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Madhuca longifolia var. latifolia (Roxb.) A.Chev: A plant with medicinal boon

Review Article

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Abstract

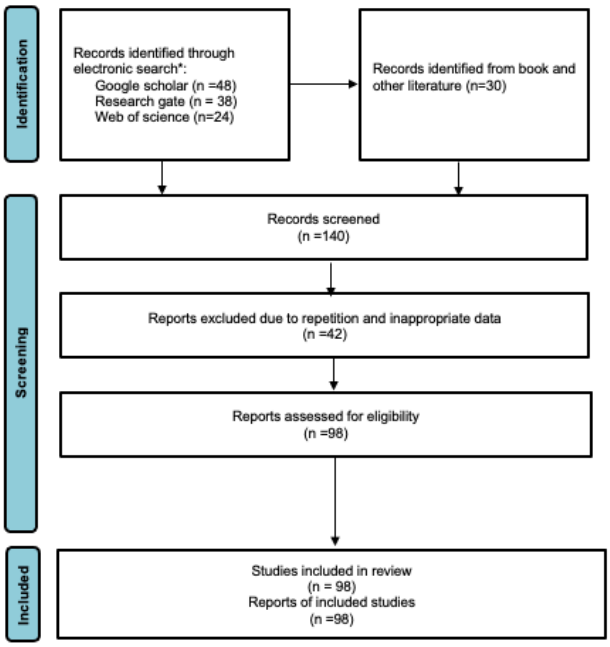
Throughout human history, people used to obtain drugs from natural resources like plants to cure their ailments and improve their health. Nowadays human beings rely more on herbal medicines for the treatment of various ailments because they show better therapeutic activity and have very little to zero side effects on the human body. *Madhuca longifolia* is also one of the plants used in this category. The plant has been used by people for its medicinal properties since the Ayurveda period (before B.C 300). The plant possesses various medicinal activities including anti-proliferative, anti-inflammatory, anti-bacterial, anti-cancer, anti-ulcer and antidiabetic, and antioxidant activity. In various parts of India, the plant is used in the treatment of different diseases in ethnomedicinal practices. The plant possesses several phytochemicals which are responsible for its medicinal properties. The primary focus of this manuscript is to emphasize the significance of diverse ethnomedical characteristics, multiple preclinical investigations, and clinical trials conducted on this particular plant. The study also encompasses the plant's geographical distribution, pharmacognostic and anatomical studies, as well as its various anthropological applications within the Indian subcontinent.

Keywords: *Madhuca longifolia, Medicinal uses, Ethnomedicine, Phytochemical, Mahua*.

Introduction

In the present-day scenario, the use of herbal-based drugs is increasing daily due to their efficacy, easy availability, low cost, and minimum or negligible side effects. According to the report of WHO, a major portion of the world's population is still dependent on herbs for their primary healthcare systems. In India obtaining medicine from plant and natural resources has a long history. In CharakSamhita, there are around 2000 medicinal plants, their uses and mode of drug administration, and the name of the disease in which a particular plant should be used are written in a documented form. *Madhuca longifolia* is also such a plant described in the previous medicine systems. In Ayurveda, Mahua is described as varnashodhak (having wound-healing activity), veeryawardhak (semen-enhancer), and vatpittashamak (help in reducing joint pain and indigestion). The present review aims to summarize all the medicinal properties, ethnobotanical uses, photochemistry, nutritional and application uses. The primary objective of this current review was to investigate the medicinal properties of *Madhuca longifolia* as documented in historical literature and to summarize contemporary scientific discoveries so that our future generations utilize the medicinal virtue of the plant and sustainable and optimum uses can be performed in such a way. The author obtained the information from various sources including research papers, and ancient Ayurvedic literature.

