Lawsonia inermis (Henna): phytochemistry, pharmacological activities, ethnomedicinal uses, and safety perspectives—A comprehensive review

JOSEPH RAYMOND ENOGHASE[1*], FAITH OSAIYEKEMWEN EDOKPOLO[2]

[1]Department of Anatomy, School of Basic Medical Sciences, University of Benin, Benin City, Nigeria
[2]Department of Environmental Management and Toxicology Faculty of Life Sciences, University of Benin, Benin City, Nigeria
*Corresponding author: email: joseph.enoghase@bmedsci.uniben.edu

Received: November 17, 2025
Accepted: December 10, 2025
Published on-line: December 31, 2025
Published: December 31, 2025

Lawsonia inermis* L. (Lythraceae), popularly known as henna, is an ancient cosmetic and medicinal plant widely used across Africa, Asia, and the Middle East. Although several reviews have summarized its ethnomedicinal relevance, few have integrated recent mechanistic, toxicological, and biotechnological findings. To provide an updated and comprehensive synthesis of the phytochemistry, pharmacological mechanisms, ethnomedicinal applications, and safety perspectives of *L. inermis*, highlighting advances from 2020–2025 and identifying future research directions. Data were collected from peer-reviewed journals indexed in Scopus, PubMed, and Google Scholar using the keywords *Lawsonia inermis*, lawsone, pharmacology, toxicity, and ethnomedicine. Emphasis was placed on recent experimental and analytical studies elucidating molecular mechanisms and structure–activity relationships. More than seventy secondary metabolites have been reported, dominated by naphthoquinones, flavonoids, triterpenes, and phenolics. Modern evidence demonstrates that *L. inermis* exerts antioxidant, anti-inflammatory, antimicrobial, hepatoprotective, anticancer, and wound-healing effects primarily through activation of Nrf2/ARE signaling, inhibition of NF-κB and COX-2, and modulation of apoptotic and fibrotic pathways. Toxicological evaluations indicate a wide safety margin for leaf-based preparations, whereas toxicity is mainly associated with adulterants such as *para*-phenylenediamine (PPD) and excessive dosing. Emerging industrial applications include green nanocomposites, biosorbents, and natural dyes. This updated review extends earlier literature by linking phytochemical diversity to specific molecular mechanisms, integrating safety and regulatory data, and outlining translational and biotechnological opportunities. Future research should prioritize standardization, pharmacokinetics, and clinical validation to enable evidence-based therapeutic utilization of *L. inermis*.

Keywords: *Lawsonia inermis*; henna; phytochemistry; pharmacology; molecular mechanisms; toxicity; ethnomedicine; safety; bioactive compounds

https://doi.org/10.61652/leksir2545341E

1. INTRODUCTION

Lawsonia inermis L. (Lythraceae) remains one of the most intensively studied ethnomedicinal shrubs in tropical and subtropical regions, valued both as a cosmetic dye and as a traditional remedy for infectious and inflammatory disorders (Al-Snafi, 2019; Rekik et al., 2019). Numerous reviews have summarized its general pharmacology and chemistry; however, most were published before 2020 (Al-Snafi, 2019; Borade et al., 2011; Chaudhary et al., 2010) and emphasize descriptive rather than mechanistic aspects (Batiha et al., 2024; Salma et al., 2024). Since then, new analytical, pharmacological, and toxicological studies have clarified compound–target relationships and molecular pathways underlying its biological effects.

Recent work (2020–2025) has documented: (i) novel metabolites identified through LC-MS and metabolomics (El-Fitiany et al., 2025), (ii) in-depth mechanistic studies describing Nrf2/ARE-mediated antioxidant and NF-κB-dependent anti-inflammatory effects (Aremu, 2023; Eldeeb et al., 2025), and (iii) toxicological reassessments distinguishing natural extracts from para-phenylenediamine (PPD)-adulterated commercial hennas (Moutawalli et al., 2023). These advances justify a contemporary, integrated evaluation.

Therefore, the present review expands upon earlier syntheses

by (a) collating phytochemical and pharmacological data from 2000–2025 with emphasis on mechanistic interpretation, (b) highlighting safety and regulatory findings rarely discussed in previous reviews, and (c) proposing translational perspectives for therapeutic and industrial development. This approach demonstrates how *L. inermis* research has progressed from descriptive ethnomedicine toward evidence-based phytopharmacology.

Table 1. Botanical features of *Lawsonia inermis*

Characteristic	Description
Family	Lythraceae
Habit	Shrub/small tree (2–7 m)
Leaves	Opposite, elliptic-lanceolate, 1.5–5 cm
Flowers	Small, fragrant, white/pink, in panicles
Fruits	Brown globose capsules
Seeds	Angular
Distribution	Africa, Asia, Middle East, sub-Saharan Africa

2. BOTANICAL DESCRIPTION AND DISTRIBUTION

L. inermis is a perennial, glabrous, branched shrub or small tree ranging from 2 to 7 meters in height. Its young branches are quadrangular and green, turning red with age. The leaves are small, opposite, entire, elliptic to lanceolate, and measure 1.5–5 cm long and 0.5–2 cm wide. Flowers are small, fragrant, white or pink, arranged in large pyramidal panicles, and produce small brown globose capsules containing angular seeds (Sen et al., 2023). The plant thrives in semi-arid and tropical climates, distributed widely across North Africa, the Middle East, South Asia, and parts of sub-Saharan Africa (Orwa et al., 2009). It is often cultivated along watercourses and hedges due to its drought resistance and ability to withstand harsh climatic conditions.

Table 1 highlights the essential morphological features of *L. inermis* which aid in its identification and botanical classification. The adaptability of the plant to diverse climates supports its wide ethnomedicinal use.

