characteristic spiny leaves and bright yellow flowers.

Table 2. Traditional uses based on plant parts

Plant Part	Traditional Use	Mode of Application
Leaves	Liver ailments, jaundice, gum infections, and fever	Decoction, mouthwash, poultice
Flowers	Cough, asthma, bronchitis	Expectorant infusion
Seeds	Toothache, snakebite antidote, constipation, sedative	Smoke inhalation, oral use
Root	Rabies, pain, eye disorders	Aqueous extract, juice
Latex	Skin infections, ulcers, leprosy, scorpion sting	Topical application
Whole Plant	Malarial infections, antibacterial, diuretic, purgative effects	Juice, decoction

Table 3. Regional ethno-medicinal applications

Region/country	Traditional application	Preparation/use
India (Himalayan region)	Malaria, liver disorders, skin infections	Plant juice with honey, latex application
Mexico	Snake venom antidote, organic pesticide	Seed paste, bio-insecticide extract
Mali / Sudan / Benin	Malarial infections	Whole plant in decoction (*Malarial-5®*)
Ethiopia (Amhara region)	Rabies treatment	Root extract (*Yahya eshoh*)
South America	Kidney pain, labour pain, headaches	Herbal tea
India (*Unani* system)	Leukoderma, skin diseases	Seed paste
Ayurveda (India)	Fever, scorpion sting, dysentery, bilious disorders	Churna, taila (powder and oil formulations)
Homeopathy	Tapeworm and intestinal parasites	Tinctures and dilutions

outlined in Table 4, which further explain its medicinal versatility.

In the *Unani* tradition, seeds are used to treat leukoderma and long-standing skin diseases[45], whereas homoeopaths use plant tinctures as medicine to cure worms in the gut, particularly tapeworms[46]. In Central and South America, beverages made from different plant parts are used traditionally to alleviate kidney pain, headache, and pain during childbirth[47]. Etymologically, the name *Argemone* is derived from the Greek word *"argema,"* denoting ocular diseases. In traditional medicine, the milky sap of the plant has been employed to treat conjunctivitis and corneal opacities[48]. The sedative and laxative effects of the seeds also justify their use for the treatment of mild anxiety, insomnia, and gastrointestinal disorders[49]. Existing scientific studies confirm the plant's antipyretic, anti-inflammatory, and broad-spectrum antibacterial activity, reiterating its therapeutic importance and renewing interest in integrative medicine and ethno-pharmacology[50]. *A. mexicana*, with its ethnically confirmed usage and potential bioactive profile, is a valuable natural product for enabling affordable rural healthcare and enhancing sustainable agriculture.

Table 4. Common therapeutic properties and uses

Pharmacological Property	Associated Traditional Use
Antimicrobial	Skin infections, gum diseases
Antimalarial	Malaria treatment across India and Africa
Expectorant	Cough, asthma, bronchitis
Laxative	Constipation
Sedative	Mild anxiety, insomnia
Antidote	Snake bites
Antiseptic	Wound healing, eczema, ulcers
Purgative	Digestive detox, leprosy-related treatment
Diuretic	Dropsy, water retention

6. Phytochemistry of *A. mexicana*

Plant-based bioactive compounds have been essential in traditional medicine and human health for decades. The plant is unique because it has a complex phytochemical composition and several pharmacological properties. Secondary metabolites such as alkaloids, flavonoids, tannins, glycosides, phenols, terpenoids, saponins, and gums have been found in various parts of the plant, for instance,