Figure 1: Flow chart of obtaining information about *Madhuca longifolia*



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Botanical Description and Geographical Distribution

Madhuca longifolia is native to the Indian sub-continent commonly known as Mahua. The tree belongs to the Sapotaceae family always evergreen but sheds its most leaves in the late spring season. The species can be found across the northern, central, and southern regions of peninsular India, as well as in Sri Lanka and Burma. It thrives in dry mixed deciduous forests, dry forests, and dry teak forests, showing optimal growth in sandy soil(1). It attains a height of up to 70 feet as shown in Figure 2. Leaves are 10 to 30 cm long, lanceolate, glabrous, and narrowed at both ends (Figure 3).The flowers are petite, succulent, and have a pale white colour. They are not only nourishing and delightful but also abundant in sugars, allowing for indefinite storage. (Figure 4). When ripe, the fruits exhibit an ovoid shape and measure 2-6 cm in length. They are fleshy in texture and have a greenish-yellow colouration (2). The tree blooms during the months of March to April, and its fruits ripen in May and June (5)

Figure 2: Whole tree of *Madhuca longifolia*

Figure 3: Leaves of *Madhuca longifolia*

Figure 4: Flowers of *Madhuca longifolia*

Classification

Kingdom: Plantae
Order: Ericaceae
Family: Sapotaceae
Subfamily: Caesalpiniodeae
Tribes: Caesalpinieae
Genus: *Madhuca*
Species: *longifolia*

Anatomy of the plant

Mahua is a highly advantageous plant extensively employed in indigenous medicine for treating diverse ailments. Microscopic studies were conducted to ascertain the anatomical characteristics of the plant. In the leaf's transverse section, there is a single-layered epidermis present on both surfaces, which is protected by a thin cuticle. Additionally, the section reveals the presence of a cortex, pith, and vascular region containing xylem and phloem. Uniseriate trichomes are found on the leaves, and paracytic stomata are present on both the upper and lower surfaces of the leaf. In the transverse section of the petiole, there is a single-layered epidermis covered with cuticles. The section also reveals the presence of vascular bundles, with the xylem encircled by phloem. Upon examining the transverse section of the stem, one can observe distinct layers including cork, cortex, xylem, phloem, and pith (6).

Ethnomedicinal description

Mahua is used by different communities and tribes for the treatment of various ailments. Detailed ethnomedicinal inventory has been given in the following Table 1:

Table 1: Ethnobotanical uses of the plant

Plant parts	Name of tribal communities	Method of drug preparation	Name of ailments	Mode of drug administration	References
Flower	Kol, Gond, and Mawasi tribe of Chitrakoot, Madhya Pradesh, India	Flowers decoction is given to the calf to expel the worms	Stomach worms (locally called *patedha*) in calf	Decoction	(3)
Leaves and Dried fruits	Tribes of Chhattisgarh and Gujarat, India	Leaves and dried fruits decoction is administered	Lack of lactation in humans and ruminants	Decoction	(4)
Bark	Tribal groups of Madhya Pradesh like Andh, Baiga, Bharia,	Bark decoction	Gum swelling	Gargling of the bark decoction	(5)

Seeds	Tribal groups of Madhya Pradesh like Andh ,Baiga, Bharia, Bhatra, Bhil, Bhujia, Gondetc (India)	Oil	Pneumonia	Massaging of the oil on the chest	(5)
Seeds	Tribal groups of Madhya Pradesh like Andh ,Baiga, Bharia, Bhatra, Bhil, Bhujia, Gondetc (India)	Seed cake decoction	Snake bites	A few drops of the decoction are put inside the nostrils which causes	(5)
Flowers	Santhal tribe of Santhalparganas (Jharkhand), Birbhum,Bankura, Midnapur and Purulia districts of West	Mahua flower drink/liquor	Diabetes mellitus	Drinking the liquor	(15)