Beyond morphology, several anatomical and ecological factors influence the plant's phytochemical profile. Glandular trichomes located on young leaves and floral tissues serve as major sites of naphthoquinone biosynthesis (Santra et al., 2023). The concentration of lawsone and associated flavonoids varies with climate, soil pH, and post-harvest drying temperature; leaves harvested during peak sunlight contain significantly higher pigment and phenolic content (Youl et al., 2024).

Chemotype studies reveal regional differences: Indian accessions produce higher lawsone (1.4–1.8 %) whereas North-African strains show greater essential-oil diversity (Elaguel et al., 2019). Such variability underscores the need for standardization when comparing pharmacological outcomes across studies.

3. ETHNOMEDICINAL AND TRADITIONAL USES

The ethnobotanical applications of *L. inermis* span thousands of years:

Table 2 summarizes traditional uses across different cultures. It illustrates the plant's versatile applications beyond cosmetics, highlighting its systemic and gynaecological uses, especially in traditional medicine systems.

Traditional applications can be grouped into dermatological, systemic, and reproductive categories, each corresponding to experimentally verified pharmacological effects. For instance, topical henna pastes used for wounds and burns align with modern evidence of enhanced fibroblast proliferation and collagen synthesis (Rekik et al., 2019). Decoctions employed for jaundice and liver disorders are consistent with its experimentally demonstrated hepatoprotective action mediated by Nrf2-driven antioxidant responses (Enoghase et al., 2024). Similarly, its historical use for fever and arthritis corresponds with observed COX-2 and cytokine inhibition in animal models (Oladunmoye and Kehinde, 2011; Tsao et al., 2020).

Recent ethnopharmacological surveys in Sudan, India, and Nigeria (2021–2023) confirm ongoing reliance on henna for both medicinal and cosmetic purposes, indicating cultural continuity and therapeutic relevance (Okoye et al., 2021; Sen et al., 2023). Nevertheless, variations in dosage forms—leaf infusions, pastes, or smoke inhalation—pose challenges for scientific validation, underscoring the need for harmonized preparation protocols.

4. PHYTOCHEMISTRY OF *LAWSONIA INERMIS*

Phytochemical investigations have identified over 70 secondary metabolites in *L. inermis*, predominantly naphthoquinones, flavonoids, triterpenes, sterols, coumarins, xanthones, and fatty acids (El-Fitiany et al., 2025; Mahkam et al., 2014; Okoye et al., 2021). Lawsone (2-hydroxy-1,4-naphthoquinone) remains the principal bioactive constituent responsible for its dyeing property and multiple pharmacological actions. Biosynthetically, lawsone arises via the shikimate–acetate pathway, with 1,4-naphthoquinone intermediates produced through polyketide cyclisation.

Structure–activity insights reveal that hydroxyl substitution on the quinone ring confers redox activity enabling electron transfer and free-radical scavenging, explaining its antioxidant and antimicrobial potency (Mustapha et al., 2024). Triterpenes such as betulinic acid and lupeol contribute to anti-inflammatory and anticancer effects through modulation of Mitogen-Activated Protein Kinase (MAPK) and caspase cascades (Naishadham et al., 2013).

Advances in analytical chemistry, LC–MS/MS, GC–MS, and NMR spectroscopy, have refined compound identification and quantification. Metabolomic profiling now differentiates chemotypes by regional origin and correlates specific metabolite fingerprints with biological potency (El-Fitiany et al., 2025). The adoption of green extraction techniques (ultrasound-assisted, supercritical CO_2) further improves yield and reproducibility (Liew et al., 2022).

Table 2. Ethnomedicinal and traditional uses of *Lawsonia inermis*

Category	Applications
Cosmetic	Hair dyeing, nail staining, body art, rituals (Chengaiah et al., 2010)
Dermatological	Wound healing, burns, ulcers, fungal infections (Rekik et al, 2019)
Systemic	Liver tonic, febrifuge, treatment for jaundice, diarrhea, dysentery (Al-Snafi, 2019; Buddhadev and Buddhadev, 2016)
Gynaecological	Menstrual regulation, menorrhagia, abortifacient (Aguwa, 1987)
General Medicine	Blood tonic, analgesic for headaches, fever, arthritis pain (Al-Snafi, 2019)

Table 3. Major phytochemical constituents of *Lawsonia inermis*

Class	Examples	References
Naphthoquinones	Lawsone, isoplumbagin, dihydroxynaphthalenes	(Mahkam et al., 2014; Okoye et al., 2021)
Terpenoids/Triterpenes	Hennadiol, lupeol, betulin, betulinic acid	(Naishadham et al., 2013)
Sterols	β-sitosterol, stigmasterol, lawsaritol	(Youl et al., 2024)
Flavonoids/Phenolics	Gallic acid, tannins, apigenin, luteolin, acacetin	(Manivannan et al., 2015)
Xanthones/Coumarins	Laxanthones I–III, lacoumarin	(Bhardwaj and Garg, 1977)
Essential Oils	Linalool, α-ionone, β-ionone	(Elaguel et al., 2019)
Fatty Acids	Linolenic, oleic, palmitic, stearic	(Sharma et al., 2016)
Trace Elements	Fe, Cu, Mn, Mo, Ca, Na, K oxides	(Boubaya et al., 2011)