leaves, stems, flowers, and roots[51]. Recent research on phytochemicals has established that the aqueous flower extract had the highest phenolic content (14 mg/g), followed by leaves (7.5 mg/g), fruits (4.62 mg/g), and stems (2.5 mg/g)[52]. Patel *et al.*,[53] have documented Methanolic stem extracts as having the highest total phenolic content (28.5 ± 1.15 mg GAE/g) and flowers with the highest flavonoid content (41.76 ± 0.74 mg QE/g). GC-MS profiling has reflected a diverse combination of chemical compounds, including steroids, aldehydes, ketones, amino acids, and heterocyclic compounds[54]. Alkaloids are the most abundant and therapeutically significant compounds in this plant. Berberine (0.041%) and protopine (0.084%) occur in ethanol extracts[55], while seeds store the maximum amount of dihydrosanguinarine, followed by berberine and sanguinarine[56]. A few other important alkaloids of the plant include chelerythrine, allocryptopine, coptisine, and dihydrochelerythrine. The seed oil of the plant contains harmful keto fatty acids like 11-oxo-octacosanoic acid and 11-oxotricontanoic acid that give it a unique yellowish colour[57]. Aerial part extracts yielded benzophenanthridine and benzylisoquinoline-type alkaloids such as (+)-argenaxine, (+)-reticulin, pancorine, and *N*-demethyloxysanguinarine[58]. New compounds have been isolated recently from methanolic extracts, such as argemexicaine A and B, 13-oxoprotopine, mexitin, protomexicine, and 8-methoxydihydrosanguinarine and flavonoids such as rutin and quercetin[59]. Nonacosane (C_{29}) and octadecane (C_{18}) were the major hydrocarbons in *n*-hexane leaf extracts[60]. The dichloromethane root extracts had alkaloids with anti-inflammatory and neuroprotective activities such as galanthamine, magnoflorine, palmatine, and coptisine[61]. These results are consistent with the traditional medicinal uses of the plant and indicate its potential in the development of new drugs for microbial infections, inflammatory diseases, and neurological disorders. Recent developments in analytical methods like high-resolution mass spectrometry and NMR have greatly facilitated our knowledge about the phytochemistry of the species, and again, the significance of this species is heightening in the fields of ethno-medicine and contemporary pharmaceutical research[50].

7. Pharmaceutical Applications

7.1 Antimicrobial Activity of *A. mexicana*

Increased occurrences of drug-resistant microorganisms have enhanced the focus on medicinal plants such as *A. mexicana*, which possesses high antimicrobial activity[59,60]. Methanolic and ethanolic seed, leaf, and stem extracts of the plant possess high inhibitory effects against a wide range of pathogens. Methanol seed extracts showed significant antibacterial activity against *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Escherichia coli*, and *Bacillus subtilis* with inhibition diameters of 22, 18, 21, and 20 mm, respectively[61]. Chloroform extracts showed MIC values between 2.0 and 5.0 mg/mL because of the presence of active alkaloids and flavonoids[62,63]. Ethanol extracts also showed significant activity against *E. coli, S. aureus, Proteus vulgaris,* and *Candida albicans*, whose MICs range from 6 to 18 mg/mL[64]. Silver nanoparticles prepared from *A. mexicana* leaf extracts exhibited antibacterial and antifungal properties[65], whereas iron oxide nanoparticles treated with ethanol extracts inhibited E. coli and Proteus mirabilis growth effectively[66]. Chloroform fractions of seed extracts containing N-demethyloxysanguinarine also showed marked antibacterial effects by disrupting bacterial membranes[67]. Stem extracts of *A. mexicana* have been effective against foodborne pathogens such as *Listeria monocytogenes*, *Clostridium botulinum*, and *Salmonella typhimurium*, producing inhibition zones up to 21.4 mm[68]. Ethanol has been identified as the most efficient solvent for extracting bioactive antimicrobial compounds. These findings highlight the potential of *A. mexicana* as a promising natural source of antimicrobial agents, particularly for addressing antibiotic resistance and infections in clinical and food-related contexts.