Pharmacological Properties

Anti-oxidant activity

A free radical is an atom or molecule with unpaired electrons in its atomic orbital, allowing it to exist independently. Free radicals are formed when oxygen reacts with certain molecules. The high amount of free radicals in the body may cause serious oxidative damage and can lead to various diseases like atherosclerosis, cancer, stroke, asthma, arthritis, and various associated diseases. These generated free radicals are eliminated by antioxidants. An antioxidant has the ability to neutralize ROS and free radicals. (7). An antioxidant reduces reactive oxygen species by donating a hydrogen atom. The methanolic bark extract of *Madhuca longifolia* exhibits dose-dependent reducing properties and the ability to donate hydrogen atoms. The extract has a high amount of phenolic compounds which may be responsible for the antioxidant activity as these compounds have hydroxyl groups that can donate hydrogen atoms thereby scavenging the free radicals. The assessment of the antioxidant potential of plant extracts involved the utilization of 1, 1-diphenyl-2-picryl-hydrazine (DPPH) for free radical scavenging activity, as well as conducting a reducing power assay and superoxide scavenging activity test. The antioxidant activity of the bark extract was quantified as IC_{50} and compared to the standard, Ascorbic acid. The obtained values were 58.13 µg/ml for the bark extract and 47.56 µg/ml for ascorbic acid (8). The antioxidant activity of the aqueous acetone extract of flowers and fruits of the plant was also determined by the DPPH scavenging activity and it was evaluated that the DPPH activity of the flower (89.4±0.1) was higher than that of the fruits both ripe (88.2±1) and unripe (88.6±0.1) and it was reported that the antioxidant activity arises due to the amount of TPC (total phenolic content) and TFC (total flavonoid content) (9).

Anti–Inflammatory Activity

Inflammation serves as a vital defence mechanism in the body. The seeds of the tree possess anti-inflammatory properties. To assess the anti-inflammatory activity, the ethanolic extract of the seed and a mixture containing saponin were utilized. Acute (carrageenan-induced inflammation), sub-acute (formaldehyde-induced inflammation), and chronic (cotton pellet granuloma) models of inflammation in rats were employed for the evaluation. The seeds of *Madhuca longifolia* were air-dried, powdered, and defatted. Ethanol extraction resulted in the production of *Madhuca longifolia* ethanol extract (MLEE), while a portion of the powder was used to extract saponin, yielding Madhuca longifolia saponin mixture (MLSM). Both MLEE and MLSM exhibited a dose-dependent reduction of carrageenan-induced oedema, indicating the involvement of saponins in inhibiting inflammation mediators. In the formaldehyde-induced paw oedema model, MLEE at doses of 10mg/kg and 15mg/kg and MLSM at doses of 1.5mg/kg and 3mg/kg significantly inhibited oedema from 6 hours onwards, surpassing the efficacy of the reference drug diclofenac sodium. In the cotton pellet granuloma model, MLEE at doses of 10mg/kg and 15mg/kg and MLSM at doses of 1.5mg/kg and 3mg/kg demonstrated superior anti-inflammatory activity compared to diclofenac sodium. *M. longifolia* saponins exhibited their anti-inflammatory properties by suppressing COX-2, iNOS, and down-regulating nuclear factor (NF)-kB, resulting in reduced production of NO, PGE2, and TNF-α, which are crucial in inflammatory processes (10). Furthermore, silver nanoparticles synthesized using leaf extract showed anti-inflammatory activity by inhibiting protein denaturation and preventing the lysis of human RBC caused by heat and hypotonic solution at concentrations ranging from 100 to 500 µg/ml (11). The aqueous leaf extract of *Madhuca longifolia* (ALEML) effectively countered diclofenac (DFC)-induced toxicity in the rat stomach and intestine, known to cause gastric toxicity. Silymarin (SLY), derived from milk thistle fruits and seeds of *Silybum marianum*, is a polyphenolic antioxidant flavonoid commonly used for gastric ulcer treatment. It served as the standard drug for comparing the effects of ALEML. In the ALEML + DFC and SLY + DFC-induced toxicity groups, the levels of intestinal and stomach antioxidants, including SOD, CAT, GSH, and Gpx, increased, resembling those of the normal control group (female Wister albino rats administered daily with 0.9% NaCl (i.p.) for 5 days). Additionally, the ALEML + DFC and SLY + DFC groups exhibited reduced ulcer index. Among them, the ALEML + DFC-treated rats displayed greater reduction compared to the SLY + DFC-treated rats and showed normal intestinal and gastric mucosa, crypts, and lacteal with no ulceration. Moreover, the ALEML + DFC-treated rats demonstrated reduced levels of cytokines (IL-1β, TNF-α) in the stomach and intestine, along with the decreased activity of Caspase-3 and COX-2, indicating the absence of cell apoptosis and tissue granulation in the gastric mucosa. This showcased the gastroprotective activity of ALEML. The plant's anti-inflammatory activity is attributed to the inhibition of prostaglandin

synthesis and reduction of intercellular cell adhesion molecule-1 through TNF-α suppression (12).

