

REVIEW ARTICLE

THE MULTIFACETED ROLE OF MADHUCA LONGIFOLIA (MAHUA) IN TRADITIONAL MEDICINE AND SUSTAINABLE DEVELOPMENT: A REVIEW

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ABSTRACT

Members of the Sapotaceae family, Madhuca longifolia (commonly called Mahua), are significant in indigenous knowledge systems and traditional Indian medicine. Originating from Sri Lanka and the Indian subcontinent, this tree is suited to regions that are prone to drought and grows well in a variety of ecological settings, including arid deciduous forests. It is prized for both its economic and therapeutic qualities. Traditional medicine has made use of the bark, leaves, flowers, fruits, seeds, and oil of the Mahua tree. Mahua is believed to have anti-inflammatory, antidiabetic, antimicrobial, hepatoprotective, antioxidant, anticancer, neuroprotective, and wound-healing properties. Flavonoids, saponins, tannins, terpenoids, glycosides, phenolic compounds, and fatty acids are among the many phytochemicals that are linked to these effects. While the seeds of mahua produce oil that has both industrial and edible uses, the flowers are also high in sugars and are used in traditional fermentation to make alcoholic beverages. M. longifolia is still underutilized in the contemporary food and pharmaceutical industries, despite its ethnomedicinal significance and encouraging bioactivities demonstrated in early research. Its taxonomy, distribution, traditional uses, phytochemical composition, and

pharmacological characteristics are all summarized in this review. In order to fully realize its potential, it also emphasizes the necessity for additional research, including safety assessments, clinical trials, and biotechnological applications. Mahua might aid in the creation of novel medications, nutraceuticals, and functional foods with more extensive scientific verification. Its sustainable use and cultivation could also help preserve biodiversity and rural livelihoods.

Keywords: *Madhuca longifolia, traditional medicine, phytochemicals, pharmacological activities, medicinal plants, extracts*

INTRODUCTION:

Throughout human history, plants have been used as traditional medicines and pharmacopoeia [33]. About 2000 medications in India are derived from plants, and efforts are still being made to find safe and reasonably priced phytomedicines [20]. *Madhuca longifolia* has several biological names, including *Bassialatifolia*, *Madhuca latifolia*, or *Roxb Madhuca indica*, *Bassia longifolia* L., *Bassia latifolia* Roxb, *Illipe latifolia* (Roxb.) F. Muell, and *J. F. Macbr Gmel*, J. F. Both species are members of the Sapotaceae family [34]. Although very little information and surveys about Mahua's pharmacological properties have been published, it has been used for non-medical purposes. This is a naturally occurring plant that is frequently grown without the need for any resources. It is a 20-meter-tall evergreen or semi-evergreen tree. Its broad, spherical crown is both complete and short, and it grows in the green forest areas of India [24]. With a red inner bark that releases a white, milky sap, the tough, brown bark is slightly cracked

and fissured. The elliptical leaves measure 15–25 cm in length and 8–15 cm in width. They have a pointed tip, an angled base, a thick texture, a hairy underside, oblique tertiary nerves, strong nerves (roughly 12 pairs), and an unbroken but wavy edge. The stalk is reddish in color and 2–4 cm long. At the end of the stems are clusters of white, meaty, pointy, sweat-scented flowers that are 2 cm long. The fruit is ovoid, fleshy, greenish in color, 2–4 cm across, and contains one to four seeds. The elongated, brown, shiny seeds are 2 cm long [17]. Because of its potent pharmacological effects, *Madhuca longifolia* is regarded as the foundation of the traditional medical system. *Madhuca* is powerful enough to create new medications. Mahua is endowed with a wide variety of chemical components that give it various medicinal qualities. The various plant parts of *Madhuca longifolia* include proteins, phenolic compounds, terpenoids, anthraquinone glycosides, mucilage, starch, and saponins and tannins. Mahua bark is used to treat swelling, leprosy, fractures, and diarrhea. The mahua plant has numerous qualities, including

antibacterial, anti-inflammatory, antidiabetic, wound-healing, and antitumor effects. [87]. Acute and chronic tonsillitis, helminthes, pharyngitis, and bronchitis can all be cured using its tonic, aphrodisiac, astringent, and cooling properties. Its leaves have been used as a poultice to treat eczema and as an expectorant for Cushing's illness, chronic bronchitis, and other conditions. The plant's aerial parts have anti-inflammatory properties. The tooth powder made from stem bark is used

to fortify gums. Mahua flowers are recognized for their high nutritious and low sugar content and are delicious. Sapogenin and other basic acids are found in its seeds [45]. They also contain a lot of edible fats [89]. Despite its value, mahua remains underexplored in research and food industries. This review highlights its current medicinal and food uses and potential for future value addition.

Table 1: The scientific classification system of *M. longifolia* is listed below [11].

Botanical name	Madhuca longifolia
Family	Sapotaceae
Subfamily	Caesalpinioideae
Genus	Madhuca
Species	longifolia
Order	Ericaleae

Regional source:

In the states of West Bengal, Maharashtra, Odisha, Madhya Pradesh, and Chhattisgarh, the mahua plant is extensively found. In the Chhattisgarh

districts of Raigarh, Ambikapur, Dantewada, Bilaspur, Mahasamund, Durg, Janjgir, Champa, etc., this tree grows easily [24].