7.2 Anti-inflammatory Activity of *A. mexicana*

Argemone mexicana shows strong anti-inflammatory activity, largely because of its rich alkaloids, flavonoids, and phenolic constituents[69]. Traditionally used to treat pain and inflammation, empirical studies now validate these ethnomedicinal claims. Methanol and ethanol leaves, stems, and roots plant extracts exhibit tremendous anti-inflammatory action in *in vivo* and *in vitro* models. Swelling was impressively decreased through ethanol extracts during a carrageenan-induced

rat paw oedema test by showing equal activity to reference anti-inflammatory drugs diclofenac sodium[70]. Inhibition of the pro-inflammatory mediators, that is, NO, prostaglandins, and cytokines, is suggested to be behind the anti-inflammatory action. Isoquinoline alkaloids, such as berberine, sanguinarine, and chelerythrine, are part of this function[62]. They inhibit the Cyclooxygenase (COX) and Lipoxygenase (LOX) pathways, which are pivotal to inflammatory reactions. The antioxidant activity of flavonoids and polyphenols found in the plant eliminates oxidative stress, thus modulating inflammation[60]. Recent research has shown that the dichloromethane root extract of *A. mexicana* contains galanthamine, magnoflorine, palmatine, and coptisine, substances known for their neuroprotective and anti-inflammatory effects[66]. The results suggest that the plant could be developed to treat inflammatory and autoimmune diseases. *A. mexicana* exhibits considerable anti-inflammatory activity, which supports its historical uses and provides new avenues for plant-based medicines.

7.3 Anti-stress and Antiallergic Activity of *A. mexicana*

Besides its traditional application concerning antibacterial and analgesic properties, recent pharmacological research has demonstrated that the plant also possesses anti-allergic and anti-stress activity[71]. The primary bioactive compounds with high activity to decrease stress and the immune system are alkaloids (berberine and protopine), flavonoids, and saponins. Experimental models indicate that stress-induced behavioural response in mice is demonstrated by plant methanolic extracts; this is illustrated in decreased anxiety-like behaviour in open field tests and enhanced plus maze[72]. Isoquinoline alkaloids' action in the central nervous system will produce effects perhaps crossing GABAergic and serotonergic pathways[73]. Plant Flavonoids' antioxidant effect protects against oxidative stress, a key element of chronic psychological stress and associated diseases[60]. By reducing lipid peroxidation and enhancing the activity of antioxidant enzymes such as catalase and superoxide dismutase (SOD), plants may prove useful under stress. By mast cell stabilisation, suppression of histamine release, and eosinophilic infiltration in sensitised animal models, chloroform and methanol extracts exert antiallergic activity[74]. Reported to inhibit pro-inflammatory cytokines and IgE-mediated hypersensitivity responses, the alkaloids sanguinarine and chelerythrine were found to exhibit such activities, indicating potential applications for allergic rhinitis, asthma, and other hypersensitivity conditions. *A. mexicana* exhibits preliminary adaptogenic and antiallergic activity, but further clinical trials are needed to confirm its efficacy in stress and allergic illnesses.

7.4 Wound Healing Activity of *A. mexicana*

Healing of wounds is a dynamic physiological process that includes inflammation, proliferation, and remodelling of tissue[75]. Traditional medicines have employed plant-based therapy to treat skin wounds, and plants are known to contain high *phytochemicals* and to regenerate. Methanolic leaf extracts of *A. mexicana* enhanced healing of wounds in Wistar albino rats with excision, incision, and dead space wound models[76]. With respect to earlier solvent extracts, Kumar *et al.*[77] reported quicker wound contraction, reduced epithelialisation time, and greater tissue strength. Another study reported that alcoholic root extracts applied as an ointment significantly promoted rates of wound closure and proliferation of the epithelium[78]. At a dose of 400 mg/kg, the ethyl acetate fraction of the fruit enhanced collagen fibre deposition, increased neovascularisation, and tensile strength[79]. The experiment showed marked inhibition of oedema and augmented granuloma formation, showing its role in the healing of tissue and inflammation control[80]. Polyherbal products containing *A. mexicana* and other medicinal plants are more effective, *e.g.*, faster revascularisation, reduced microbial load, and higher granulation tissue development, which points towards a synergistic effect on wound healing[81]. *Phytochemicals* of the plant, *e.g.*, berberine, chelerythrine, and flavonoids, have been found to enhance fibroblast proliferation, enhance angiogenesis, and regulate cytokine activity, favouring fast tissue regeneration[76]. The antibacterial activity also prevents infection in the wound, providing cleaner healing conditions[82,83]. *A. mexicana* is a tissue-regenerative and antibacterial plant with several possible uses, such as treating wounds and skin injuries.