Anti–Diabetic Activity

Diabetes mellitus is a group of metabolic disorders that occurs due to defects in insulin secretion and action. The methanolic extract of the bark displayed anti-hyperglycaemic activity in normal, glucose-induced, and streptozotocin (STZ) induced diabetic rats in a dose dependant manner when compared with the standard anti–diabetic agent glibenclamide. A dose of 200 mg/kg methanolic extract produced a maximum reduction in glucose level. (13) According to Kumar et al (2011), the methanolic, petroleum ether, and aqueous extracts of the bark were administered to the STZ and STZ–nicotinamide–induced diabetic rats among which the methanolic extract at a dose level of 75mg /kg was the most effective in decreasing the elevated blood glucose level, cholesterol, triglycerides and increasing the HDL levels in the diabetic rats (14). A study was also done on the diabetic and lipid profile of the Santhal tribe where the alcoholic Mahua drink made from the flowers was consumed at a large scale. Only the tribal males were chosen for the study, many of whom, but not all, were regular drinkers and the results of the study showed that the regular consumers of the drink had lower fasting blood sugar FBS (89.97±26.96 mg/dl) as compared to the non – consumers(118.9±56.03 mg/dl). While evaluating the lipid profile the differences in total cholesterol, HDL and LDL cholesterol were statistically significant except for the VLDL and triglycerides. The value of HbA_{1c} in the Mahua consumers was 6.09±0.53 and in the non–consumer group was 6.8± 1.5 which was also significant statistically. These results thus indicated that regular uptake of the Mahua drink can improve cholesterol and its lipoprotein components and can also prevent the onset of diabetes mellitus (15). The ethanolic bark extract of the plant at the dose level of 200 mg/kg also displayed a maximum glucose-lowering effect on the STZ-induced diabetic rats (16).

Anti-cancer activity

Silver nanoparticles were synthesized using the leaf extract of the plant and evaluated for their anticancer activity on SiHa cervical cancer cell line and MDA-MB-231 breast cancer cell line at various concentrations. The nanoparticles exhibited more potent anticancer effects compared to the Adriamycin-positive control group at concentrations of 10, 20, 40, and 80 µg/mL (11). Furthermore, the methanolic leaf extract of the plant was orally administered to rats treated with DMBA (7, 12-Dimethylbenz(a)anthracene), a carcinogen used to induce mammary carcinomas. Administration of the extract at doses of 100 and 200 mg/kg reduced tumour occurrence and growth. At a dose of 200 mg/kg, the tumour size and volume were significantly smaller, similar to the effect of the standard anticancer agent vincristine used for breast cancer treatment. Moreover, the extract at 200 mg/kg normalized the levels of 17 E2 (a breast cancer stimulant), TBARS, GSH, CAT, SOD, and GPx. It also improved ductal epithelium and inhibited ductal hyperplasia at this dose level. Flavonoids such as quercetin, kaempferol, myricetin, isorhamnetin, and genistein present in the leaves of the Mahua tree may contribute to breast cancer prevention through their antioxidant and apoptotic activities. Notably, quercetin, a potent anticancer agent for breast cancer treatment, is found in the leaves of the Mahua tree, possibly explaining its anticancer properties (17). Additionally, an acetone extract from the leaves exhibited anticancer activity against Ehrlich Ascites Carcinoma (EAC) in mice. Administration of the extract at a dose of 500 mg/ kg orally increased the mean survival time and decreased the tumour cell count, volume, and weight, comparable to the standard drug 5-Fluorouracil. The extract also restored altered haematological parameters, such as total WBC count, proteins, and PCV, caused by tumor inoculation. The primary compound responsible for these activities was identified as the flavonoid quercetin (18). Moreover, nanoparticles embedded in *Madhuca longifolia* extract (MLAgNPs) were assessed for their anticancer activity in rats with hepatic cancer induced by diethylnitrosamine (DEN). *Madhuca longifolia* AgNPs at doses of 20 and 30 mg/kg increased body weight, reduced the number of hepatic knobs, downregulated serum marker enzymes (ALT, AST, ALP, alpha-fetoprotein), decreased pro-inflammatory cytokines (TNF-α, NF-kB, IL-6), reduced LPO levels, increased antioxidant levels (SOD, catalase, GSH, GPx, G6PD), enhanced Ca2+ ATPase and Na+/K+ ATPase activity, and maintained the well-defined structure of liver cells altered by tumour induction (19). Lastly, the ethanolic bark extract of the plant was tested for cytotoxic activity against MCF-7 breast cancer cell lines, displaying significant cytotoxicity with an IC50 value of 31.20 µg/mL (20).