Table 2: Vernacular names of *Madhuca longifolia* in different languages [23].

Language	Vernacular Names of <i>M. longifolia</i>
English	Honey tree, butter tree
India	Mahua
Sri Lanka	Mi, Illuppai
Sanskrit	Madhukah
Bengali	Mohua
Oriya	Mahula
Kannada	Errape
Telugu	Ippi
Tamil	Illuppai
Malayalam	Irippa
Gujarati	Mahuda
Marathi	Mahu and muvda
Marwari	Dolma



(A)



(B)



(C)



(D)



(E)



(F)

Figure 1: Photographs of *Madhuca longifolia* tree (A) fruits, (B) mahua tree, (C) seeds, (D) dried flowers, (E) yellowish flowers, and (F) leaves.

Distribution and habitat:

The species is found throughout northern, central, and southern regions of Sri Lanka and India. Of the two varieties, var. *latifolia* is found in some areas of central and northern India as well as Burma, while var. *longifolia* is distributed throughout Sri Lanka and southern India, extending northward to Maharashtra and Gujarat. It is typical in dry teak timberlands, dry salwood, and dry blended deciduous woods. Although it can grow in a variety

of soil types, the tree thrives in sandy soil. It also grows on calcareous, clayey, bouldery, and shallow soils [18].

- Maximum temperature: 28–50°C; minimum temperature: 2–12°C
- Elevation: 1200 meters
- Rainfall per year: 550–1500 mm

It requires intense light and can withstand drought [38].

Cultivation and collection:

Mahua seeds, which are used to extract oil, are produced in India in quantities of 0.12 million tonnes. India produces roughly one million tons of mahua flowers annually. Mahua seed and flower collection is encouraged by the Indian state government because it provides jobs for a large number of people. Mahua can be self-sown or planted. March through April is when flowers bloom [38]. Although flowering frequently outpaces seed production during this time, seeds are normally collected in May, June, and July. Villagers pick the fruits by hand or with bamboo sticks, usually in the morning. Up to 15 kilograms

of seeds, known locally as tori, can be collected in a single day during the busiest times for collection. It is possible to extract about 250 milliliters of oil from every kilogram of seeds. After being vacuum-purified, this oil is sold and used widely in homes. To prevent fungal spoiling, the oil is stored in airtight earthen pots or baskets and is frequently extracted using indigenous methods. While the pulp is consumed, the seeds are extracted from the fruits. Gully oil, the extracted oil, is crucial [61]. Mahua should be taken in doses of 10–15 g (The Ayurvedic Pharmacopoeia of India) [85].

Table 3: The economic, nutritional, and medicinal qualities of Madhuca indica [56].

Properties	Descriptions
Medicinal Properties	Hepatoprotective, Wound healing, Antiburns, Bone healing, Emollient, Skin disease, Rheumatism, Headache, Laxative, Anti Haemorrhoids, Bronchitis, Anti ulcer, As tringent, Tonsillitis, Swelling gum, Diabetes, Stomach.
Nutraceutical Properties	Increase Immunity, Facilitate digestion, Antioxidant, Stimulant, Tonic, Energetic, Glucose booster, Etc.
Economical Properties	In Alcohol production, Jelly, Sweet candy, C hocolate, Jam, Vegetable, Biodiesel, Fuel production, Oil production, Fertilizer, Animal food, Etc.

Useful parts of plants:

In small or large amounts, every part of a plant has some medicinal qualities. A plant's active ingredients can vary greatly among its parts, making one part potentially poisonous while another is

relatively innocuous. The various parts of the plant can be categorized based on their respective functions. Roots, bark, leaves, flowers, fruits, seeds, and oil are among them [57].

Table 4: *Madhuca longifolia*'s traditional applications in India

Sr.no.	Tree part(s)	uses	Reference(s)
1.	Seeds cake	Anti-inflammatory, anti ulcer, and hypoglycaemic activity	[70]
2.	Bark	Rheumatism, ulcer, inflammation, bleeding, spongy gums, tonsillitis, diabetic, stomach ache, anti snake poisoning, astringent, emollient, fracture, itching ,antidiarrhea	[3]
3.	Flower	Analgesic activity, Anticancer activity, Antioxidant activity	[17]
4.	Leaves & bark	Wound healing activity	[6]
5.	Leaves	Antipyretic activity, Anti fertility activity, Anti -oxidant activity, Antiulcer activity	[17]
6.	Leaves and stem	Antimicrobial activity	[6]
7.	Seeds	Analgesic Anti-inflammatory Anti-microbial	[63]

Phytochemistry:

The active ingredients found in the various plant parts, which may be

present in small or large amounts, determine the plant's therapeutic value [57].