Table 4. Pharmacological activities of *Lawsonia inermis*

Activity	Findings / Effects	References
Antimicrobial	Inhibits *S. aureus*, *E. coli*, *Salmonella*, fungi, dermatophytes	(Al-Snafi, 2019; Matotoka et al., 2023)
Anti-inflammatory	Reduced inflammation in animal models	(Tsao et al., 2020)
Immunomodulatory	Enhanced phagocytic activity, antibody modulation	(Chaudhary et al., 2010)
Antioxidant	Increased antioxidant enzyme levels, reduced lipid peroxidation	(Elaguel et al., 2019)
Hepatoprotective	Protection against toxin-induced damage, lead acetate protection	(Enoghase et al., 2024)
Anticancer	Cytotoxicity against MCF-7, HepG2, carcinoma cell lines	(Kapadia et al., 2013; Kamal and Jawaid, 2010)
Wound Healing	Accelerated wound closure, collagen synthesis	(Amrita and Singh, 2001; Rekik et al., 2019)
Nootropic	Enhanced memory and learning	(Mir et al., 2019)
Tuberculostatic	Activity against *Mycobacterium tuberculosis*	(Sharma, 1990)
Molluscicidal	Effective against snail vectors	(Al-Snafi, 2019)

Table 3 provides a chemical breakdown of *L. inermis*. Lawsone is the major dye compound, while flavonoids, sterols, and terpenoids contribute to its pharmacological versatility.

5. PHARMACOLOGICAL ACTIVITIES

Table 4 consolidates the wide pharmacological spectrum of *L. inermis*.

Recent investigations reveal that the pharmacological spectrum of *L. inermis* extends far beyond traditional wound-healing or antimicrobial claims. Modern research integrates biochemical assays, molecular docking, and *in vivo* pathway analyses to clarify mechanistic underpinnings. The following subsections summarize major activities with emphasis on mechanisms and experimental context.

5.1. Antioxidant mechanisms

Henna extracts demonstrate strong free-radical-scavenging activity across DPPH, ABTS, FRAP, and ORAC assays, frequently exceeding 80 % inhibition at 100 μg mL^{-1} (Elaguel et al., 2019; El-Fitiany et al., 2025). Flavonoids such as quercetin and catechin donate electrons to neutralize reactive oxygen species (ROS) while lawsone undergoes reversible redox cycling that quenches singlet oxygen. *In vivo*, leaf extract administration significantly increases superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) and lowers lipid peroxidation (MDA) (Eldeeb et al., 2025). These findings support activation of the Nrf2/ARE pathway, leading to transcriptional up-regulation of antioxidant enzymes.

5.2. Anti-inflammatory and analgesic effects

In carrageenan-induced paw-oedema and formalin pain models, ethanolic henna leaf extract produced 54–63 % inhibition comparable to diclofenac (Tsao et al., 2020). Mechanistic assays reveal down-regulation of COX-2, iNOS, TNF-α, and IL-6, with suppression of NF-κB p65 nuclear translocation (Batiha et al., 2024). Molecular docking studies show strong binding affinity of lupeol and lawsone to COX-2 catalytic residues, confirming structure-based anti-inflammatory potential (Mahkam et al., 2014).

5.3. Antimicrobial and antifungal activities

Henna exhibits broad antimicrobial activity against *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella typhi*, and multiple fungi including *Candida albicans* (Al-Snafi, 2019; Matotoka et al., 2023). The mechanism involves disruption of microbial membranes and inhibition of bacterial DNA gyrase and β-lactamase enzymes. Electron microscopy demonstrates cell-wall disintegration after exposure to lawsone-rich fractions. Incorporation of henna extract into biopolymer films further enhances antimicrobial properties for wound-dressing applications (Liew et al., 2022).

5.4. Anticancer and cytotoxic potential

Cytotoxicity against MCF-7 (breast), HepG2 (liver), and HeLa (cervical) cell lines has been attributed to induction of mitochondrial-mediated apoptosis (Kamal and Jawaid, 2010; Kapadia et al., 2013). Recent studies report cell-cycle arrest at G_2/M phase through modulation of p53, Bax/Bcl-2, and caspase-3/9 (El-Fitiany et al., 2025). Lawsone derivatives isolated in 2023 exhibited lower IC_{50} values (22–45 μM) and selectivity toward tumor cells. Docking simulations reveal strong interactions with topoisomerase II and tubulin-binding domains, suggesting multi-target cytotoxicity (Diogo, 2025).

5.5. Hepatoprotective and renoprotective effects

Administration of hydro-ethanolic henna extract (200 mg kg^{-1}) protected rats from carbon-tetrachloride- and lead-acetate-induced hepatotoxicity, significantly reducing serum ALT, AST, ALP, and bilirubin (Enoghase et al., 2024). Histopathology confirmed restoration of hepatic architecture. Mechanistically, activation of Nrf2/HO-1 and inhibition of TGF-β1 signaling prevent oxidative and fibrotic damage. In nephrotoxicity models, henna normalized creatinine and blood urea nitrogen (BUN) while decreasing renal malondialdehyde (MDA), indicating antioxidant-based nephroprotection (Firdous and Fayed, 2021).