Anti-microbial activity

Using the leaf extract of the plant, silver nanoparticles were synthesized and assessed for their antimicrobial activity. The results revealed that the nanoparticles exhibited maximum activity against *Escherichia coli*, with a zone of inhibition of 20mm at a concentration of 250 µg/ml, comparable to the standard antibiotic ciprofloxacin. The silver ions present in the nanoparticles interacted with the sulfur and phosphorus components of the bacterial DNA, leading to its destruction and subsequent cell death. Additionally, the nanoparticles hindered DNA replication and inhibited microbial growth (11). Furthermore, silver nanoparticles created using flower extracts were tested for their antibacterial activity against both Gram-negative bacteria (*Escherichia coli, Salmonella typhimurium*) and Gram-positive bacteria (*Bacillus cereus*, *Staphylococcus saprophyticus*). The antibacterial activity was found to be dose-dependent, with an increase in the concentration of the nanoparticles correlating with a larger zone of inhibition. *Staphylococcus saprophyticus* exhibited the highest sensitivity, with a zone of inhibition of 20mm at a dose level of 400 µg/ml. Minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) tests were performed, showing a sequential increase in

MIC and MBC values from *Staphylococcus saprophyticus* to *Bacillus cereus, Salmonella typhimurium*, and *Escherichia coli*. Gram-positive bacteria demonstrated higher sensitivity to the nanoparticles compared to gram-negative bacteria, which can be attributed to the presence of a capsule in the cell wall of gram-negative bacteria (21). Moreover, the methanolic leaf extract of the plant was evaluated for its antibacterial activity against *Escherichia coli*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus*, as well as its antifungal activity against *Aspergillus niger, Penicillium* sp., and *Scytalidium* sp. The highest inhibition was observed against *Staphylococcus aureus* (zone of inhibition: 1.9cm), followed by *Escherichia coli* (zone of inhibition: 1.8cm). *Pseudomonas aeruginosa* showed a zone of inhibition of 1.2cm. Among the tested fungal strains, negative results were obtained for *Aspergillus niger* and *Penicillium* sp., while *Scytalidium* sp. displayed a positive result with a zone of inhibition (22). Additionally, cupric oxide nanoparticles synthesized using the flower and seed extract of the plant exhibited antibacterial activity against Escherichia coli (gram-negative), *Staphylococcus aureus*, and Bacillus subtilis (gram-positive), with a zone of inhibition of 15.67±0.58mm and 14.67±0.58mm, respectively, at specific concentrations (23). Saponins extracted from the seeds also demonstrated antibacterial activity, showing a significant zone of inhibition against *Lactobacillus* species, *Streptococcus salivarius*, and *Streptococcus mutans* MTCC 890. The MIC and MBC values were highest for *Streptococcus mutans* MTCC 497 (24). Moreover, silver nanoparticles created using the methanolic leaf extract of the plant exhibited both antibacterial and anti-biofilm activities against *Escherichia coli* and *Staphylococcus aureus* (92).