Table 5: *Madhuca longifolia* phytoconstituents

Sr. N.	Part of Plant	Chemical Constituent	Reference
1	Leaves	Dglucoside, stigmasterol, β carotene, xanthophylls, erthrodiol, palmitic acid, myricetin, 3-O-arabinoside, 3-O-L-rhamnoside, quercetin, 3-galactoside; 3 β -caproxy and 3 β -palmitoxy-olean-12-en-28-ol, oleanolic acid, β sitosterol, 3-O- β -Dglucoside, 3 β -caproxyolcan-12-en-28 ol, β -carotene, n-octacosanol, sitosterol, quercetin, β sitosterol - β -Dglucoside, n hexacosanol	[88],[5], [77],[74]
2	Bark	Ethylcinnamate, sesquiterene alcohol, α -terpeneol, 3 β monocaprylic ester of erythrodiol and 3 β -capryloxy oleanolic acid. α - and β - amyrrin acetates.	[55]
3	Seeds	Arachidic acid, oleic acid, linolenic acid, aspartic acid, Protobassic acid, lysine, Myristic, palmitic and stearic acids, isoleucine, cysteine, α -alanine, glycine, and leucine, methionine, proline, threonine, myricetin, serine, quercetin, Misoaponin A and saponin B, Madlongiside A, B, C, D	[36]
4	Fruits	n-hexacosanol quercetin and dihydroquercetin, β -sitosterol and its 3 β -Dglucoside, α - and β - amyrrin acetates.	[21]
5	Flower	Vitamins A & Vitamins C	[43]
6	Nut-shell	Arthritis, bladder infections	[60]

Pathophysiological activity:

1. Analgesic activity:

Since analgesics reduce pain without impairing consciousness or changing mice's other afferent inputs' body temperature, *Madhuca longifolia* has an antipyretic effect [67]. The six animals (mice) in the group were given the methanolic extract of *Madhuca longifolia* orally. Following an injection of acetic acid, the amount of writhing that occurred over the next half hour was noted. The decrease in abdominal constriction between mice and control animals after receiving the extract is a measure of anti-analgesia [89]. It has been demonstrated that *M. longifolia* flower extracts, both alcoholic and aqueous, have analgesic effects. Graded doses of both extracts (4.0 to 64.0 mg/kg, i.m. X 3 days) demonstrated dose-dependent analgesic effects when tested on rats or mice using the tail flick, hot plate, and chemical writhing techniques [23].

2. Anticancer activity:

Cancer is the most deadly and prevalent chronic illness in history, and there are numerous chemical and herbal treatments for it on the market. In order to fight cancer, recent developments in anticancer research have concentrated on enhancing immunotherapy, targeted therapy, and natural substances like flavonoids [40, 29]. Additionally, *M. longifolia* has been demonstrated to possess chemopreventive qualities on human cancer cell lines. [17]. Utilizing the plant's leaf extract, silver

nanoparticles were created and tested for anticancer effects on the SiHa cervical cancer cell line and the MDA-MB-231 breast cancer cell line at different concentrations [55]. With concentrations of 10, 20, 40, and 80 µg/mL, the nanoparticles demonstrated stronger anticancer effects than the Adriamycin-positive control group [68]. Moreover, rats given DMBA (7,12-Dimethylbenz(a)anthracene), a carcinogen that causes mammary carcinomas, were given the plant's methanolic leaf extract orally. When administered at doses of 100 and 200 mg/kg, the extract decreased the growth and incidence of tumors [55]. Four distinct fruit-seed fractions, including methanol, ethanol, acetone, and chloroform, were utilized to conduct in vitro anticancer experiments against the human cancer cell line (HeLa), and the MTT assay was employed to assess the inhibition of cell growth. The findings demonstrate the very good to moderate anticancer activity of the different fruit-seed extracts of *M. longifolia* [20].

3. Antioxidant activity:

Numerous investigations have validated *M. indica*'s potential as a potent antioxidant, with consequences for functional foods and health supplements. It has potential for use in pharmacological and nutraceutical applications due to its exceptional antioxidant capacity [2]. Because hydroxyl groups can act as hydrogen donors, mahua extracts are known to naturally have antioxidant qualities. A compound's capacity to reduce

can be a key indicator of its possible antioxidant activity. To evaluate the ethanolic extract of the bark, leaves, or flowers of Mahua plants, free radical scavenging activity was measured using 1,1-diphenyl-2-picryl hydrazine (BPPH), reducing power assay, and superoxide scavenging activity [86]. The ethanolic bark extract of Madhuca Indica's reducing property suggests that it can donate hydrogen atoms in a dose-dependent manner [89]. After comparison, the assay's results showed that they were just as effective as ascorbic acid, a naturally occurring antioxidant. As demonstrated by the extract, a higher concentration of ascorbic acid results in a more powerful radical-scavenging effect [86]. Using ascorbic acid as a reference standard, the

antioxidant activity of methanol extracts of *M. indica*'s leaves and bark was assessed. Ascorbic acid was found to have an IC₅₀ value of 45.738 µg/ml. The plant parts that showed antioxidant activity were the leaves and bark, with IC₅₀ values of 61.832 µg/ml and 66.342 µg/ml, respectively [8]. Several experiments showed that the acetone extract had a higher antioxidant activity than the other solvent extracts (acetone extract>methanol extract>ethanol extract>water extract) of Mahua flowers and fruit. The findings showed that Mahua's fruit and flowers are rich in natural antioxidants and polyphenols. Consequently, they might be helpful as functional food ingredients that improve human health. [83].

