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PHARMACOLOGICAL AND TRADITIONAL PERSPECTIVES ON *LAWSONIA INERMIS*: A HOLISTIC APPROACH TO ITS MULTIPURPOSE USES – A REVIEW

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ABSTRACT

There is an unbreakable bond within people and plants. Plants are vital sources for human survival, food, medication, warmness, clothing, housing, as well as the air that we breathe. Apart from the essential utilization, plants also play an important role in fascination and beautification. From the plant kingdom, several plants are there which play versatile role in varietal aspects or human society. In this context, *Lawsonia inermis* is a popular multipurpose plant and it has great therapeutic importance due to its natural bioactive compounds with pharmacological activities as well as has popularity as a cosmetic among females and males in different rituals and fashions. Apart from that, it has immense significance in traditional medicine, for which recent researches has focused only on its pharmacological properties. Besides, it has differential use in cosmetic industries for its colouring, astringent, and conditioning properties. However, *Lawsonia* plays a versatile role in the textile industry, in pollution treatment, in waste water treatment, in preparation of biofertilizer, in sanitization, in corrosion protection and many more. But the fact is that, society is not aware about the other potential use of *L. inermis* due to lack of knowledge and information. This review will put light on the other important useful aspect for which the plant is otherwise known as cash crop or multipurpose plant. The present report provides a comprehensive review on the unexplored part of *L. inermis* which could enable the plant as an important candidate for the benefit of society and the environment.

Keywords : *Lawsonia inermis*, Herbal Cosmetics, Anti-Pollutant, Anti-Corrosion, Green Nano-Technology

Introduction

All the plants in the mother earth are precious however they are categorized according to their utilization. Plants which have more than one substantial contribution are multipurpose plant. They may provide food, fodder, medicine, firewood, prevent soil erosion and pollution, act as sink for CO_2 and methane, act as windbreakers and noise absorbers etc. Among them, *Lawsonia inermis* L. is one important multipurpose plant. *L. inermis* is commonly known as Henna or Mignonette tree (syn. *L. alba* Lam. Or *L. ruba* L. *L. spinosa* L.) and belongs to family Lythraceae [https://www.cabi.org/isc/datasheet/29956]. In India, Henna has different vernacular names viz., Mehendi in Hindi/Urdu Mendika, Rakigarbha in Sanskrit, Mayilanchi in Kanada, Mailanchi in Malayalam, Muruthani in Tamil, Manjuati in Oriya, Mehndi in Bengali (Kirtikar and Basu, 2005). Henna plant grows as tall shrub or a small tree to height of 6-7 meter. *L. inermis* is a profusely-branched glabrous, deciduous, woody (Figure-1A). Greyish-brown colour bark, young branches are unarmed but become spine-tipped when get older. Quadrangular young branches turned red with age. Leaves are small, entire, subsessile, opposite, elliptic to broadly lanceolate, 1.5-5 x 0.5-2 cm, Inflorescence is a large pyramid-shaped cyme. Flowers are small, white, numerous; in large pyramidal terminal cymes, fragrant, 4 petals crumpled

in the bud (Figure 1B). Calyx with 2-mm tube; white or red petals orbicular to obovate; eight stamens, inserted in pairs on the rim of the calyx tube; ovary 4 celled, 5 mm long style, erect. Fruits are small, brown, globose capsules 4-8 mm in diameter, many-seeded, opening irregularly, split into 4 sections, with a persistent style (Figure 1C). Seeds are of 3 mm across, numerous, smooth, pyramidal, with hard and thick seed coat with brownish colouration [Figure 1D & E] (Orwa *et al*., 2009; Chaudhary *et al*., 2010). (Figure-1)

Henna has been extensively used over the times for medical and cosmetic purposes (Charisty *et al*., 2012; Rahmoun *et al*., 2013). Ancient history of India describes its diverse use and also plays appreciable role in Ayurvedic or natural herbal medicines (Chaudhary *et al*., 2010). As it's Henna, un-doubtly popular in cosmetics. It is popular in India for its cooling nature so applied to hand, hair and feet in hot Indian summer. It is cultivated as commercial crop (Rajwar and Khatri, 2011; Agarwal *et al*., 2014) or as cash crop (Ram and Sekhawat, 2011). The pharmacological properties of *Lawsonia* have been the main focus on recent reviews and was described in detail in better way (Patel & Patel, 2017; Sen *et al*., 2023; Muheyuddeen *et al*., 2023; Supian & Osman, 2023; Moutawalli *et al*., 2023). In addition, this plant has also flourished in the cosmetic industry. However, this plant shows its performance in other important but less-considered aspects like use in textile dyeing, UV absorbency, sanitization, as anti-pollutant, as biofertilizer, in removal of harmful bacteria from wastewater, as bacterial staining, as anti-corrosion agent, as anti-pollutant and farming for economic value and many more. Due to all its beneficial uses, we can also consider this plant as blessing for environment. The aim of this review is to present a state-of-the-art assessment of *Lawsonia* in broad assessment that has never discussed before.