7.5 Anti-fertility Activity of *A. mexicana*

Plant has been conventionally used in a few traditional systems of folk medicine for reproductive health management, and recent research has shown its potential anti-fertility activity in male and female models[84]. Experimental studies with ethanolic and methanolic seed and root extracts documented the reduced fertility indices in rodents[85]. Treatment of ethanolic extracts in female rats resulted in fewer implantation sites and disrupted oestrous cycles, which indicates anti-implantation and ovulation-suppressing activities[86]. Histopathological studies showed changes in uterine and ovarian tissues, *i.e.*, thinning of the endometrium and atresia of follicles, possibly due to hormonal imbalance triggered by plant bioactives[87]. Seed extracts in male rats induced a significant decrease in the motility, count, and viability of sperms, and in serum testosterone levels[88]. Testicular histopathology indicated seminiferous tubule degeneration, reduction in spermatogenic cell layers, and altered Leydig cell function[89]. These reproductive alterations are attributed to the action of bioactive alkaloids such as sanguinarine and berberine, which may act on the hypothalamic-pituitary-gonadal axis or exert direct cytotoxic action on gametogenic cells[82]. Flavonoids and phenols might also play a role through interference with prostaglandin production and uterine contractility[90]. *In vitro* studies further revealed that *A. mexicana* extracts suppress fertilisation by impacting the integrity of the zona pellucida and reducing sperm-egg binding[91]. These findings suggest their potential use in the development of plant-derived contraceptive drugs, though toxicity and safety testing are essential before they can be used in humans.

7.6 Antidiabetic Activity of *A. mexicana*

Diabetes mellitus is a chronic metabolic disorder occurring in millions of people worldwide[92]. *Ayurveda* practice has more and more employed herbal remedies for the regulation of blood sugar. *A. mexicana* revealed promising antidiabetic potential against diabetic animal models in preclinical studies[93]. *A. mexicana* aerial parts aqueous extracts lowered the blood glucose level in alloxan-induced diabetic rats significantly at doses of 200 and 400 mg/kg compared with normal antidiabetic drugs such as glibenclamide (5 mg/kg)[94]. Hydroalcoholic extracts administered orally in a dose of 150 mg/kg for 21 days brought serum biochemical parameters such as cholesterol, triglycerides, urea, and creatinine into normalcy and enhanced body weight in diabetic rats[95]. Antidiabetic activity of the plant was also confirmed in streptozotocin-induced diabetic Wistar albino rats, where hydroalcoholic extracts (400 mg/kg) possessed significant reductions in fasting blood glucose levels, similar to metformin (300 mg/kg)[96]. Hypoglycaemic activity was exhibited by chloroform and aqueous fractions, due to their high antioxidant activity[97]. Phytochemical estimation indicates flavonoids, alkaloids, and phenolic compounds in *A. mexicana* increase insulin sensitivity and provide protection to pancreatic β-cells[98]. Treatment increased endogenous antioxidant defence systems, as represented by elevated levels of glutathione (GSH) and catalase (CAT), which are usually low in diabetes[99]. Plant possesses therapeutic value in the management of diabetes and its complications through glycaemic control, antioxidant action, and lipid modulation[100]. Toxicological and clinical investigations are required for validation in human subjects.

7.7 Antimalarial Activity of *A. mexicana*

Plant has been used in traditional medicine for centuries to treat febrile diseases, especially in malarial-endemic areas[101]. Current scientific studies confirm the antimalarial efficacy of the compound, which is mainly due to its high concentration of isoquinoline alkaloids, including berberine, chelerythrine, and sanguinarine[102]. Ethanolic and aqueous extracts proved to be strong *in vitro* activators against *Plasmodium falciparum*, their IC_{50} being in the range 15-25 µg/mL, strain depending[103]. *In vivo* studies on chloroquine-standardised mice infected with *Plasmodium berghei* revealed the efficacy of the oral treatment by ethanolic leaf extract to reduce parasitemia and show improved survival when administered at dosages of 200-400 mg/kg and compared with regular drugs such as chloroquine[104]. The reported effects are likely due to the interference of the plant with parasite metabolism and detoxification processes of heme, besides its antioxidant activities that antagonise host oxidative stress during infection[105]. Among the significant case studies in Burkina Faso, one examined the ethno-pharmacological utilisation of *A. mexicana* decoctions for the treatment of uncomplicated malaria by rural