5.6. Wound-healing and dermatological applications

Topical gels containing 5–10 % henna extract accelerated wound closure in rats versus controls (El Massoudi et al., 2023; Rekik et al., 2019). Increased hydroxyproline, collagen, and

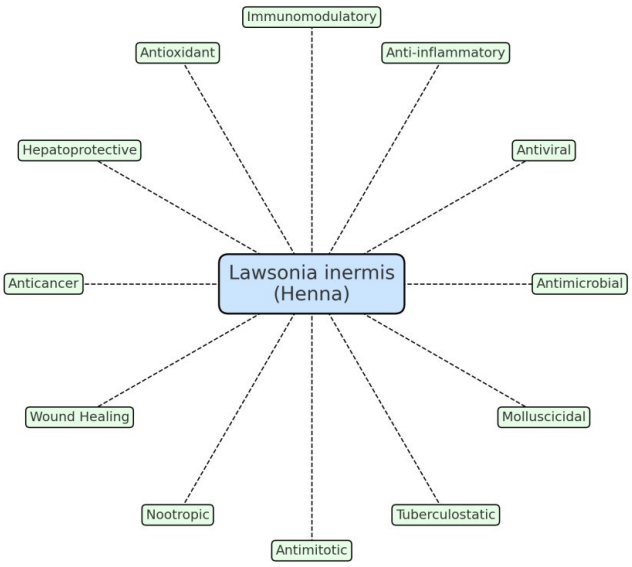

Figure 1. Pharmacological activities of *Lawsonia inermis*

angiogenesis indicate enhanced fibroblast activity. These outcomes substantiate ethnomedicinal claims and validate henna's use in modern wound-care formulations.

5.7. Neuropharmacological and cognitive effects

Aqueous extracts improved learning and memory retention in mice exposed to scopolamine, correlating with elevated hippocampal acetylcholine and antioxidant enzyme levels (Abaissou et al., 2020). The activity likely arises from modulation of acetylcholinesterase and attenuation of neuro-oxidative stress.

5.8. Industrial and biotechnological applications

Beyond medicine, henna constituents serve as natural dyes, corrosion inhibitors, and biosorbents for heavy-metal removal (Abd-El-Haleem, 2023). Recent nanotechnology studies incorporated henna extract into ZnO and Fe_3O_4 nanocomposites exhibiting dual antimicrobial and photocatalytic activity, linking phytochemistry with environmental remediation.

5.9. Integrative summary

Collectively, these findings indicate that *L. inermis* exerts multitarget pharmacological actions mediated by redox regulation, enzyme inhibition, and signal-transduction modulation. The diversity of molecular targets (Nrf2, NF-κB, p53, COX-2) positions henna as a promising candidate for multitarget phytotherapy.
This schematic diagram illustrates the diverse pharmacological effects of *L. inermis*, including antimicrobial, anticancer, hepatoprotective, antioxidant, and immunomodulatory actions Figure 1. The central placement of the plant name reflects its role as a multipurpose medicinal species, while the surrounding activities highlight its multidimensional pharmacological potential.

6. SAFETY AND TOXICOLOGICAL CONSIDERATIONS

Table 5 underscores the dual nature of *L. inermis*: while generally safe at traditional doses, higher concentrations and adulterated preparations can cause toxicity. Its abortifacient activity necessitates caution in pregnancy.
Toxicological evaluations indicate that *L. inermis* is generally safe at therapeutic doses, yet specific extracts and adulterated products present distinct risks.

6.1. Acute and sub-chronic toxicity

In mice, oral administration of aqueous or ethanolic leaf extracts up to 5000 g kg^{-1} produced no mortality or behavioral abnormalities (Aremu et al., 2022). Sub-chronic dosing (28 days, 400 mg kg^{-1}) elicited no significant alterations in hepatic or renal histology (Enoghase et al., 2024; Firdous and Fayed, 2021). However, seed extracts at higher concentrations (≥ 1 g kg^{-1}) have produced mild hepatocellular vacuolation and elevated serum enzymes (Moutawalli et al., 2023). These effects are reversible upon cessation, suggesting adaptive metabolic stress rather than irreversible injury.

6.2. Reproductive and developmental effects

Early experimental reports (Aguwa, 1987) and subsequent animal studies indicate that *L. inermis* extracts can have uterotonic and abortifacient effects: Aguwa (1987) reported dose-dependent pregnancy termination in rodents, while later experimental work showed pregnancy loss accompanied by increased serum estrogen and decreased progesterone after hydroalcoholic root extract (Esteki and Miraj, 2016), and uterotonic activity, estrous cycle disruption and reduced uterine/ovarian weights after seeds extract (Agabna et al., 2016).

6.3. Dermal and allergic reactions

Natural henna rarely causes dermatitis; most reported allergic responses result from adulteration with para-phenylenediamine (PPD) used to intensify color (Nadjib et al., 2013). Contact-patch testing confirms that pure henna is hypoallergenic, whereas "black henna" containing PPD triggers severe erythema and blistering. Regulatory bodies in the EU restrict PPD concentrations in skin products to < 2 %, and unapproved mixtures pose ongoing consumer risks (Al-Enezi and Aldawsari, 2022).

6.4. Hepato- and nephrotoxicity mechanisms

At supra-therapeutic doses, naphthoquinones such as lawsone can undergo redox cycling to generate semiquinone radicals, producing oxidative stress in hepatocytes and renal tubules (Revathi et al., 2025). Co-administration of antioxidants (vitamin E, N-acetylcysteine) mitigates these effects, confirming an ROS-mediated mechanism.

6.5. Human safety and regulatory status

Henna is approved for cosmetic use in many regions but not for systemic therapeutic claims. The United States Food and Drugs Administration (U.S. FDA) allow its application solely as a hair dye (Sienkiewicz-Szłapka et al., 2025). Clinical reports show that topical use of 5–10 % henna preparations is safe even on compromised skin, provided products are free of PPD and heavy-

Table 5. Toxicological and safety considerations of *Lawsonia inermis*

Aspect	Observation / Findings	References
Reproductive Toxicity	Abortifacient activity of roots in rodents	(Aguwa, 1987)
Hepatotoxicity/Nephrotoxicity	High doses of *L. inermis* seed extract have been reported to cause elevations in liver enzymes (AST, ALT, ALP) and mild histopathological changes in the liver, kidney, and gut, but without evidence of necrosis, hemorrhage, or overt organ dysfunction	(Moutawalli et al., 2023; Revathi et al., 2025)
Allergic Reactions	Dermatitis from adulterated products (PPD)	(Nadjib et al., 2013)
General Safety	Leaf-based extracts relatively safe; no overt toxicity at 400 mg/kg	(Enoghase et al., 2024)

metal contamination (Niazi et al., 2022). Nevertheless, henna should be avoided in individuals with G6PD deficiency, as lawsone can induce oxidative haemolysis in neonates and susceptible adults (Saghi et al., 2023).