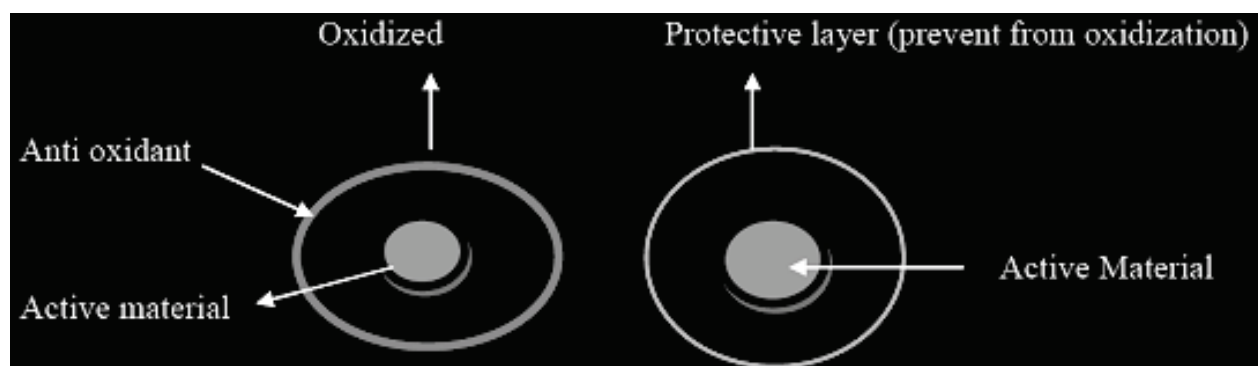


Figure 2: Antioxidant Protective Coating to Prevent Oxidation of Active Material

4. Anticonvulsant activity / epileptic activity:

Pentylentetrazole (PTZ)-induced convulsion in mice treated with benzodiazepines as a standard medication was used to test the anticonvulsant properties of the methanol extract of Madhuca longifolia heartwood [57]. An

electroconvulsimeter is used to induce seizures in all of the groups. Before seizures were induced, 14 days were spent administering the different extracts of Madhuca longifolia fruits and seeds, including ETL, MTL, ATN, and CLM. The length of time that different stages of epilepsy lasted was noted [7]. The

GABAergic and opioid systems of *Madhuca longifolia* may be responsible for its apparent efficacy in treating absence seizures [58]. Additionally, research indicates that it might have an active component with an anticonvulsant property that could aid in the management or treatment of absence seizures [17]. Animals in Group I received 1% w/v SCMC (1 ml/100 g). Animals in Group II received phenytoin (PTN) suspension in 1% w/v SCMC at a dose of 25 mg/kg. Group III: Animals administered extract ETL (200 mg/kg p.o.) suspended in 1% w/v SCMC. Animals in Group IV were given extract MTL (200 mg/kg p.o.) suspended in 1% w/v SCMC. Animals in Group V received extract ATN (200 mg/kg p.o.) suspended in 1% w/v SCMC. Animals in Group VI received extract CLM (200 mg/kg p.o.) suspended in 1% w/v SCMC [7].

5. Anthelmintic activity:

The gastrointestinal helminths develop resistance to the currently available conventional anthelmintic medications, making anthelmintic resistance a common problem in the treatment of helminth infections [22]. Because resistance development is becoming a bigger concern, it's important to keep an eye on how well current medications are working and look into new treatment options [52]. The effectiveness of methanolic leaf extracts has been tested in anthelmintic studies using *Peritoma posthuma*, an organism that resembles intestinal roundworms anatomically. Using

albendazole as the positive control, the extract showed notable anthelmintic activity, albeit with a transient effect. While anthelmintic activity was demonstrated in both aqueous and methanolic extracts, the methanolic extract performed better. Another study found that when piperazine was used as the standard medication, a dose of 60 mg/ml of methanolic leaf extract demonstrated significant activity against the parasitic roundworm *Ascaridia galli*. According to some theories, the mechanism of action entails lowering the amount of glycogen in parasites and preventing them from absorbing glucose and lactic acid, which inhibits energy metabolism and ATP synthesis and increases helminth motility [64].

6. Antimicrobial activity:

The alcoholic extract of *M. longifolia*'s leaves and flowers was tested for antimicrobial activity against *Aspergillus niger*, *Bacillus subtilis*, *Staphylococcus aureus*, and *Aspergillus oryzae*. Therefore, research has verified that extracts from *M. longifolia* exhibited noteworthy antimicrobial properties against test microorganisms. Certain multi-drug resistant (MDR) bacteria, such as MDR *Escherichia coli*, MDR *Klebsiella pneumoniae*, and MDR *Pseudomonas aeruginosa*, were significantly impacted by the ethanolic extract of leaves. The potential for creating novel therapeutic agents against resistant bacteria is demonstrated by this extract's capacity to exhibit synergistic effects with currently

available antibiotics [10]. Aqueous stem extract demonstrated the potential to be used as a treatment for oral conditions like dental caries and demonstrated antimicrobial activity against *Streptococcus mutans*, a common oral bacteria. Chlorhexidine served as the reference medication in the study, which employed the agar well diffusion method [25]. By using agar well diffusion and microdilution assays, the antimicrobial activity of petroleum ether, chloroform, ethyl acetate, and methanol extracts of *M. longifolia* bark was evaluated against *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Bacillus subtilis*. Of the 64 extracts tested, 27 exhibited good activity in the well diffusion assay. All extracts exhibited significant activity in the microdilution assay, indicating that *Madhuca* has strong antimicrobial properties. [1]