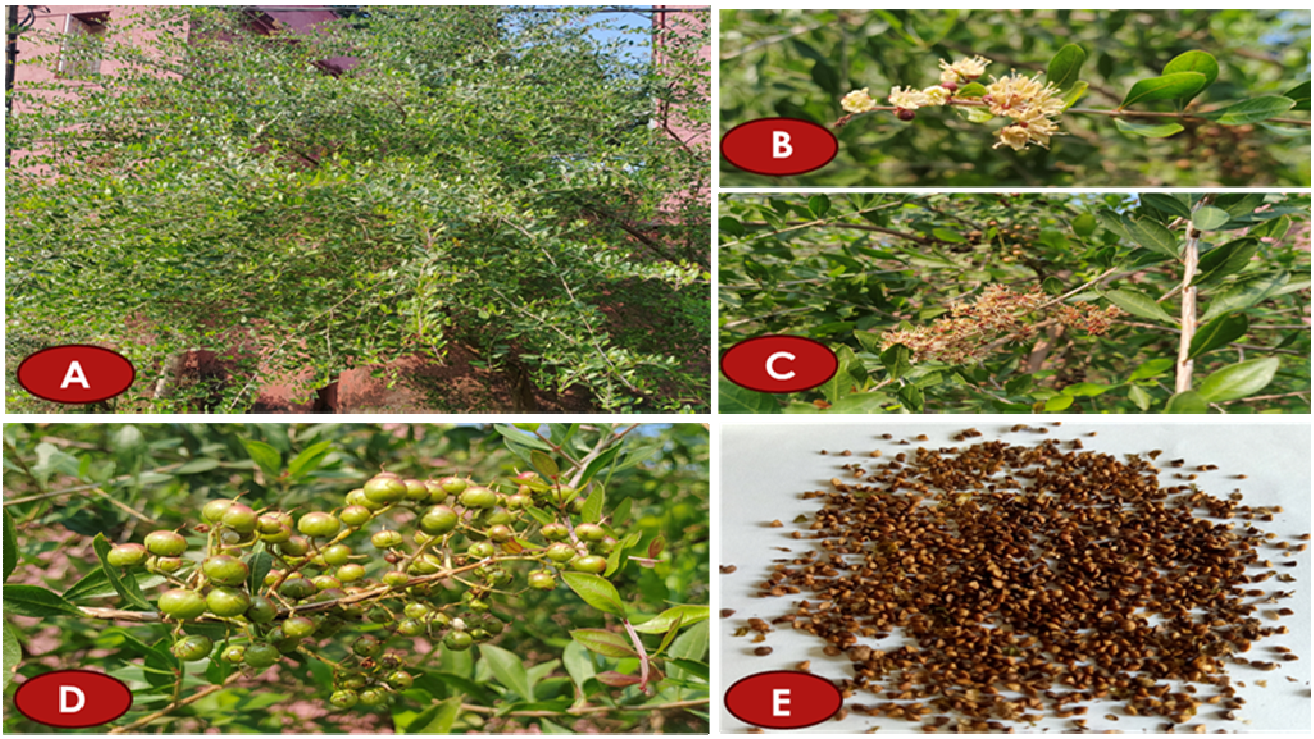

Fig. 1: A. Whole Plant of *Lawsonia inermis*, **B**. Flowering Twig, **C**. Mature Flowering Branch, **D**. Fruit Capsules, **E**. Seed of Henna

Medicinal value

Traditional use

L. inermis is being used in numerous traditional and folklore system of medicine across the world for treatment of mostly unrelated ailments. Almost all parts of the plants including roots, leaves, seeds and flowers are used in treatment of various ailments (Jeyaseelan *et al*., 2012). In India it is known for its use in Ayurvedic system of medicine as well as folkloric medicine (Chaudhary *et al*., 2010; Agarwal *et al*., 2014). The plant has also ethnomedicinal importance in Odisha, India. This plant has been used by local traditional healers for the treatment of Jaundice in Koraput district and as preventative for hair loss in Kandhamal district, Odisha whereas; it has been applied for Leprosy and skin diseases in other districts of Odisha, India (Panigrahy *et al*., 2016). The people of the Kalahandi district, Odisha, India use leaf paste and

stem decoction for the treatment of skin itching, eye infection, and induction of abortion (Mallik *et al*., 2012). Traditional uses of diverse parts of *Lawsonia inermis* are depicted below (Table-1).

Table 1: Traditional Uses of *Lawsonia inermis*

Sl. No.	Plant parts	Traditional uses	References
1.	Leaves	Ophthalmia, skin diseases, smallpox, spermatorrhoea, dysuria, diuretic, boils, bronchitis, ores, syphilitic, scabies, amenorrhoea and spleen illnesses, headache, vulnerary, hemicrania,	Mallik *et al*., 2012 Khare, 2007 Dixit *et al*., 2010
2.	Flower	Treating insomnia	Kirtikar and Basu, 2005 Al-Rubiay *et al*., 2008
3.	Seed	Cure for liver disorders and ghee with seed powder mix is used to cure Dysentery	Sharma *et al*., 2012 Charoensup *et al*., 2017
4.	Bark	Use as a decoction for burn wounds, orally taken as a medicine to cure spleen enlargement illness, jaundice, and an alternative in leprosy and skin disease	Nishteswar, 2013 Panigrahi *et al*., 2016
5.	Root	Use for gonorrhoea and herpes infection, sore eyes treatment, boil, hysteria, and nervous disorder treatment	Charoensup *et al*., 2017 Ahmed *et al*.,2000

Pharmacological use

A number of ethno-medicinal uses of *L. inermis* have been substantiated by biological activities studies (Table-2). It has a wide range of biological activities including wound healing, hepatoprotective, anti-diarrheal, immunostimulant, anti-inflammatory, anti-sickling, anti-bacterial, anti-fungal, anti-viral, diuretic activity, analgesic, antiparasitic, Molluscicidal effect, anti-angiogenesis, anti-urolithic, anti-diabetic, Anti-malarial, nootropic activity, antioxidant, antifertility, anti-urolithiasis and anticancer effects.

Antibacterial effect

Various types of solvent extracts (ethanol, ethyl acetate, methanol, aqueous, and hexane) of different plant parts of *L. inermis* have been shown to inhibit a wide spectrum of both gram-positive and gram-negative bacteria. A number of reports reveal the bioactivity of the major compound Lawsone along with other compounds against a broad spectrum of human pathogens like *Pseudomonas aeruginosa*, *Staphylococcus epidermidis*, *Staphylococcus aureus*, *Escherichia coli, Bacillus subtelis, Shigella sonnei*, *S. typhi, Klebsiella pneumoniae*, *Staphylococcus epidermidis*, and *Enterococcus faecalis, Salmonella enterica*, *Listeria monocytogenes* and *Staphylococcus intermedius* (Yang and Lee, 2015; Yusuf *et al*., 2016). In a study, it has been seen that the chloroform extracts of henna showed high antibacterial activity against Bacteria like *Staphylococcus aureus* (gram +ve) and *Escherichia coli* (gram -ve) are two pathogens that cause foodborne and nosocomial infections respectively (Zannat *et al*., 2023).

Nowadays, researchers are taking an interest in using *Lawsonia* extract as nanoparticles and nano-emulsions in nanotechnology and achieving success in inhibiting antibacterial activity against a variety of diseases. carbon dots or CDs prepared by hydrothermal synthesis from henna leaves has been proven effective on kill both Gram+ and Gram- bacteria at far lower concentrations than a standard prescription antibiotic. The ethyl acetate extract from the fruit was efficient against *E. coli* and *Bacillus subtilis*, whereas the extract from the flower was effective against *Pseudomonas aeruginosa* and *Staphylococcus aureus* (Shahshahanipour *et al*., 2019). For a comparison study, an aqueous extract of *L. inermis* L. leaves were used to synthesise magnesium oxide (MgO) nanoparticles by chemical and green methods. The organic biomolecules on the surfaces of the green-produced MgO NPs contributed to their strong antibacterial activity. When compared to chemically produced MgO NPs, the green-produced nanoparticles showed a larger inhibition zone for *B. subtilis*, *S. aureus*, *E. coli*, and *P. vulgaris* (Akshaykranth *et al*., 2021). In very recent, Henna extract as nano-emulsion (HENE) was found more effective against *E. coli*, *S. aureus*, *B. subtelis*, *S. typhi*, *Klebsiella*, and *P. aeruginosa* compared to HE (bulk henna extract), and penicillin (Ghazy *et al*., 2023).