Hepatoprotective activity

The hepatoprotective activities of the ethanolic leaf extract of the Mahua tree were investigated in rats induced with acetaminophen (APAP) toxicity, which is known to cause liver and renal damage, and can be fatal in humans and experimental animals. APAP-treated animals exhibited elevated serum levels of glutamate oxaloacetate transaminase (GOT), glutamate pyruvate transaminase (GPT), alkaline phosphatase (ALP), and total bilirubin, along with decreased protein levels, indicating liver damage. However, administration of the leaf extract at doses of 500 and 700 mg/kg prevented hepatotoxicity induced by APAP. The APAP-treated groups displayed liver enlargement, severe centrilobular necrosis, and fatty infiltration, while treatment with the extract reversed these symptoms, demonstrating its hepatoprotective potential [25]. Furthermore, the 70% ethanolic extract of the leaves showed hepatoprotective activity in rats with carbon tetrachloride (CCl_4)-induced hepatotoxicity. The extract effectively restored the reduced levels of glutathione (GSH) back to near-normal levels. In-vivo inhibition of lipid peroxidation was observed with the extract at doses of 20 and 40 mg/kg. Increased serum levels of serum glutamate pyruvate transaminase (SGPT) and total cholesterol were normalized upon treatment with the extract at a dose of 40 mg/kg. SGOT levels were also restored with doses of 20 and 40 mg/kg, reaching 139.120 and 92.70, respectively. Treatment with 40 mg/kg of the extract reversed the serum levels of total and direct bilirubin to 1.331 and 0.282, respectively. The rise in serum ALP level was also normalized to 176.60 and 112.78 with doses of 20 and 40 mg/kg of the extract, indicating its hepatoprotective effects (26).

Nephroprotective activity

At doses of 500 and 700 mg/kg, the ethanolic leaf extract of the Mahua plant demonstrated nephroprotective effects by reducing the levels of serum urea, creatinine, haemoglobin (Hb), packed cell volume (PCV), and differential leukocyte count (DLC), and mean corpuscular volume (MCV), while increasing the levels of uric acid. The study suggests the antioxidant potential of leaf extract is responsible for the hepato-nephro protective action (25).

Anti-ulcer activity

The administration of the ethanolic extract of the seed at a dose of 10 mg/kg resulted in a reduction in the ulcer index in rats with pylorus-ligation-induced gastric ulcers, suggesting potential anti-ulcer activity. It is speculated that the seed extract of plants inhibits histamine production and acts as a scavenger for the free radicals present in the stomach (27). Similarly, the methanolic leaf extract demonstrated anti-ulcer activity in rat models of pylorus ligation, ethanol-induced, and naproxen-induced gastric ulcers at doses of 100, 200, and 400 mg/kg.The anti-ulcer activity of the leaf extract is attributed to its ability to significantly increase the gastric pH and mucin content in the stomach while reducing the total acidity and pepsin activity. It is widely recognized that an increase in mucin content is associated with the prevention of ethanol-induced ulcers (28).

Anti-helminthic activity

The methanolic leaf extract at a dose of 50mg/ml displayed significant activity against *Pheritima posthuma* (29). The methanolic and ethanolic extract of the flower at doses 20, 40, and 60 mg/ml also showed anti-helminthic activity against *Pheritima posthuma* (30). Methanolic leaf extract at a dose of 60 mg/ml also showed significant anti-helminthic activity when compared to the standard drug Piperazine (31-32).

Larvicidal and Ovicidal activity

Larval emergence was inhibited from the egg sacs of *Heterodera cajani* when treated with extracts of the seed cakes of Mahua. Aqueous extracts o the Mahua oil cakes also displayed significant larvicidal and ovicidal properties against *Meloidogyne incognita* (33-35).

Spermicidal activity

Seed saponins (Misaponin B) at a concentration of 320 µg/ml for rats and 500 µg/ml for humans exhibited potential spermicidal activity by increasing

membrane lipid peroxidation which lead to structural and functional disintegration of the sperm plasma membrane and acrosomal vesicle (36). Steroid and triterpenoid saponins present in the seeds also displayed potential spermicidal activity (35-37).