7. Antihyperglycemic activity:

Anti-hyperglycemic or antidiabetic drugs work by controlling blood sugar levels in people with diabetes. These therapies aim to decrease the liver's synthesis of glucose, increase insulin secretion, or improve insulin sensitivity [64]. A strong antidiabetic agent and dose-dependent antihyperglycemic action were shown by the methanolic extract of *M. longifolia* bark [82]. The extract's hypoglycemic action is thought to either increase β -cell activity in the pancreas or inhibit intestinal glucose absorption or tissue-level glucose uptake. In comparison to the glibenclamide control, studies using streptozotocin-

induced diabetic rats demonstrated that the highest glucose-lowering activity was attained when a dose of 200 mg/kg of methanolic extract was given. Additionally, the extract improved renal function and decreased total cholesterol [64]. According to a study, the α -glucosidase assay revealed greater inhibition in the proanthocyanidin-enriched fraction and the highest polymeric proanthocyanidin-containing fraction that was separated from the bark extract. This demonstrated the scientific backing for the long-standing practice of using a decoction of *M. longifolia* to treat diabetes patients [9]. The ability to reduce mitochondrial dysfunction, lactate dehydrogenase levels, and GLUT expression in tissues was demonstrated by the fact that hydro-ethanolic fractions from leaves were effective against high-fat diet-induced diabetes and obesity, which led to particular patterns of GLUT expression and mitochondrial action. Better insulin sensitivity and consequently antidiabetic action result from hydro-ethanolic extract's ability to reverse the GLUT imbalance [32].

8. Anti-ulcer and gastroprotective activity:

One illness that affects a lot of people is gastritis. Even though there are synthetic drugs to prevent stomach damage, research is being done to find new drugs from the possible natural compounds of different medicinal plants because of the serious side effects [64]. According to a study that used rats with gastric toxicity caused by diclofenac and silymarin as a control, an

aqueous leaf extract of *M. longifolia* was found to have gastroprotective activity. The ulcer index, antioxidant assay, histopathological alterations, cytokines, and protein expression levels all demonstrated that the aqueous leaf extract

of *M. longifolia* suppressed gastric toxicity [81]. The 70% ethanolic extract of *M. longifolia* bark demonstrated dose-dependent anti-ulcer activity in a different study involving rats with indomethacin-induced ulcers [11].

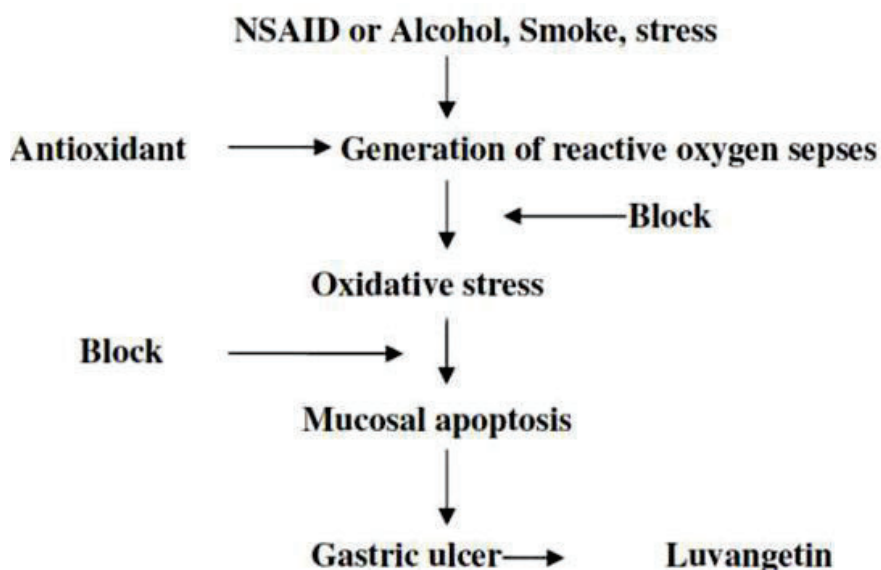


Figure 3: Potential Mechanism of Mahua's Anti-Ulcer Action [89]

9. Wound healing:

The process of wound healing includes the following stages: hemostasis, inflammation, proliferation, and remodeling. The efficiency of wound healing depends on a number of variables, such as age, nutritional status, and the presence of infections. Utilizing natural substances, biomaterials, stem cells, and growth factors to promote tissue regeneration is the main focus of current research on improving healing techniques [92]. When compared to betadine control, a 5% w/w ointment of *M. longifolia* bark and leaf ethanol extracts was able to

significantly speed up the rate of wound healing and epithelization [73]. Another study found that flavan-3-ols from the methanolic bark extract had antibacterial activity. Additionally, fractions enriched with polymeric proanthocyanidins, which are composed of flavan-3-ol units, demonstrated antibacterial activity against *Staphylococcus aureus*, which naturally inhabits human skin, suggesting that the extract can help with wound healing. In contrast to monomeric, dimeric, trimeric, and tetrameric forms of flavan-3-ols, only proanthocyanidin fractions and polymeric proanthocyanidins have shown antibacterial effects. Therefore, it is

hypothesized that a higher degree of polymerization could result in a stronger activity [64].

10. Immunomodulatory activity:

Madhuca indica's immune-boosting qualities have been known since the days of Ayurveda. The plant's leaves, bark, flowers, and fruits have all been used to strengthen people's immune systems. These components are used by the Chhattisgarh tribal people to strengthen their immune systems and enhance life vitality. A few researchers have examined and documented *Mahua*'s immunological properties. All dried parts, including leaves, bark, flowers, and fruits, were prepared into an ethanolic extract, which was then tested orally in sheep blood cells (SRBC) antigen over the course of a seven-day immunization period. Cyclophosphamide and levamisole were taken as prescribed. Since the extract demonstrated good efficacy, it was taken into consideration for additional research to make it more pertinent [62, 76].