Virucidal effects

Traditionally, henna is known to effective against whitlow, warts, itchy skin and herpes due to anti-viral effects. Additionally, nowadays various extracts of henna being tested in laboratories against some of viruses. Ethanol extracts of *L. inermis* plant materials

and seed show anti-viral activity against Sembiki Forest Virus (SFV) (El-Askary *et al*., 2020) and Sindbis virus (Mouhajir *et al*., 2001) respectively. In very recent, the anti-viral activity of methanolic extract of henna leaves against a model virus (bacteriophage MS2 DSM 13767) has been proven. For which, *Lawsonia* could be suggested as potential alternative sanitiser (Majiya *et al*., 2023).

Anti-fungal results

L. inermis aqueous, ethanolic, and methanolic leaf extracts exhibit stronger antifungal activity when compared to other extracts, like aqueous and ethanolic pomegranate peel and seed extracts against several strains of *Candida albicans* (Singla *et al*., 2013; Samadi *et al*., 2019). A recent study showed henna leaves extract achieved antifungal effects against *Aspergillus flavus*, *A. ochraceus*, *Penicillium ochrochloron, Candida albicans*, *A. niger* and *P. funiculosum* (Elansary *et al*., 2020). HENE (Henna Extract as Nano-Emulsion) shows high antifungal effect over *Penicillium digitatum*, *Aspergillus terreus* and *Saccharomyces cerevisiae* as compared to penicillin and HE (Henna Extract) (Ghazy *et al*., 2023).

Anti-malarial activity

Henna extracts in petroleum ether and ethyl, showed antimalarial efficacy against the *Plasmodium falciparum* FcB1-Columba and FcM29-Cameroon strains (Babili *et al*., 2013). The study examined the *in-vitro*, *in-vivo* activity of different *L. inermis* L. extracts and constituents. The results disclosed that fraxetin and the leaves extract which is done by ethyl acetate shows effectiveness against *Plasmodium falciparum* strain NF-54 and *Plasmodium berghei* strain respectively (Singh *et al*., 2017).

Molluscicidal effect

Lymnaea acuminate and *Indoplanor bisexustus* are the vector of endemic fascioliasis that caused by flukes like *Fasciola gigantica* and *F. hepatica*. Synthetic molluscicides that are being applied are highly toxic for nature, so natural remedy seems the best alternative for discarding the molluscas. *Lawsonia inermis* exhibits molluscicidal activity against *Lymnaea acuminate* and *Indoplanor bisexustus* in its leaf, bark, and seed extracts. From them, henna seed mixed with *Cedrus deodara*, powdered *Allium sativum*, and neem oil, works wonders against them. (Singh *et al*., 2001).

Antioxidant effect

By using DPPH and ABTS assay it has proved that Methanolic (Chaibi *et al*., 2017) and ethanolic extracts of seed show higher antioxidant capacity due to the presence of high concentration of phenolic and flavonoid while Chloroform and hexane, petroleum ether, aqueous, dichloromethane extracts showed no antioxidant activity (Esteki and Miraj, 2016).

With an IC50 value of 22.9 μM, the Lawsone molecule extracted from mehndi leaves demonstrated a significant antioxidant potential, the capacity to release a proton, and the possibility that the hydroxyl group carrying C-2 may stabilize ABTS radicals (Darvin, 2018).

Antiangiogenic activity

The process by which newly created blood vessels ascend from the pre-existing blood vasculature is known as angiogenesis, and it is dynamically controlled. It is an important process for living organisms to develop blood vessels for normal growth. However uncontrolled growth and division of vessels may lead to abnormal growth or it may work for cancer development. Thus, blood vessel supply to cancer cells should be prevented by a process known as anti-angiogenesis, by this process tumors become necrotic in the absence of circulatory supply (Esa *et al*., 2023). A study has demonstrated the antiangiogenic possibility of an ethyl acetate extract of *Alternaria alternata* a terrestrial endophytic fungus that was derived from the leaves of the *L. inermis*. The extract substantially decreased the number of blood vessels, showing the inhibition of angiogenesis (Bendre and Gonjari, 2019).

Hepatoprotective effect

Butanolic extract of henna leaves shows *in-vivo* hepato-protective effect against male Wistar rats with 2-acetylaminofluorene (2-AFF) induced hepatic damage. Total bilirubin content and liver weight come to control when the ethanolic extract of the dried leaves of *Lawsonia inermis* used. (Latha *et al*., 2005).

The ethanolic and aqueous extract *L. inermis* seed exhibited hepatoprotective activity against rats that suffered from hepatic damage caused by paracetamol and showed significant reduction in serum enzymes alkaline aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), Acid Phosphatase (ACP), Protein and Bilirubin (Selvanayaki and Ananthi, 2012; Mohamed *et al*., 2016).

Anti-inflammatory

The anti-inflammatory efficacy of *L. inermis* methanolic extracts is demonstrated in a mouse model utilizing an acetic acid-induced writhing test. It has been seen that methanolic leaf extract inhibited the pain-stimulating agents (Imam *et al*., 2013). When several extracts from henna seeds, including those

made from hexane, chloroform, and methanol, were evaluated, it became clear that methanolic extracts had the highest anti-inflammatory action of all, as compared to hexane and chloroform extracts (Chaibi *et al*., 2017). Rats significantly and dose-dependently experienced analgesic, antipyretic, and anti-inflammatory effects from the crude ethanolic extract of *L. inermis* as Compared to butanol and chloroform extracts. A pure substance that is 2-hydroxy-1,4-naphthaquinone, also known as lawsone isolated from chloroform extract shows those effects.

Analgesic effects

Present investigations informed that *L. inermis* possesses a significant analgesic activity over the other plants used before and the standard drug diclofenac which tested against Wistar rats. This result matches with Ghannadi *et al*. (2005) who claimed that *L. inermis* Linn. leaf and black seed oil extracts by ethanol exhibit a dose-dependent analgesic, antipyretic effect, and anti-inflammatory activity (Aremu *et al*., 2023).

Antipyretic effects

Our bodies naturally react to illnesses by raising a fever. Doctors advise managing body temperature, nevertheless, above 38.5°C. Antipyretics are the go-to medications for treating excessive fevers. According to Humaish's research from 2017, the ethanolic leaf extract of henna indicates a substantial antipyretic impact that is comparable to ketoprofen (Humaish, 2017).