6.6. Toxicokinetics and future safety needs

Limited pharmacokinetic data exist. Lawsone demonstrates rapid dermal absorption with conjugation to glucuronides and renal excretion (Nair et al., 2024). Future research should quantify systemic exposure after topical and oral administration to define precise safety margins.

6.7. Summary of safety profile

Overall, leaf-based preparations are considered low-toxicity when used appropriately. Safety concerns stem primarily from adulterants, excessive doses, or genetic predispositions (G6PD deficiency). Establishing standardized extract specifications and quality-control protocols will be essential for therapeutic development.

7. DISCUSSION AND FUTURE PERSPECTIVES

The present synthesis demonstrates that *L. inermis* remains a phytochemically and pharmacologically rich species with a wide safety margin when properly standardized. Yet despite decades of research, most investigations remain descriptive, with limited translational integration. The existing literature converges on several consistent mechanisms, chiefly antioxidant, anti-inflammatory, and antimicrobial effects, but comparatively few studies have verified these pathways *in vivo* or at the molecular target level.

Earlier reviews primarily catalogued plant uses and constituent classes (Batiha et al., 2024; Salma et al., 2024). The current review advances the field by consolidating recent (2020–2025) evidence on signaling pathways such as Nrf2/ARE, NF-κB, MAPK, caspase, and **p53**, thereby connecting the phytochemistry of henna to specific mechanistic outcomes. For example, the demonstration that lawsone and lupeol can directly inhibit COX-2 and activate antioxidant genes provides a biochemical rationale for traditional anti-inflammatory applications (Khantamat et al., 2021; Park et al., 2023).

Nonetheless, substantial research gaps persist:

- **Standardization and quality control:** Variability in lawsone and flavonoid content across regions hinders reproducibility. Adoption of validated chromatographic fingerprints and quantification of marker compounds are essential for pharmacopoeial standardization.
- **Dose–response and pharmacokinetics:** Only a handful of studies report plasma concentrations or metabolic pathways of henna constituents. Comprehensive pharmacokinetic profiling is required to predict bioavailability and guide safe dosage ranges.
- **Clinical translation:** Despite numerous animal experiments, controlled human trials of *L. inermis* remain scarce. A few small studies have evaluated henna in humans for indications such as wound healing (Niazi et al., 2022), and inflammatory dermatoses (Niazi et al., 2020), but robust trials are limited. Small pilot studies could further explore topical henna for chronic wounds, inflammatory skin conditions, or hepatoprotective effects.
- **Safety surveillance:** Post-marketing monitoring of commercial henna preparations is limited. Contamination with para-phenylenediamine or heavy metals continues to pose dermatologic and systemic risks. Harmonized quality-assurance frameworks similar to those for other herbal products are needed.
- **Omics and systems-biology approaches:** Integrative metabolomics, transcriptomics, and proteomics could elucidate compound synergy and network pharmacology, revealing new targets beyond oxidative stress pathways.
- **Industrial and environmental exploitation:** The application of henna derivatives in nanocomposites, biosorbents, and corrosion-inhibiting materials demonstrates untapped economic potential that merits further research under sustainable-production frameworks.

In summary, the research trend for *L. inermis* is shifting from ethnopharmacology toward evidence-based phytomedicine. To remain relevant and innovative, future studies should combine chemical standardization with mechanistic and translational approaches that meet modern regulatory expectations.

8. CONCLUSION

Lawsonia inermis (henna) represents a paradigmatic example of how a traditional plant remedy can evolve into a candidate for modern phytopharmaceutical development. Its broad spectrum of activity, encompassing antioxidant, anti-inflammatory, antimicrobial, hepatoprotective, and wound-healing effects, is now supported by mechanistic data linking specific compounds to molecular pathways. When used in standardized forms, leaf-based preparations demonstrate favorable safety profiles, while toxicities are largely restricted to adulterated or overdosed formulations.

This updated review contributes to the existing body of knowledge by integrating recent chemical and mechanistic discoveries with toxicological insights and industrial applications, thereby offering a holistic perspective that surpasses earlier descriptive reviews. Continued multidisciplinary research encompassing phytochemistry, molecular pharmacology, toxicology, and clinical sciences will be essential to translate henna from a traditional multipurpose plant into an evidence-based therapeutic and biotechnological resource.

AUTHOR CONTRIBUTIONS

Joseph Raymond Enoghase conceived the study and prepared the initial manuscript. Faith Osaiyekemwen Edokpolo contributed to data collection, literature analysis, and manuscript editing. All authors approved the final version.

CONFLICT OF INTEREST

The authors declare that they have no financial and commercial conflicts of interest.

FUNDING

No external funding was received for this work.

REFERENCES

Abaissou, H. H. N., Foyet, H. S., Wado, E. K., Nkwingwa, B. K., Kamda, J. L. D., Djomessie, L. B. K., others, and Bum, E. N. (2020): Cholinergic-enhancing and antioxidant effect of *Vigna subterranea* (L.) Verdc.(Fabaceae) landrace aqueous extract on scopolamine-induced amnesia in male swiss mice, *Pharmacognosy Research*, **12**(3), 303–312.