Anti-pyretic activity

Crude methanolic extract from aerial parts of the tree reduced the elevated temperature in brewer's yeast-induced pyrexia rat model at doses of 50, 100, and 200 mg/kg thus exhibiting anti-pyretic functions. Flavonoids, steroids, and triterpenes present in the extract are responsible for antipyretic activities (38-40).

Anti-stress Activities

Madhuca longifolia ethanolic bark extract exhibited anti-stress activity in anoxia-induced stress mice. Two different doses (EMLB-1: 100 mg/kg and EMLB-2: 200 mg/kg) were administered to the mice. It has been shown that the administration of EMLB-2 resulted in notable effects, including the prolongation of convulsion duration in the anoxia stress model and the improvement of mice's swimming time in the endurance test. Both EMLB-1 and EMLB-2 doses demonstrated significant reductions in the serum levels of glucose, triglycerides, cholesterol, blood urea nitrogen, and cortisol in rats when compared to the control group. Furthermore, EMLB-2 demonstrated noteworthy protective effects on organs including the liver, adrenal gland, spleen, and testes. These findings indicate that EMLB possesses significant mood-elevating properties. However, further investigations are needed to uncover the exact mechanism responsible for its anti-stress effects (94).

Phytochemical composition of the plant

Leaf

The qualitative analysis of the methanolic and aqueous extracts indicated the presence of various compounds including alkaloids, carbohydrates, proteins, saponins, tannins, and triterpenoids (41). Through GC-MS and HPTLC analysis, multiple compounds were identified, such as quercetin, furfural, imidazoles, furan carboxylic acid, piperidine, pyrazole, chromones, pyrrolidone, propanoic acid (1.76%), butanoic acid (1.8%), benzoic acid (2.5%), phenolic compounds, lactones, D-allose, manofuranosides, tritetracontane (7.89%), and nonacocosane (11.12%) in the petroleum ether extract of the leaves (42-44). Additionally, other phytoconstituents present in the leaves include palmitic acid, erhtrodiol, myricetin and its 3-O-arabionoside and 3-O-L-rhamnoside, 3-galactoside, 3β-palmitoxy-olean-12-en-28-ol, oleanolic acid, β-sitosterol and its 3-O-β-D-glucoside, stigmasterol, β-sitosterol-β-D-glucoside, n-hecacosanol, 3-β-caproxyolcan-12-en-28-ol, n-octacosanol, and sitosterol (32), (49), (83).

Bark

During phytochemical screening, the presence of alkaloids, phenolics, flavonoids, carbohydrates, proteins, and saponins was detected. Subsequent analysis using column chromatography, IR, and NMR techniques led to the identification of specific compounds including β-amyrin acetate, 21-hydroxy-3-oleanylmyricitate, ursolic acid, n-hexyl-3-acetyl betulinate, and 3-(27-carboxy oleanyl)-octanate. Additionally, ethyl cinnamate, sesquiterpene alcohol, α-tocopherol, 3β-mono caprylic ester of eythrodiol, and 3β-caprylic oleanolic acid were also identified (42), (56-59), (83).

Flower

The flower's essential oil was subjected to analysis using gas chromatography (GC) equipped with a flame ionization detector and GC coupled with mass spectrometry (GC-MS). The results revealed the presence of several major components, including farnesol (29.56%), α-farnesene (12.84%), dendrolasin (8.95%), 2,3-dihydrofarnesal (8.69%), nonanal (5.69%), and β-farnesene (4.38%). Furthermore, the flowers were found to contain vitamin A and vitamin C (32), (42), (45-48), (83).

Fruit

From the fruit coat compounds like triterpenoid madhucic acid, isoflavone madhushazone and a bis (isoflavone) called madhusalmone were isolated and their structures were explained using spectral analysis, including the 2D-NMR technique. Other compounds in the fruit includequercetin, dihydroquecertin, β-sitosterol, α and β amyrin acetates, n-hexacosanol, 3β-D-glucoside (32), (42), (50-52), (83).