Anti-sickling

In some countries, sickle cell anemia is a frequent condition. These sickle shaped cells block blood vessels, which reduces the amount of oxygen carried by the blood. It was discovered that an aqueous extract of henna leaves inhibited sickling and increased the oxygen affinity of HbSS blood (Sandhanam *et al*., 2018). It has been established that henna (*L. inermis*) can prevent sickle cell development. The 2-Hydroxy-1,4-Naphthoquinone (lawsone), a component of henna, is what gives its anti-sickling properties by making red blood cells more oxygen-affine. Henna possesses anti-sickling properties, which have been demonstrated by incubating whole blood from individuals with sickle cell disease with aqueous and methanolic henna extracts (Tayel *et al*., 2021).

Antidiabetic effect

The quantitative determination of the maltose from the maltose standard curve was used to assess the anti-diabetic impact of methanolic extracts of *L. inermis*. When compared to being left untreated, the plant's methanolic leaf extract greatly reduced the amylase's enzymatic activity (Imam *et al*., 2013). The mice with alloxan-induced diabetes showed decrease in blood glucose levels when treated with *L. inermis* leaves extract by ethanol (Ankita *et al*., 2017).

Nootropic effects

Methanolic extract of henna tested against albino mice in a staircase test with different dosage of extract shows effects in mice (Ahmed *et al*., 2016). This extract was also tested for anxiolytic potential using white dark box model in mice. Aqueous extract of *L. inermis* leaves was investigated against albino mice with Parkinsons diseases (PD) and the extract caused a drop in the level of cataleptic scores and intensification in SOD (Superoxide Dismutase) activity (Shastry *et al*., 2012). 2-hydroxy-1,4 napthoquinone or lawsone extracted from chloroform, hexane extract of *L. inermis* does not show any anti-cholinesterase activity as compared to methanolic, ethanolic, hexane extract (Chibi *et al*., 2017).

According to research, *L. inermis* extract in ethanol and chloroform can restore memory loss brought on by free radical-induced memory impairment. Although the precise mechanism is unknown, *L. inermis*'s antioxidant properties may be to blame for the plant's nootropic potential (Mir *et al*., 2019).

Recently it has been proved that ethanolic extract of *L. inermis* has neuroprotective effects against chronic con-induced neuropathic pain (CCI) because of its anti-oxidant and anti-inflammatory properties (Rakhshandeh *et al*., 2021).

Anti-ulcer effects

When aqueous, chloroform, and ethanol extracts of henna leaves were administered to model rats with pylorus ligation and aspirin-induced ulcers. The chloroform extract demonstrated a considerable, dose-dependent decrease of ulcers in aspirin-induced ulcers. Nonetheless, the outcomes demonstrated that the volume of stomach acid discharges, overall acidity, and ulcer index were all considerably reduced by the aqueous, ethanol, and chloroform extract (Goswami *et al*., 2011). In alloxan-induced diabetic mice, *L. inermis* demonstrated strong hypoglycaemic and hypolipidemic effects. It has seen that the extract brings the levels of glucose, cholesterol, and triglycerides back to normal (Arayne *et al*., 2007).

A significant decrease in PH, total and free acidity, as well as the same improvement in the biochemical parameters, showed that the use of nano formulation significantly improved all of the ulcer parameters that had been evaluated. The improvement

even outperformed that of the control group treated with untreated *L. inermis* L. leaves. The histopathology findings and further studies both corroborated these conclusions (Mohammed *et al*., 2022).

Anti-diarrhoeal effects

Compared to the control group, the ethanol extract had anti-diarrheal efficacy at a dosage of 500 mg/kg. (Hsouna *et al*., 2016). The mice with castor oil induced diarrhea, when treated with ethanolic extract of the leaf of henna showed anti-diarrhoeal activities.

Burn/ wound healing effects

Surgery, an accident, or other events might leave wounds. It is still difficult to identify topical wound-healing treatments. To examine their effects, 0.9% normal saline, green and chemically produced chitosan nanoparticles (Ch-NPs), and female albino rats that had undergone cutaneous surgery were treated. It was observed that nanoparticles were found to increase wound contraction percent (WC%), shorten healing time, and decrease wound surface area (WSA). Histological findings showed that treated rats had improved epithelialization, dermal differentiation, collagen deposition, and angiogenesis when compared to control rats (p 0.05). Consequently, it was determined that the investigated nanoparticles' effects on wound healing are encouraging (Metwally *et al*., 2023).

Ethanolic extract of *Lawsonia inermis* studied against rat with excision, incision shows wound healing activity in does dependent manner. An ointment prepared from the dried form of henna, *Adiantum capillus*-veneris, *Aloe vera* paste tested against wound healing activity in rats (Galehdari *et al*., 2016).

Abortifacient effect

Henna plants were traditionally used for abortion before. In a recent test it has been seen that when the henna extracted by hydroalcohol, was injected into pregnant mice between 1st to 7th day of their pregnancy, due to increasing serum estrogen level and decreasing progesterone level, an abortive effect was seen in some injected mice (Esteki *et al*., 2016).

It was discovered that, in a dosage-dependent way, the methanolic extract was the most efficient in causing abortion in mice, rats, and guinea pigs. There was evidence of human abortion brought to light across multiple Nigerian regions (Semwal *et al*., 2014).

Anti-urolithiatic activity

Alcohol extract of *L. inermis* bark conveys reduction against stone-forming constituents in urine and in the kidney. Rat suffering from urolithiasis induced by ethylene glycol manifests an anti-urolithiatic effect when treated with alcohol extract (Patel *et al*., 2017). Significant anti-urolithiatic efficacy was demonstrated by hydroethanolic extract against stones caused by calcium oxalate, and check the level of urine pH, total protein, magnesium, phosphorus, calcium, etc. to protect the kidney (Kore *et al*., 2011).

Anti-cancer activity

By preventing the S-phase of the cell cycle, the drugs Lawsone and juglone prevented the proliferation of HCT-15 (human colon cancer cells). Lapachol, Atovaquone and dichloroallyl lawsone are only a few of the anticancer medications that were synthesized using lawsone as a starting material. When the anticancer effect of total methanolic extract of henna and octreotide was studied in nitrosamine-induced hepatocellular carcinoma in mice, it was determined that the same extract of *L. inermis* and octreotide treatment had an effective chemo preventive action because it could reduce oxidative stress and desensitize cellular growth receptor to SST (Abdel *et al*., 2015).

The *L. inermis* methanolic seed extract demonstrated significant 5-lipoxygenase, moderate acetylcholinesterase (AChE), and excellent antioxidant activity. The chloroform extract provided the most effective Henna seed action against human breast cancer cells (HTC-116) (Chaibi *et al*., 2017).