Abd-El-Haleem, D. A. (2023): Back to nature: henna extracts from nanotech to environmental biotechnology–a review, *BioTechnologia*, **104**(4), 421. https://doi.org/10.5114/bta.2023.132776

Agabna, N. M., Shaddad, S. A., Mudathir, A. K., Abulgassim, A. I., and Kalid, S. (2016): The effects of Lawsonia inermis seeds on estrus cycle and reproductive hormones of female albino rats, *World Journal of Pharmaceutical Research*, **5**(5), 266–280.

Aguwa, C. N. (1987): Toxic effects of the methanolic extract of *Lawsonia inermis* roots, *International Journal of Crude Drug Research*, **25**(4), 241–245. https://doi.org/10.3109/13880208709055201

Al-Enezi, M. H., and Aldawsari, F. S. (2022): Study of P-phenylenediamine (PPD) concentrations after hair dye mixing: a call for safety reassessment, *Cosmetics*, **9**(2), 41. https://doi.org/10.3390/cosmetics9020041

Al-Snafi, A. E. (2019): A review on *Lawsonia inermis*: A potential medicinal plant, *International Journal of Current Pharmaceutical Research*, **11**(5), 1–13. https://doi.org/10.22159/ijcpr.2019v11i5.35695

Amrita Singh, A. S., and Singh, D. K. (2001): Molluscicidal activity of *Lawsonia inermis* and it binary and tertiary combinations with other plant derived molluscicides, *Indian Journal of Experimental Biology*, **39**(3), 263–268.

Aremu, A. (2023): *Lawsonia inermis* linn. Positively improves the expression of various inflammatory cytokines and apoptotic cell death biomarkers of streptozotocin-induced diabetic wistar rats, *Veterinary Sciences and Practices*, **18**(3), 123–132. https://doi.org/10.5152/VetSciPract.2023.23150

Aremu, A., Oridupa, O. A., Akorede, G. J., Olatunji, A. O., Basiru, A., Ahmed, A. O., and Raufu, I. A. (2022): Safety evaluation of *Lawsonia inermis* on physiological, andrological and haematological parameters of male Wistar rats, *Journal of Basic Medical Veterinary*, **11**(2), 75–89. https://doi.org/10.20473/jbmv.v11i2.32483

Batiha, G. E. S., Teibo, J. O., Shaheen, H. M., Babalola, B. A., Teibo, T. K. A., Al-Kuraishy, H. M., others, and Papadakis, M. (2024): Therapeutic potential of *Lawsonia inermis* Linn: a comprehensive overview, *Naunyn-Schmiedeberg's Archives of Pharmacology*, **397**(6), 3525–3540. https://doi.org/10.1007/s00210-023-02735-8

Bhardwaj, D. K., Seshadri, T. R., and Singh, R. (1977): Xanthones from *Lawsonia inermis*, *Phytochemistry*, **16**(10), 1616–1617. https://doi.org/10.1016/0031-9422(77)84044-2

Borade, A. S., Kale, B. N., and Shete, R. V. (2011): A phytopharmacological review on *Lawsonia inermis* (Linn.), *International Journal of Pharmacy and Life Sciences*, **2**(1), 536–541.

Boubaya, A., Marzougui, N., Yahia, L. B., and Ferchichi, A. (2011): Chemical diversity analysis of Tunisian *Lawsonia inermis* L. populations, *African Journal of Biotechnology*, **10**(25), 4980–4987.

Buddhadev, S. G., and Buddhadev, S. S. (2016): Ayurvedic medicinal plant *Lawsonia inermis* Linn.: a complete review, *Pharma Science Monitor*, retrieved from internet: https://www.cabidigitallibrary.org/doi/full/10.5555/20163254128, **7**(2).

Chaudhary, G., Goyal, S., and Poonia, P. (2010): *Lawsonia inermis linnaeus*: a phytopharmacological review, *International Journal of Pharmaceutical Sciences and Drug Research*, **2**(2), 91–98. https://doi.org/10.25004/IJPSDR.2010.020202

Chengaiah, B., Rao, K. M., Kumar, K. M., Alagusundaram, M., and Chetty, C. M. (2010): Medicinal importance of natural dyes—a review, *International Journal of PharmTech Research*, **2**(1), 144–154.

Diogo, E. B. T. (2025): *Electrochemical sulfenylation and photocatalytic transformations as complementary tools for green organic synthesis*, phd, Universidade Federal de Minas Gerais, retrieved from internet: https://hdl.handle.net/1843/852.

El Massoudi, S., Zinedine, A., Rocha, J. M., Benidir, M., Najjari, I., El Ghadraoui, L., others, and Errachidi, F. (2023): Phenolic composition and wound healing potential assessment of Moroccan henna (*Lawsonia inermis*) aqueous extracts, *Cosmetics*, **10**(3), 92. https://doi.org/10.3390/cosmetics10030092

Elaguel, A., Kallel, I., Gargouri, B., Ben Amor, I., Hadrich, B., Ben Messaoud, E., Gdoura, R., Lassoued, S., and Gargouri, A. (2019): *Lawsonia inermis* essential oil: Extraction optimization by RSM, antioxidant activity, lipid peroxidation and antiproliferative effects, *Lipids in Health and Disease*, **18**(1), 196. https://doi.org/10.1186/s12944-019-1141-1

Eldeeb, F. A., Noseer, E. A., Abdelazeem, S., Ali, E., Basher, A. W., Abdalla, M. A. A., and Ibrahim, H. H. (2025): Effect of dietary supplementation of *Lawsonia inermis* and *Acacia nilotica* extract on growth performance, intestinal histopathology, and antioxidant status of broiler chickens challenged with coccidiosis, *BMC Veterinary Research*, **21**(1), 2. https://doi.org/10.1186/s12917-024-04409-w