communities[106]. During a high season of malaria with restricted availability of conventional antimalarial drugs, local health workers gave an infusion of a plant prepared from its aerial parts to the patients suffering from the disease[107]. Clinical follow-ups indicated a dramatic improvement in fever and parasitemia after five days, particularly among patients with mild and moderate symptoms[108]. The World Health Organisation acknowledged this community-based programme as an effective model of incorporating traditional medicines into primary care in underserved populations[109]. This is an example of the potential of the plant as a cost-effective and easily accessible antimalarial agent in circumstances where there is restricted access to pharmaceutical agents[110]. *A. mexicana* exhibits encouraging activity under laboratory and field conditions, indicating its potential as an antimalarial medicinal plant[111]. However, large-scale clinical trials and toxicity tests must be conducted in order to confirm its safety and efficacy for more extensive use.

7.8 Cytotoxic Activity of *A. mexicana*

In vitro studies have confirmed the cytotoxic potential of *A. mexicana* against both healthy and cancerous cell lines[112]. Uddin *et al.*[113] employed the MTT assay to assess the effects of methanolic leaf extract on healthy mouse fibroblasts (NIH3T3) and three human cancer cell lines: AGS (gastric carcinoma), HT-29 (colon adenocarcinoma), and MDA-MB-435S (breast carcinoma). The extract demonstrated the highest activity against MDA-MB-435S cells, with an IC_{50} of 1.82 mg/mL, suggesting a selective cytotoxic effect. Subsequent research conducted by Chang *et al.,*[114] examined the cytotoxic effects of specific alkaloids extracted from *A. mexicana*. Chelerythrine exhibited the highest efficacy against human gastric cancer (NUGC) cell lines, whereas angoline displayed inhibitory effects on both nasopharyngeal carcinoma (HONE-1) and NUGC lines (Figure 2).

Moderate cytotoxicity was noted for (+)-argenaxine, while compounds such as N-demethyloxysanguinarine, pancorine, (+)-higenamine, and (+)-reticuline exhibited differing levels of activity. Bioactive alkaloids are thought to exert cytotoxic effects through the induction of apoptosis, disruption of cell cycle progression, and modulation of intracellular signalling pathways in tumour cells. Chelerythrine is recognised for its function in inhibiting Protein Kinase C (PKC), a pathway frequently linked to cancer progression and survival. The evidence indicates that both crude extracts and isolated alkaloids from plants exhibit significant anticancer potential. Further studies are necessary to evaluate their selectivity, toxicity, and mechanisms *in vivo* prior to considering therapeutic applications.

7.9 Nematicidal Activity of *A. mexicana*

Argemone mexicana has been identified as a promising botanical nematicide that is effective against economically significant root-knot nematodes, with a particular emphasis on Meloidogyne incognita and *M. javanica*, according to recent research[115]. Aqueous and methanolic extracts from the plant's leaves and seeds have been shown to cause considerable juvenile mortality and limit nematode growth in host plants[116]. In recent controlled greenhouse tests, foliar and soil treatments of aqueous extracts (0.2-0.5%) significantly decreased root galling and nematode populations in crops like okra and chickpeas[117]. Treated plants also had higher root biomass and protein content than untreated controls, demonstrating both protective and restorative effects on host tissues[118]. Methanolic and polar solvent extracts proved to be more nematicidal effective compared to non-polar extracts, most likely due to the enhanced solubility of the bioactive flavonoids and alkaloids[119]. These compounds have been found to interfere with neuromuscular function and metabolic processes in worm larvae, leading to rapid immobilisation and death[120]. Current research