The ethanolic extract of *L. inermis* has noteworthy inhibitory efficacy against human alveolar basal epithelial cancer cell lines (A549), colon cancer cell lines (DLD1), and liver cancer cell lines (HepG2), according to an in vitro investigation. MTT, ROS, MMP, PI, and chromatin condensation assays have all demonstrated the cytotoxic, anti-proliferative, and anti-cancerous activities of lawsone (2-hydroxy-1,4-naphthoquinone) (Ishteyaque *et al*., 2020).

The green approach of producing $ZnFe_2O_4$ (zinc ferrite) nanoparticles using *L. inermis* leaf extract was effective. The created nanoparticles have the properties of zinc ferrite nanoparticles, which were discovered in magnetic studies to have saturation magnetization at room temperature and to have strong anticancer efficacy against breast cancer (MCF-7) cell lines (Sarala *et al*., 2020).

As Medication for male infertility

Overall, the study's findings demonstrated that LPS (lipo-polysaccharide) reduces sperm quality, increases testicular tissue damage, and drastically lowers blood testosterone levels. Additionally, abnormalities in the germinal epithelium and a reduction in the quantity of sperm cells in the seminiferous tubules are shown by a histological

investigation. However, the model group treated with 500 mg/kg of *L. inermis* extract saw an increase in sperm count and improved germ cell layer structure. *L. inermis* extract may lower oxidants, increase sperm quantity, motility, and viability, and lessen damage to testicular tissue (Shahidpour *et al*., 2023).

As vaginal suppository

One typical method of delivering drugs directly into the vagina is through vaginal suppositories. Small pills called suppositories are put into the vagina directly, melt within the body, soak into the vaginal wall, and release medicine into the circulation. In recent research, it has revealed that the henna-based vaginal suppository has acceptable physicochemical characteristics and antibacterial activity against some gynecological problems (Firdous *et al*., 2023).

As nano-emulsion

In a recent, cutting-edge study, Henna Extract as bulk (HE) and Henna Extract as Nano Emulsion (HENE) which was made using ultrasonic emulsification, were compared. These two extracts' microbial and fungal properties were examined. HENE shown superior antibacterial activity against *P. aeruginosa, E. coli* and *B. cereus*. HENE had a stronger antifungal impact than penicillin and HE, especially against *S. cerevisiae*, *A. terreus,* and *P. digitatum.* (Ghazy *et al*., 2023).

Table 2: Pharmacological Effect of Different Extracts of *L. inermis*

Sl. No.	Extract	parts used	Activities	Effect against	References
1.	Ethanolic	Leaves	Anti-bacterial	*Pseudomonas aeruginosa, Staphylococcus epidermidis*	Yusuf *et al*., 2016
		Root	Anti-tumor	Dalton's lymphoma ascites-induced mice	Priya *et al*., 2011
		Leaf	Virucidal	*Sindbis* virus	Mauhajir *et al*., 2001
		Leaf	Anti-fungal	Strains of *Candida albicans*	Singla *et al*., 2013
		Seed	hepatoprotective	Rats with Paracetamol induced hepatic damage	Mohamed *et al*., 2016
		Leaf & Seed	Analgesic	Wister rats	Aremu A *et al*., 2023
		Leaf	Anti-diarrhoeal	Castor oil induced diarrhoea in mice	Hsouna *et al*., 2016
		Dried henna	Burn/wound healing	Excised and incised rats	Galehdari *et al*., 2016
		Bark	Anti-urolithiatic	Rat Kidney stones caused by calcium oxalate	Kore *et al*., 2011
		Seed, Bark, Leaf	Molluscicidal effect	*Lymnaea acuminata, Indoplanor bisexustus*	Singh *et al*., 2001
		Leaves	Anti-cancer	Human alveolar basal epithelial cancer cell line (A549), colon cancer line, liver cancer cell line	Ishteyaque *et al*., 2020
			Nootropic effect	Free radical-induced memory impairment in mice Chronic con-induced neuropathic pain (CCI)	Mir *et al*., 2019 Rakhshandeh *et al*., 2021
2.	Methanolic	Leaf	Anti-inflammatory	Acetic acid induced writhing test in mice	Imam *et al*., 2013
		Leaf	Anti-diabetic	Alloxan induced diabetic mice	Ankita *et al*., 2017
			Nootropic	Albino mice in stair case test	Ahmed *et al*., 2016
		Root	Abortifacient	Mice, rats, guinea pig	Semwal *et al*., 2014
		Leaf	Anti-sickling	Human blood sample	Tayel *et al*., 2021 Sandhanam *et al*., 2018
		Seed	Anti-oxidant		Chaibi *et al*., 2017
		Leaf	Anti-viral	Model virus bacteriophage MS2, DSM 13767	Majiya *et al*., 2023
			Anti-cancer	Nitrosamine induced	Abdel *et al*., 2015

				hepatocellular carcinoma in mice	
3.	Butanolic	Leaf	hepatoprotective	2-AFF induced hepatic damage in male wister rat	Latha *et al*., 2005
4.	Aqueous	Leaf	Anti-fungal	*Candida albicans*	Singla *et al*., 2013
		Whole plant	Anti-cancer	Ehrlich ascites carcinoma	Zumrutdal *et al*., 2008
		Leaf		2 staged skin cancer which is induced by DMBA and a model mouse with B16F10 melanoma tumour	Raja *et al*., 2009
		Seed	Hepatoprotective	Paracetamol induced hepatic damage in rats	Selvanayaki and Ananthi, 2012
		Leaf	Nootropic	Albino mice with Parkinsons disease (PD)	Shastry *et al*., 2012
5.	Chloroform	Leaf	Anti-ulcer	Aspirin induced ulcer in rats	Goswami *et al*., 2011
		Seed	Anti-cancer	human breast cancer cells (HTC-116)	Chaibi R *et al*., 2017
		Leaf	Anti-bacterial	*E. coli*, *Staphylococcus aureus*	Zannat KE *et al*., 2023
6.	Alcoholic	Bark	Anti-urolithiatic	Ethylene glycol induced urolithiasis in rats	Patel and Patel, 2017
7.	Ether and ethyl petroleum	Leaves	Anti-malarial	*P. falciparum* FcB1-columba and FcM29 cameroon strains	Babili *et al*., 2013
	Ethyl acetate	Leaves	Anti-malarial	*P. falciparum* strain NF-54 and *P. berghei* strain	Singh *et al*., 2017
			Antiangiogenetic	Chick embryo	Bendre and Gonjari, 2019
8.	Henna extract as nano-emulsion (HENE)		Anti-fungal	*Penicillium digitatum Saccharomyces cerevisiae*	Ghazy *et al*., 2023
			Anti-bacterial	*E. coli, B. cereus* and *P. aeruginosa*	
9.	Chitosan nano-particles		Burn/wound healing	Female albino rat	Metwally *et al*., 2023
10.	Zn-Fe nano-particles	Leaf	Anti-cancer	Breast cancer MCF-7 cell line	Sarala *et al*., 2020

Other Important Uses

Like medicinal uses, *L. inermis* has so many other uses and those are discussed below in Table 3 and figure 2.