11. Neuropharmacological activity:

By altering cellular pathways, receptors, ion channels, and neurotransmitter systems, neuropharmacology research aims to develop drugs that target the nervous system to treat mental and neurological conditions and return the brain to normal function [44]. In one earlier study, the neuropharmacological activity was assessed using the methanolic extract and derivative of madhucic acid extracted from the leaves. The results were reported methodically using a number of techniques, including spontaneous motor activity, the marble burying test, the Eddy's hot plate method, and phenobarbitone-induced sleeping time. Additionally, in mice, the extract and the compound showed notable antinociceptive and central nervous system depressant effects. Additionally, it was noted that phenobarbitone improved the amount of time that people slept and that it decreased spontaneous motor activity and marble burying activity [31]. The actophotometer used to assess the neuropharmacological activity of *mahua* extracts is displayed in the figure.

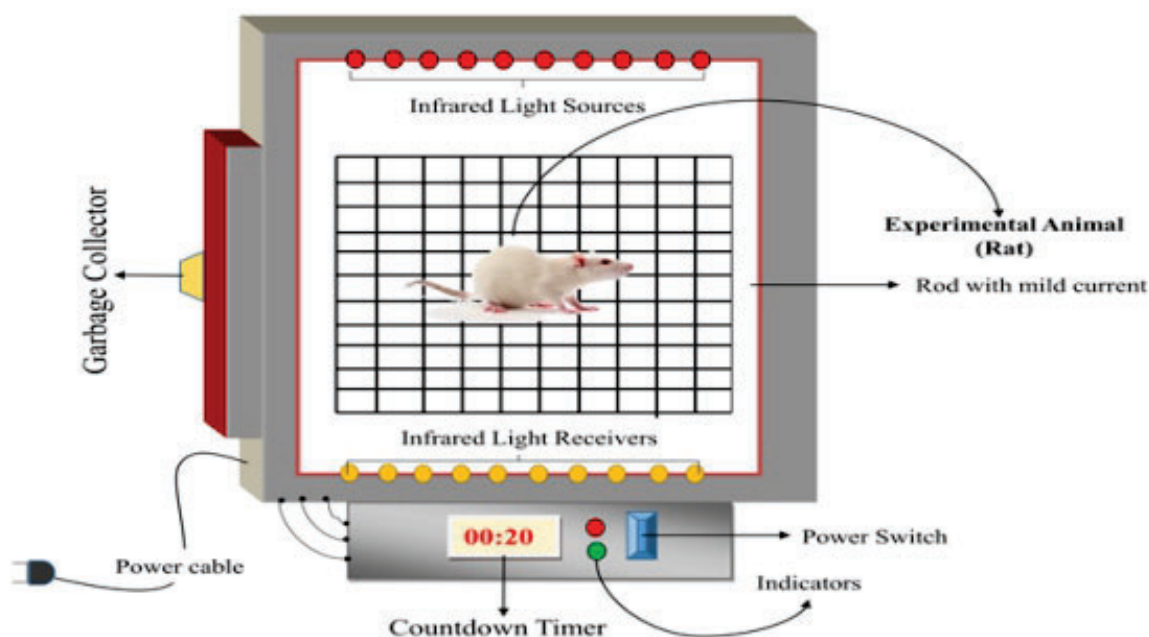


Figure 4: Mahua extracts' neuropharmacological activity is assessed using an actophotometer [56].

12. Anti-inflammatory activity:

Histamine and serotonin are two examples of the different chemical mediators released by the injured cell that cause swelling or inflammation [91]. The body uses inflammation as a defense mechanism [4]. The HRBC (Human Red Blood Cell) method and the inhibition of protein denaturation were used to confirm the anti-inflammatory properties of silver nanoparticles made from *M. longifolia* leaf

extract. In contrast to sodium diclofenac, the reference medication, silver nanoparticles demonstrated a notable level of activity. Using aspirin and sodium diclofenac as standard medications, respectively, the HRBC method was used to examine heat-induced hemolysis and hypotonicity-induced hemolysis. Bovine serum albumin was utilized in the study on the inhibition of protein denaturation, and the standard medication was diclofenac sodium [68].

$$\text{Percentage inhibition} = \text{Control} - \frac{\text{Treated}}{\text{Control}} \times 100$$

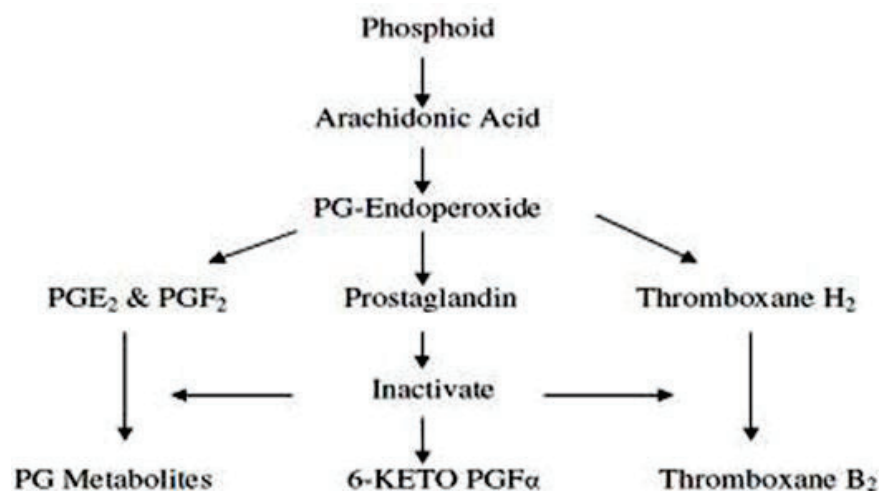


Figure 5: Biosynthesis and Metabolism of Prostaglandin [89].