El-Fitiany, R. A., El Nahas, R., Al Balkhi, S., Aljaeedi, S., Alblooshi, A., Hassan, F. M., Khaleel, A., Samadi, A., and Khasawneh, M. A. (2025): Alchemy in nature: The role of *Lawsonia inermis* extract choice in crafting potent anticancer metal nanoparticles, *ACS Applied Materials & Interfaces*, **17**(3), 4637–4661. https://doi.org/10.1021/acsami.4c19585

Enoghase, R. J., Osarinmwian, I. B., Osegbe, E. D., Abu, J., Abukadiri, M., and Ajufoh, C. Z. (2024): Hepatoprotective effects of *Lawsonia inermis* aqueous extract against lead acetate-induced liver injury in Wistar rats, *Medtigo Journal of Medicine*, **2**(4), e30622418. https://doi.org/10.63096/medtigo30622418

Esteki, R., and Miraj, S. (2016): The abortificient effects of hydroalcoholic extract of *Lawsonia inermis* on BALB/c mice, *Electronic Physician*, **8**(6), 2568. https://doi.org/10.19082/2568

Firdous, S. M., and Fayed, M. A. (2021): Evaluation of nephroprotective effects of *Lawsonia inermis* bark extract: A biochemical approach, *INNOSC Theranostics and Pharmacological Sciences*, **4**(1), 60–65. https://doi.org/10.36922/itps.v4i1.219

Kamal, M., and Jawaid, T. (2010): Pharmacological activities of *Lawsonia inermis* linn.: a review, *International Journal of Biomedical Research*, **1**(2), 62–68. https://doi.org/10.7439/ijbr.v1i2.56

Kapadia, G. J., Subba Rao, G. S. R., Sridhar, R., Ichiishi, E., Takasaki, M., Suzuki, N., and Tokuda, H. (2013): Chemoprevention of skin cancer: Effect of *Lawsonia inermis* L. (henna) leaf powder and its pigment artifact, lawsone, in the Epstein–Barr virus early antigen activation assay and in two-stage mouse skin carcinogenesis models, *Anti-Cancer Agents in Medicinal Chemistry*, **13**(10), 1500–1507. https://doi.org/10.2174/18715206113139990096

Khantamat, O., Dukaew, N., Karinchai, J., Chewonarin, T., Pitchakarn, P., and Temviriyanukul, P. (2021): Safety and bioactivity assessment of aqueous extract of Thai Henna (*Lawsonia inermis* Linn.) Leaf, *Journal of Toxicology and Environmental Health, Part A*, **84**(7), 298–312. https://doi.org/10.1080/15287394.2020.1866129

Liew, W. C., Rosly, E. S., Muhamad, I. I., Pa'e, N., Zaidel, D. N. A., and Yunus, N. A. (2022): Green extraction of *Lawsonia inermis* L. leaves for antimicrobial active packaging film, *Chemical Engineering Transactions*, **97**, 229–234. https://doi.org/10.3303/CET2297039

Mahkam, M., Nabati, M., and Rahbar Kafshboran, H. (2014): Isolation, identification and characterization of lawsone from henna leaves powder with soxhlet technique, *Iranian Chemical Communication*, **2**(1), 34–38.

Manivannan, R., Aeganathan, R., and Prabakaran, K. (2015): Antimicrobial and anti-inflammatory flavonoid constituents from the leaves of *Lawsonia inermis*, *The Journal of Phytopharmacology*, **4**(4), 212–216. https://doi.org/10.31254/phyto.2015.4404

Matotoka, M. M., Mashabela, G. T., and Masoko, P. (2023): Phytochemical content, antibacterial activity, and antioxidant, anti-inflammatory, and cytotoxic effects of traditional medicinal plants against respiratory tract bacterial pathogens, *Evidence-Based Complementary and Alternative Medicine*, **2023**(1), 1243438. https://doi.org/10.1155/2023/1243438

Mir, N. T., Saleem, U., Anwar, F., Ahmed, B., Ullah, I., Hira, S., Ismail, T., Ali, T., and Ayaz, M. (2019): *Lawsonia inermis* markedly improves cognitive functions in animal models and modulate oxidative stress markers in the brain, *Medicina*, **55**(5), 192. https://doi.org/10.3390/medicina55050192

Moutawalli, A., Benkhouili, F. Z., Doukkali, A., Benzeid, H., and Zahidi, A. (2023): The biological and pharmacologic actions of *Lawsonia inermis* L., *Phytomedicine Plus*, **3**(3), 100468. https://doi.org/10.1016/j.phyplu.2023.100468

Mustapha, A., AlSharksi, A. N., Eze, U. A., Samaila, R. K., Ukwah, B. N., Anyiam, A. F., others, and Ibrahim, M. A. (2024): Phytochemical composition, in silico molecular docking analysis and antibacterial activity of *Lawsonia inermis* linn leaves extracts against extended spectrum beta-lactamases-producing strains of Klebsiella pneumoniae, *BioMed*, **4**(3), 277–292. https://doi.org/10.3390/biomed4030022

Nadjib, B. M., Aloui, R., Bouslama, L., and Saad, H. (2013): Toxicity and allergic reactions associated with henna, *Toxicology Reports*, **1**, 123–131. https://doi.org/10.1016/j.toxrep.2013.01.006

Nair, A. S., Sekar, M., Gan, S. H., Kumarasamy, V., V. Subramaniyan, Wu, Y. S., others, and Wong, L. S. (2024): Lawsone unleashed: A comprehensive review on chemistry, biosynthesis, and therapeutic potentials, *Drug Design, Development and Therapy*, 3295–3313. https://doi.org/10.2147/DDDT.S463545

Naishadham, P., Sushma, P. R., Dasika, R., Tangirala, S., and Tangirala, S. (2013): Evaluation of organic hair dye formulation by an environment friendly process, *International Journal of Pharmaceutical Sciences Review and Research*, **21**, 152–157.