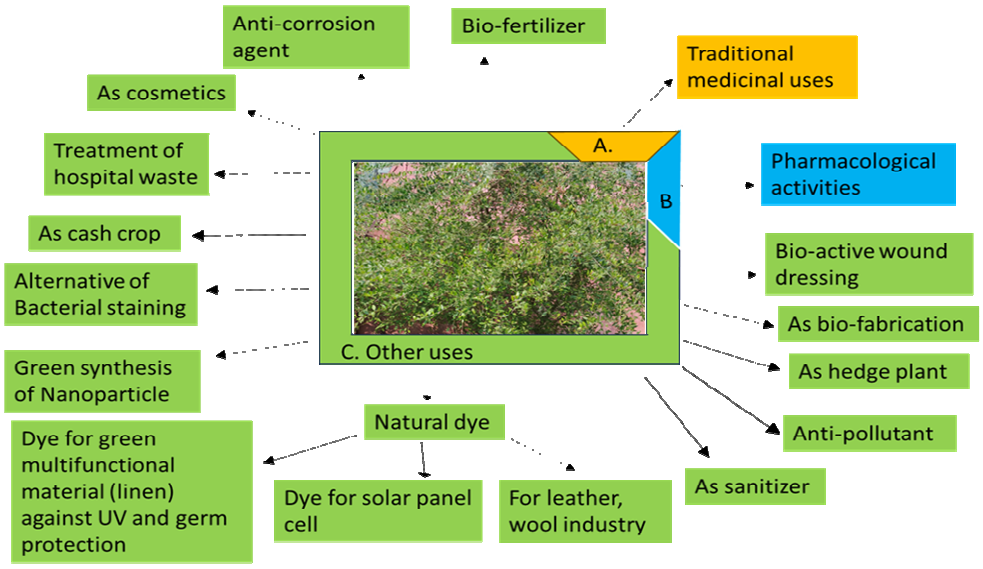

Fig. 2 : A Schematic Representation for Multipurpose Use of *Lawsonia inermis* L.

As cosmetics

Herbal cosmetics are now in style and in high demand. Since ancient times, both men and women have made extensive use of cosmetics to improve their appearance. Nowadays people prefer natural products over chemicals as they are free of synthetic chemicals and have comparably fewer side effects than synthetic cosmetics (Joshi and Pawar, 2015). Henna is very popular among men and women of all over the world. The hands, wrists, feet, and legs are often the only body parts decorated with henna leaves paste for weddings and social events by different religious peoples (Table 3). Recently, *L. inermis* along with *Beta vulgaris* (natural colouring agents) were reported to prepare herbal lipstick (Obat and Bosire, 2022). In traditional as well as in modern era, henna is used as temporary body designing or tattooing process with no side effects (Basas, 2007). Due to colouring effect of Henna leaves, it is used to dye the hair, and beard of men. Henna flowers are being used as perfume and base for many local scents for their aroma. *L. inermis* is now being used as an herbal shampoo along with other herbal plants like *Calendula officinalis, Aloe vera* and the results showed excellent conditioning performances on hair (Telrandhe, 2023).

For treatment of hospital wastewater

Lawsonia inermis (Henna) and *Myrtus communis* (Yass), two locally accessible plants, were employed in the current investigation to treat polluted water and isolate harmful bacteria in hospital's wastewater that are without treatment facilities. Alcoholic plant extract found effective against harmful bacteria like *Staphylococcus Xylosus*, *Serratia ficaria* and *Klebsiella oxytoca* those found in the hospital wastewater (Edan *et al*., 2023).

As bacterial staining agent

Due to the presence of colouring component i.e. Lawsone, the cold and hot aqueous leaf extracts of henna were successfully used as counter stains in the Gramme staining process (Jeyathilakan *et al*., 2012). So, *L. inermis* also plays an important role as an alternative good staining agent.

Popularity in nano-technology:

Nanotechnology is now applied in a number of fields, including materials engineering, mechanical engineering, physics, agriculture, energy, and biology.

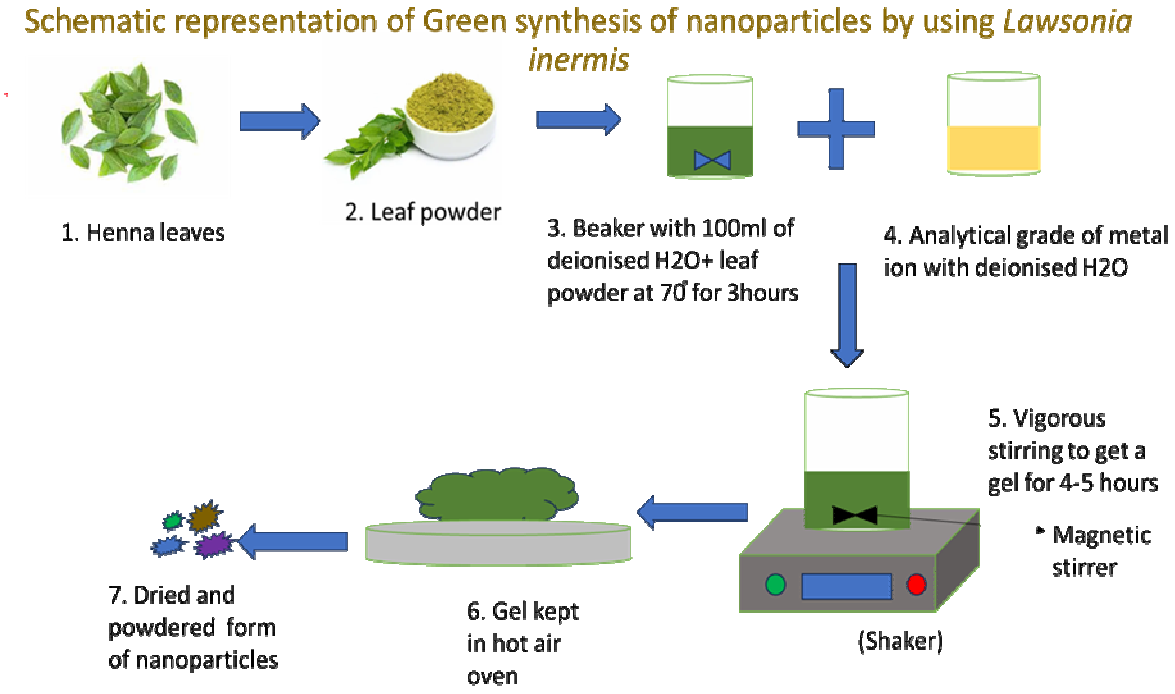

Fig. 3: Schematic Representation of Green Synthesis of Nanoparticles by Using *L. inermis.*