13. Hepatoprotective activity

In order to mitigate liver and kidney damage brought on by infections, toxins, or chronic illnesses, hepatoprotective and nephroprotective medications are crucial. These treatments work in a variety of ways, including regenerative, anti-inflammatory, and antioxidant effects [19]. In a rat model of acetaminophen-induced toxicity, ethanolic leaf extract of *M. longifolia* showed possible hepatoprotective and nephroprotective effects. The study found that the concentrations of neutrophils, mean corpuscular hematocrit, mean corpuscular Hb content, uric acid, granulocytes, and platelets were decreased, while the levels of hemoglobin (Hb), serum urea, packed cell volume, total leukocyte count, creatinine, mean corpuscular volume, differential leukocyte count, and body weight were elevated [54]. A different study using rat models of diclofenac-

induced hepatotoxicity showed that aqueous leaf extract exhibited hepatoprotective activity, as evidenced by reports of cytokine levels, liver enzyme markers, antioxidant parameters, and histopathological alterations. Furthermore, by analyzing protein expression levels, antioxidant activities in kidney tissue homogenate and plasma, renal histopathology, and renal enzyme markers that showed significant attenuation of cellular injury, redox homeostasis restoration, and renal function recovery, the same study also showed that aqueous leaf extract is a potent nephroprotective agent [80].

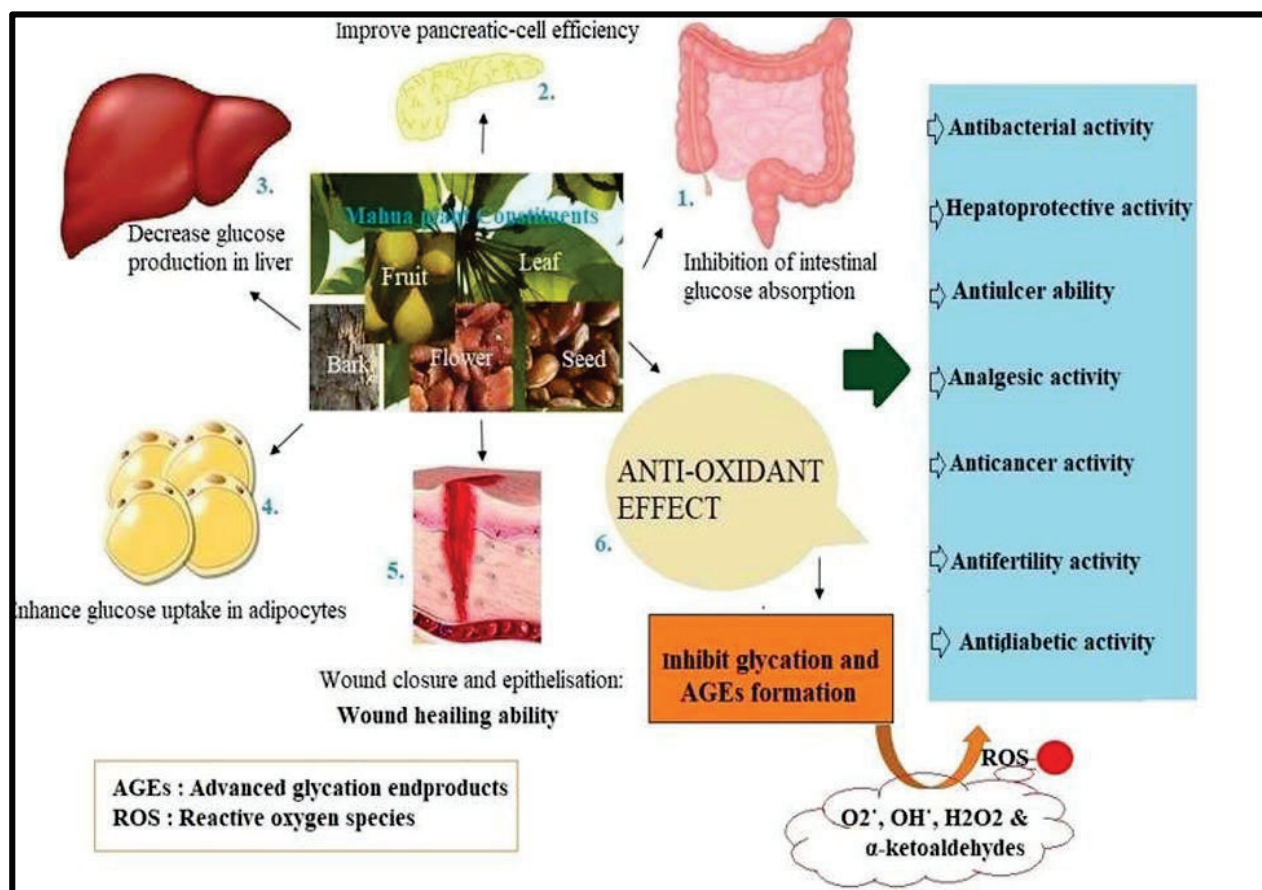


Figure 6: Potential mechanisms underlying the botanical activities and applications of mahua plant extract. 1. Mahua extract may block the intestinal absorption of glucose; 2. increase the efficiency of pancreatic cells; 3. reduce the liver's production of glucose; and 4. increase tissue-level glucose uptake (adipocytes). 5. Mahua's bark and leaves greatly speed up wound healing and epithelial activity; 6. Mahua is recognized for its inherent antioxidant qualities [86].