Niazi, M., Mehrabani, M., Namazi, M. R., Salmanpour, M., M. Heydari, Karami, M. M., others, and Mehrbani, M. (2020): Efficacy of a topical formulation of henna (*Lawsonia inermis* L.) in contact dermatitis in patients using prosthesis: A double-blind randomized placebo-

controlled clinical trial, *Complementary Therapies in Medicine*, **49**, 102316. https://doi.org/10.1016/j.ctim.2020.102316

Niazi, M., Parvizi, M. M., Saki, N., Parvizi, Z., Mehrbani, M., and Heydari, M. (2022): Efficacy of a topical formulation of henna (*Lawsonia inermis Linnaeus*) on the itch and wound healing in patients with epidermolysis bullosa: A pilot single-arm clinical trial, *Dermatology Practical & Conceptual*, **12**(3), e2022115. https://doi.org/10.5826/dpc.1203a115

Okoye, I. F., Alaekwe, I. O., and Abba, O. (2021): Uv-vis spectrophotometer analysis of film grown using natural dye from *Lawsonia inermis* (henna plant), *Nigerian Journal of Physics*, **30**(2), 135–139.

Oladunmoye, M. K., and Kehinde, F. Y. (2011): Ethnobotanical survey of medicinal plants used in treating viral infections among Yoruba tribe of South Western Nigeria, *African Journal of Microbiology Research*, **5**(19), 2991–3004. https://doi.org/10.5897/AJMR10.004

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., and Simons, A. (2009): Agroforestree database: A tree reference and selection guide version 4.0, World Agroforestry Centre.

Park, J. S., Rehman, I. U., Choe, K., Ahmad, R., Lee, H. J., and Kim, M. O. (2023): A triterpenoid lupeol as an antioxidant and anti-neuroinflammatory agent: impacts on oxidative stress in Alzheimer's disease, *Nutrients*, **15**(13), 3059. https://doi.org/10.3390/nu15133059

Rekik, D. M., Ben Khedir, S., Daoud, A., Ksouda Moalla, K., Rebai, T., and Sahnoun, Z. (2019): Wound healing effect of *Lawsonia inermis*, *Skin Pharmacology and Physiology*, **32**(6), 295–306. https://doi.org/10.1159/000501730

Revathi, S., Nasser, E. K., Wafaa, H. H., Altemimi, A. B., Sutikno, S., and Abedelmaksoud, T. G. (2025): *Lawsonia inermis* extract: Antibacterial, anticancer and antioxidant properties, *Food Systems*, **8**(1), 73–80. https://doi.org/10.21323/2618-9771-2025-8-1-73-80

Saghi, A., Gao, J. L., Giampietro, L., and Amiri-Ardekani, E. (2023): A mechanistic analysis of henna in G6PD deficiency patients, *Toxicologie Analytique et Clinique*, **35**(1), 23–32. https://doi.org/10.1016/j.toxac.2022.09.003

Salma, R., Vijay, V., Vijayakumar, A. R., and Deepa, N. (2024): A review on phytochemical, pharmacological, and toxicological properties of *Lawsonia inermis* L., *Journal of Pharma Insights and Research*, **2**(3), 155–166. https://doi.org/10.69613/cg9khw36

Santra, I., Mukherjee, S., Haque, S. M., and Ghosh, B. (2023): Occurrence and diversity of major naphthoquinones in higher plants: Their distribution and conservation strategies, 375–435 *in Medicinal plants: Biodiversity, biotechnology and conservation*, Springer Nature Singapore, Singapore. https://doi.org/10.1007/978-981-19-9936-9_15

Sen, S., Borthakur, M. S., and Chetia, D. (2023): *Lawsonia inermis* Linn: a breakthrough in cosmeceuticals, *Sciences of Phytochemistry*, **2**(1), 99–120. https://doi.org/10.58920/sciphy02010128

Sharma, A. (1990): Tuberculostatic activity of *Lawsonia inermis*, *Indian Journal of Medical Research*, **91**, 94–97.

Sharma, R. K., Goel, A., and Bhatia, A. K. (2016): *Lawsonia inermis* Linn: A plant with cosmetic and medical benefits, *International Journal of Applied Sciences and Biotechnology*, **4**(1), 15–20. https://doi.org/10.3126/ijasbt.v4i1.14728

Sienkiewicz-Szłapka, E., Janysz, A., and Wróbel, M. H. (2025): Quantification of lawsone and p-Phenylenediamine in natural henna products for hair colouring available in poland, *Contact Dermatitis*, **92**(4), 261–272. https://doi.org/10.1111/cod.14739

Tsao, Y. C., Chang, Y. J., Wang, C. H., and Chen, L. (2020): Discovery of isoplumbagin as a novel NQO1 substrate and anti-cancer quinone, *International Journal of Molecular Sciences*, **21**(12), 4378. https://doi.org/10.3390/ijms21124378

Youl, O., Sombié, E. N., Boly, R., Koala, M., Zoungrana, A., Savadogo, S., others, and Traoré, M. (2024): Phytochemical analysis and antimicrobial activity of *Lawsonia inermis* leaf extracts from burkina faso, *American Journal of Plant Sciences*, **15**(7), 552–576. https://doi.org/10.4236/ajps.2024.157038