Nanoparticles have recently been employed effectively in the food sector as powerful anti-oxidant larvicidal, anti-fungal, and anti-bacterial agents as well as for prolonged medication release, photocatalytic degradation, detection, and the treatment of illnesses. The biological technique appears to have several benefits over other synthesising processes, despite the emission of poisonous dangerous chemical compounds as side products in the chemical method and expensive, time-consuming equipment in the physical method. This approach is also known as a "green method" since it is simple, inexpensive, and less hazardous than others. According to research, Ag-NPs are made utilising *L. inermis* in a green manner, and their toxicity has not yet been established. The aqueous *L. inermis* extract used to make the Ag-NPs has potent anti-cancer and anti-microbial activities (Figure 3). Treatment for breast cancer can be achieved using Ag-NPs created from *L. inermis* extract (Alhomaidi *et al*., 2022).

As a natural dye

For leather, wool and fabric industry

The leather business uses a lot of synthetic dyes, some of which are carcinogenic, thus environmental concerns are looking for dye products made from natural materials, which may offer various benefits including lower toxicity and biodegradability. A study has focused on utilising aqueous henna leaf extract, which contains the natural dye class naphthaquinone chemical lawsone, to colour leather in an environmentally responsible manner. With more henna extract application, the leather's colour deepened and various hues were produced depending on the type of mordant employed (Musa *et al*., 2009). The natural dye of henna i.e., lawsone binds to animal fabrics (wool, silk, leather) easily because they can strongly bind to animal proteins as compared to plant-origin fabrics (cotton, flax or linen etc) (Annapoorani and Sundarraj, 2014).

As dye for solar panel cell

The vast majority of thin-film panels of solar cells and silicon solar cell wafers that have reached the end of their useful lives might cause significant ecological issues in the future owing to the hazardous wastes that may be left behind. According to reports, 1.58 kg of CO_2 are released into the environment for every kilogramme of silicon. On the other hand, one of the most promising groups of photovoltaic systems for transforming solar energy into electricity is dye-sensitized solar cells (DSSCs). It provides a substitute that has a straightforward production method, is inexpensive, and has a great deal of potential for use on a wide scale (Vekariya *et al*., 2016). Recent research demonstrates that DSSCs have a record for high efficiency of power conversion and are particularly beneficial as unconventional, cost-effective solar systems. In a study, it was discovered that when the dyes from *L. inermis* (Laali) were extracted and

purified forms were applied to solar cells, the UV-Vis, FTIR, and EIS characterizations of the dyes revealed an increase in band gap, lower charge resistance adequate functional group, after the purification. This could help positively to increase the efficiency of solar cell devices (Akwolu *et al*., 2023).

As a dye for green multifunctional textile material (linen)

Humans now using textile materials for a variety of purposes, and their multipurpose qualities make them in great demand. Interest in linen has been growing, and textile goods with additional value are now being created by modifying this fibre to serve several purposes. Natural colouring with a henna and copper sulphate mixture was used to alter linen cloth and the production of linen dyed with henna as a green, multipurpose textile material was conducted recently. It has been demonstrated that this modified henna-dyed linen shows improved protection against germs, UV radiation protection, free radicals and antioxidant activity, it was proved by utilising FTIR, TGA, and SEM methods (Yadav *et al*., 2019).

As a hedge plant

Hedge plants are the kind of vegetation that delineates the border between two houses and fields. Some people claim that these plants offer some degree of seclusion and wind protection. Some hedge plants are evergreen and just produce lovely patterned leaves, while others are blooming and produce small flowers. The henna plant is a perennial shrub that can grow as high as twenty feet (6 metres) tall and has many branches. The plant is bush-like and grows quickly. It is frequently cultivated as specimen trees in gardens or clipped to provide a live hedge around houses, school boundaries and other structures (Kumar *et al*., 2013). It may also be utilised as a field barrier to divide two kinds of crops. Sometimes, due to the thorns on it, this plant act as a formidable barrier in many places.

Use for Bio-fabrication

According to research, it is possible to biosynthesize metal oxide nanoparticles in an efficient and environmentally friendly manner. It has been discovered that the methanolic seed extract of *L. inermis* includes phyto-active substances that serve as a stabiliser and reductant for the manufacture of zinc oxide nanoparticles (ZnO-NPs), which is followed by calcination. ZnO-NPs is useful for making biosensors, optoelectronics, and bio-medical devices, among many other things (Bhatt *et al*., 2023).

As bioactive wound dressing agent

A novel bioactive wound dressing for burn wounds based on electrospun poly (L-lactide-co-D L-lactide) PLDLLA nanofibers containing *L. inermis* (LI) or PLDLLA-LI has been shown to reduce the wound area by almost 90% over the course of 19 days of therapy. According to the histological findings, the wound treated with the PLDLLA-LI nanofibrous sample as opposed to the wound treated without LI showed a markedly improved epithelial layer appearance and thickness of around 40%. In addition to epithelialization, it has been discovered that the wound treated with PLDLLA-LI wound dressing includes collagen fibers that are compressed but not necrotic (Bayati *et al*., 2023).

As anti-corrosion agent

It was looked into if commercial henna (*L. inermis*) might prevent the corrosion of aluminium alloy when submerged in saltwater. The 25mm x 25mm x 3mm aluminium alloy (5083) was prepared. For 60 days, the immersion test was carried out in saltwater with various henna concentrations. According to the findings, henna contains significant amounts of lawsone, which forms isolation layers on the aluminium alloy surface to aid in the chemisorption or adsorption process. At 88% (500 ppm), the corrosion inhibition efficacy was determined to be the greatest. Henna was shown to be a great natural aluminium alloy inhibitor in saltwater (Milošev *et al*., 2012). The mild steel corrosion in well water has been controlled using an aqueous extract of henna leaves. The iron-lawsone complex makes up the protective film. The Langmuir adsorption isotherm is obeyed when inhibitor molecules adsorb on metal surfaces (Devi *et al*., 2020).