Table 6: Pharmacological Characteristics of Extracts from *M. indica* and a Few Isolated Substances.

Sr. No.	Type of Activity	Parts/extracts/chemical constituents	Reference
1.	Antifertility activity	Leaves: Methanolic extract	[72]
		Seeds: Aqueous extract]	[28]

2.	Antifungal activity	Leaves: Aqueous/methanolic extract	[53]
		Flowers: Aqueous/ethanolic extract	[65]
3.	Antihyperglycemic activity	Leaves: Methanolic extract	[37]
4.	Antiulcer activity	Leaves: Aqueous extract	[48]
		Leaves: Methanolic extract	[47]
		Seeds: Ethanolic/alkaloid extract	[70]
		Bark: Aqueous /ethanolic extract	[66]
		Leaves: Methanolic extract	[47]
		Leaves: Methanolic extract/3,5,7,3,4 -Pentahydroxy flavone	[46]
5.	Antibacterial activity	Leaves and Bark: Aqueous /methanolic extract	[8]
6.	Antioxidant activity	Bark: Phenolic/methanolic extract	[14]
		Leaves and Bark: Methanolic extract/Myricetin/Quercetin/â-Sitosterol	[49]
		Bark: Methanolic extract	[35]
		Bark: Aqueous /methanolic extract	[16]
		Leaves: Aqueous/acetone extract	[41]
		Leaves, Bark and Dried wood: Ethanolic extract	[42]
		Flowers: Methanolic extract	[30]
7.	Analgesic activity	Leaves, Bark and Flowers: Methanolic extract	[75]
		Leaves: Methanolic extract	[75]
8.	Antidiabetic activity	Bark: Aqueous extract	[26]
		Seeds: Ethanolic/alkaloid extract	[12]
9.	Anti-inflammatory activity	Leaves, Bark and Flowers: Methanolic extract	[1]
		Leaves: Pet. ether/ethyl acetate/methanolic extract	[65]

10.	Anti-microbial activity	Seeds: Ethanolic/alkaloid extract	[13]
		Bark: Ethanolic extract	[84]
		Leaves: Aqueous/acetone extract	[41]
		Leaves and Bark: Methanolic extract	[39]
		Bark: Ethanolic extract	[35]
		Bark: Organic extract	[51]
		Leaves, Bark and Flowers: Methanolic/aqueous extract	[69]
11.	Antipyretic activity	Flowers and Seeds: Methanolic extract/3,4 -Dihydroxy-5,2-dimethoxy-6,7- methylenedioxy isoflavone	[78]
12.	Hepatoprotective activity	Leaves, Bark and Flowers: Methanolic extract	[13]
13.	Anticancer activity	Bark and Leaves: Ethanolic extract	[71]
14.	Cytotoxic activity	Flowers: Methanolic extract	[27]
15.	Anthelmintic activity	Bark and Leaves: Methanolic extract	[30]
16.	Antinociceptive activity	Bark: Methanolic extract	[65]
17.	Antidiarrhoeal activity	Bark: Ethanolic extract	[65]
18.	Inhibitory activity	Bark: Ethanolic extract	[59]
19.	Tyrosinase inhibitors	Bark: Methanolic extract/Madhucoside A/ Madhucoside B/ Protobassic acid	[65]
20.	Immunomodulatory activity	Fruits: Methanolic extract/Ursolic acid	[15]
21.	Wound healing capacity	Leaves, Bark and Flowers: Ethanolic extract	[73]
22.	Toxicity	Leaves, Bark and Flowers: Ethanolic extract	[79]
23.	Radioprotective Activity	Root and Seed oil: Phenolic extract	[90]
24.	Cardioprotective effect	Leaves: Methanolic extract/3,5,7,3,4 -Pentahydroxy flavone	[50]

CONCLUSION:

Madhuca longifolia is an extremely beneficial plant that can be used as a traditional remedy as well as a possible source for contemporary medications and dietary supplements. Because of the numerous natural compounds it contains, it offers a wide range of health benefits, such as lowering blood sugar, protecting the brain, preventing infections, and even aiding in the treatment of cancer. Early scientific studies have supported traditional knowledge about this plant, but further investigation and human clinical trials are still required. Mahua is not yet commonly utilized in the food or pharmaceutical industries, despite its high nutritional content and therapeutic benefits. This creates excellent prospects for the development of novel medications and health products. Additionally, the plant plays an important role in rural areas by supporting local economies and promoting sustainable farming. To fully realize its potential, more research from different scientific fields is needed. This can help turn *Madhuca longifolia* into a reliable source of modern, safe, and effective health products.

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