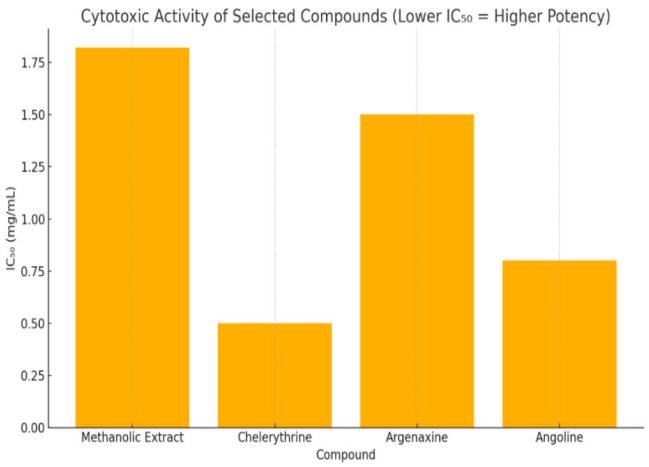


Figure 2. IC_{50} values of selected *A. mexicana* compounds indicate their cytotoxic potency.

has also considered the application of *A. mexicana* in nanoparticle-based delivery systems[121]. Silver nanoparticles with their leaf extract green-synthesised showed enhanced nematode death and reduced root infection in brinjal and tomato plants, likely due to enhanced penetration and enhanced bioactivity for longer durations[122]. In addition, seed-soaking treatments with aqueous plant extracts have proved to be effective in curbing early-stage invasion by nematodes and can thus serve as a potential pre-sowing preventive measure in nematode-susceptible areas[123]. In light of growing demand for environment-friendly and residue-free alternatives to chemical nematodes, *A. mexicana* presents an effective natural means for integrated nematode control[124].

8. Toxicological Profile of *A. mexicana*

While the plant possesses several therapeutic properties, its toxicological potential cannot be overlooked. The plant contains toxic isoquinoline alkaloids such as sanguinarine, berberine, dihydrosanguinarine, and chelerythrine, which are primarily responsible for its adverse effects when consumed in excess or unregulated forms.

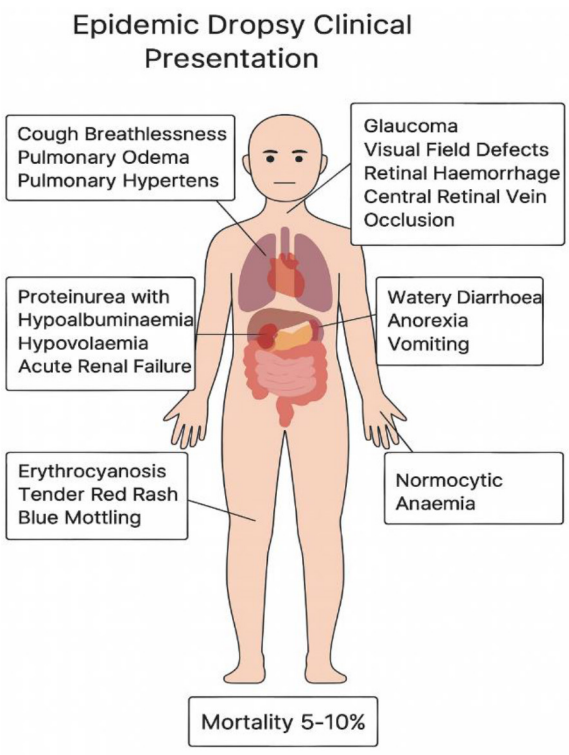


Figure 3. Symptoms of epidemic dropsy due to argemone oil contamination affect multiple organs.

8.1 Seed Oil and Epidemic Dropsy

Argemone mexicana seed oil, commonly adulterated with edible oils, has been found to cause epidemics of epidemic dropsy, a poisonous disease with the symptoms of oedema, diarrhoea, glaucoma, and failure of the heart[125] as shown in Figure 3. The condition occurs primarily due to the toxicity of sanguinarine and dihydrosanguinarine, which damage mitochondrial activity and capillary permeability[126].