As Biostimulant / biofertilizer

Any chemical or microbe administered to plants with the intention of improving growth and yield characteristics is referred to as a plant bio-stimulant. In a recent study, the growth-stimulating ability of Henna soil application was evaluated on Lemongrass, and the results suggest that the treatment considerably increased leaf length and number compared to the control (Ibrahim and Idris, 2020).

As Farming for economic security

Its leaves may be used to make a red-orange dye that is used to colour leather, silk, wool, and human body parts including skin, hair, and fingernails. This plant shows immense significance in the field of medicine and other important uses. According to financial research, Pali's high-quality henna makes it a lucrative and alluring alternative for farmers to make a living. The farmers in the area benefit from Henna's sustainable revenue since it can withstand high salinity, drought, and occurrences of pests and illnesses. Whereas other crops can't grow there, this one can. In

Pali, Rajasthan, henna farming yields 250 kg to 2500 kg of leaves every year from the first to the fourth year of cultivation from barren fields (Singh *et al*., 2021).

The findings are also consistent with research by Noonari (Noonari, 2015), which revealed that henna farmers in Pakistan made an average net revenue of Rs. 54406 per acre and a gross income of Rs. 121600.00. The economic evaluation showed that it may give economic security and a successful and appealing choice for rural lives.

Anti-pollutant

Brilliant green (BG) dye is typically used in large-scale textile dying, paper printing, and the dying of wood and fibre products. Health risks are associated with this dye since it is thought to be very harmful to the lungs, skin, and eyes (Kismir and Aroguz, 2011). It has been demonstrated that *L. inermis* Seed Powder (LISP) can remove Brilliant Green (BG) dye (93%) from aqueous solution when further chemically treated with orthophophoric acid (CTLISP). In comparison to other types of absorbent, the CTLISP has high monopolar adsorption capacity and good regeneration (Ahmad and Ansari, 2020).

According to the green synthesis approach, Au-Ag BNPs are ecologically safe and may have catalytic reduction/degradation activity against organic dyes that are harmful to the environment. The aqueous portion of *L. inermis* seed extract was used to create Gold-Silver Bimetallic Nanoparticles (Au-Ag BNPs) via ultrasound-assisted green synthesis. They used a UV-Vis light source to demonstrate the effectiveness of manufactured Au-Ag BNPs as a green catalyst in the reduction/degradation reaction of 4-nitrophenol (4-NP) and methyl orange (MO) dye that pollutes the environment when present with NaBH4 (Akilandaeaswari and Muthu, 2021). In other investigations, it was seen that Henna (*L. inermis*) extract was used to create and stabilise metallic gold nanoparticles (Au-NPs). When those extracted Au-NPs were tested against a persistent organic pollutant i.e., DDT, the result showed high degradation of DDT, which proved that these nanoparticles have the capacity for environmental clean-up (Abd El-Aziz *et al*., 2018).

As sanitiser

The crude ethanolic extract of henna has the potential to serve as a substitute sanitiser. (Majiya and Galstyan., 2023). The bioactivity of henna leaf methanolic extract was examined in 4 solutions in different studies. Acetate-HCL (AH) Buffer (pH 4.6), Phosphate Buffer Saline (PBS) (pH 7.2), Tris-HCL (TBH) Buffer (pH 8.6), and Distilled Water (dH20) were the buffers with the highest antibacterial activity (AH > dH_2O >>>> TBH > PBS). High and rapid antibacterial and antiviral activities of the extract were maintained and observed in AH and dH20, indicating that the extract would be suitable for making sanitisers for topical and environmental applications such as hand, object, and surface sanitization, particularly in locations where conventional alcohol-based sanitisers are lacking. (Table 3)

Table 3: Other Uses of *L. inermis*

Sl. No.	Uses		Plant parts used	References
1.	As cosmetics	Henna paste as art on hand, beard	Leaves	Joshi and Pawar, 2015
		As natural lipstick	Henna leaves + *Beta vulgaris*	Obat and Bosire, 2022
		As tattooing art	Leaves	Basas, 2007
		Shampoo and conditioner	Leaves	Telrandhe, 2023
2.	Hospital waste water treatment		*L. inermis* + *Myrtus communis*	Edan *et al*., 2023
3.	As bacterial staining		Leaf extract of henna	Jeyathilakan *et al*., 2012
4.	Green nano-particle production		Whole plant	Alhomaidi *et al*., 2022
5.	As natural dye	Dye for leather, wool and fabric industry	Aqueous henna leaf extract	Musa *et al*., 2009 Annapoorani and Sundarraj, 2014
		Dye for solar panel cell	Laali dye from *L. inermis*	Akwolu *et al*., 2023 Vekariya *et al*., 2016
		For production of green multifunctional material (linen)	Henna extract + Copper Sulphate mix	Yadav *et al*., 2019
6.	As hedge plant		Whole plant	Kumar *et al*., 2013

7.	As Bio-fabrication	Methanolic seed extract of *Lawsonia inermis*	Bhatt *et al*., 2023
8.	As bioactive wound dressing	Poly (L-lactide-co-D L-lactide) PLDLLA nanofibers with *L. inermis* (LI) or PLDLLA-LI	Bayati *et al*., 2023
9.	As anti-corrosion agent	Aqueous extract of henna leaves	Milošev *et al*., 2012 Devi *et al*., 2020
10.	Biofertilizer	Whole plant	Ibrahim and Idris, 2020
11.	Farming for economic security	Total plant	Singh *et al*., 2021 Noonari, 2015
12.	Anti-pollutant	Green synthesis of gold silver bimetalic Nanoparticles (Au-Ag-BNPs)	Ahmad and Ansari, 2020 Abd El-Aziz *et al*., 2018 Akilandaeaswari and Muthu, 2021
13.	As sanitiser	Ethanolic extract of henna	Majiya and Galstyan, 2023

Conclusion

This review concluded that every part of this plant is so important, it has been used as elements for diverse use in different sectors. Henna has been contributing in the multi-dimensional inclusion of medicine, cosmetic, economic, environmental, and social sustainability. Numerous global studies on eco-efficiency or eco-effectiveness in various contexts have been conducted on Lawsone. In this context, *L. inermis* could be used as an important candidate with additional contributions to economy of the country. However, more studies on the potential use of *Lawsonia inermis* in other important sectors could be done basically in the field of agriculture and most importantly for environment protection for multipurpose use in different sectors, the promotion of its cultivation is a prerequisite. Though this plant is a cash crop and easy to maintain, but cultivated only in a few areas of India. So, more production of this plant would be a booster to explore the versatility of this plant in other important areas.

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