8.2 Organ Toxicity and Cytotoxicity

Latest research has indicated that long-term exposure to the plant extracts, particularly in higher doses, induces hepatotoxicity, nephrotoxicity, and haematological alterations in animal models[127]. Significant elevation of serum liver enzymes (ALT, AST), urea, and creatinine has been noted, indicating likely liver and kidney tissue damage[128]. Histopathological findings have also indicated hepatic and renal architectural degeneration in toxic doses[129]. Moreover, methanolic extracts have demonstrated cytotoxic effects not only against cancerous cells but also on normal fibroblast cell lines, indicating that the therapeutic window must be carefully determined[130]. To mitigate these toxicological risks, several detoxification strategies have been explored. **Modern processing techniques,** such as hydro-distillation, solvent partitioning, or selective purification, help eliminate harmful alkaloids while preserving beneficial *phytochemicals*. **Encapsulation technologies,** including nano- and microencapsulation, enable controlled release and targeted delivery, thereby reducing systemic toxicity. Additionally, **dose optimisation based on therapeutic index** ensures safe administration by balancing efficacy and potential harm. Together, these methods enhance the safety profile of *A. mexicana* for potential pharmacological use.

8.3 Reproductive Toxicity

High-dose treatments in male rodents have shown evidence of spermatotoxic effects, reduced sperm viability, and testosterone suppression, indicating potential reproductive toxicity if misused[131].

9. Safe Use Considerations

Despite its medicinal value, *A. mexicana* should not be used without proper dosage standardisation. Topical and external uses may be safer in controlled concentrations, but oral intake must be cautiously monitored or avoided unless formulated under clinical guidance. Ongoing research is focusing on nanoparticle encapsulation and targeted delivery systems to reduce systemic toxicity while preserving therapeutic benefits.

10. Conclusion

Plant is a robust and fascinating herb with multiple possible medicinal uses, but also with a toxicity risk. The bioactive plant, founded on ancient knowledge that dates back thousands of years and ratified by recent scientific data, displays an interesting pharmacological profile consisting of antibacterial, antimalarial, anti-inflammatory, antidiabetic, and cytotoxic activities. Each plant part, such as roots, leaves, seeds, latex, and flowers, possesses medicinal potential due to its high and diverse content of phytoconstituents, like the isoquinoline alkaloids and flavonoids. The plant stands out as it is both therapeutic and hazardous: therapeutic against fatal diseases like cancer, infection, metabolic disorder, and reproductive health, yet hazardous when used inappropriately, especially because of the toxic hazard of seed oil, which leads to epidemic dropsy and organ damage. The fine line that exists between treatment and risk creates an enormous necessity for clinical medical evidence, rigorous dose standardisation, and safety in preparation. Plant is a ray of hope in the modern struggle against drug resistance, untreatable disease, and the call for ecologically friendly medical science, a blending of ancient medicinal wisdom with postmodern pharmacological healthcare practitioners, to appreciate its significance in holistic medicine. The plant shows us that the best of nature's medicines are frequently masked in complexity, perhaps through threatening defences and foul-tasting extracts. When employed rightly and precisely, plants can revolutionise the field of phytotherapy. Future research should now focus on validating the plant's therapeutic claims through in vivo experiments and well-structured clinical trials, while also assessing formulation safety to minimise toxic effects. Moreover, its medicinal use must be aligned with international regulatory frameworks, such as the WHO guidelines on the safe use of herbal medicine, to ensure public health protection and promote evidence-based phytotherapeutic development.

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12. Author Contribution

Conceptualisation: M.N. and PB.; methodology: M.N., A., and I.K.; software: N.S. and D.N.; validation: M.N. and I.K.; formal analysis: A. and I.K.; investigation: M.N., A., and P.S.V.; resources: S.Sa. and G.S.; data curation: D.N. and N.S.; writing and original draft preparation: M.N. and A.; writing, review and editing: I.K.; visualisation: P.A.P. and Sh.S.; supervision: M.N. All authors have read and agreed to the published version of the manuscript.

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