Seed

Various phytoconstituents are present in Mahua seeds which include many amino acids includingα-alanine,aspartic acid, cystine, glycine, isoleucine and leucine, lysine, methionine, proline, serine, threonine. The seed also possesses many fatty acids such as arachidic acid, linoleic, oleic,myristic,palmitic, andstearic acids. In addition to this Mi-saponin A and B are also present (42), (53-55).

Nutritional properties of Mahua flower and seed

Flower

Flowers contain a good amount of vitamin C, carotene which is the precursor of vitamin A, and minerals like calcium and phosphorous along with a few amounts of protein and fats. Jam prepared from flowers is also very nutritious containing proteins, fat, carbohydrates, and calcium (60). Mahua flowers are also used as natural organic sweeteners and can also replace the sucrose in fruit bars and thus help in reducing calories (61-62). Flowers contain abundant natural sugars such as glucose, fructose, sucrose, and more (63). A brief account of the nutrient composition and physicochemical characteristics of the flowers is given in the following Table 2 (64-66), (68-69). Mahua flowers also contain all types of essential amino acids (70, 93).

Table 2: Mahua Flower Composition

S.No.	Constituents	Fresh Flowers	Dry Flowers
1	Moisture	73.6-76.82 (%dry basis)	11.61-19.8 (%wet basis)
2	Ph	4.6	-------
3	Starch(g/100g)	0.94	-------
4	Ash%	1.5	1.4-4.36
5	Total sugar(g/100g)	47.35-54.06	41.62
6	Total invert%	54.24	-------
7	Cane sugar%	3.43	-------
8	Reducing sugar(g/ 100g)	36.3-5.62	28.12
9	Protein%	6.05-6.37	5.62
10	Fat%	1.6	0.09-0.06
11	Fibre%	10.8	-------
12	Calcium(mg/100g)	45	0.14-8
13	Phosphorous(mg/ 100g)	22	0.14-2
14	Carotene(mg/100g)	307	--------
15	Vitamin C(mg/100g)	40	7

Seed

About 40% of pale yellow semi-solid fat is present in the seeds of Mahua. The seed oil is commonly known as "Mahua Butter". The oil content of the seed varied from 33 to 43% weight of the kernel (54). The major fatty acids in Mahua butter are oleic acid, palmitic acid, stearic acid, and linoleic acid. The Mahua fat is also one of the richest natural sources of carotenoids (82). The nutrient composition of the Mahua seed/seed oil is given in the following Table 3 (53-54), (62), (84).

Table 3: Mahua Seed/Seed Oil Composition

S.No.	Constituents	Value
1	Refractive index	1.452-1.462
2	Saponification value	187-197
3	Iodine value	55-70
4	Unsaponifiable matter	1-3
5	Palmitic acid C 16:0 (%)	24.5
6	Stearic acid C 18:0 (%)	22.7
7	Oleic acid C C 18:0 (%)	37.0
8	Linoleic acid C 18:2(%)	14.3
9	Protein	16.9%
10	Fibre	3.2%
11	Carbohydrates	22%
12	Ash	3.4%
13	Saponins	2.5%
14	Tannins	0.5%

Traditional Uses of Plant

Due to their high sugar content, flowers are commonly used as natural sweeteners in the preparation of traditional dishes such as Halwa, Kheer, Meethi Poori, and Barfi. The Santhal tribe in Odisha combines Mahua flowers with grains like Rice, Jowar, and Ragi, or root crops like sweet potato to make cakes. In impoverished tribal communities, dried flowers are boiled with Tamarind and Sal seeds and consumed as a grain substitute. Additionally, flowers are utilized as cattle feed, improving the health and milk production of livestock (67), (70-72), (1). In the North-West region of India, dried flowers are used to produce wine with an alcohol content ranging from 20% to 40%. The tribal people of Orissa make a country liquor called Mahuli from the flowers (70-71), (73). Flowers are also utilized in the production of various other products such as jam, jelly, marmalade, Mahua bar, candy, toffee, squash, ladoo (a type of sweet), wine, brandy, Mahua vermouth, acetone, lactic acid, and citric acid (67), (70), (74-81). Mahua butter, which is rich in saturated and monounsaturated fatty acids and low in polyunsaturated fatty acids, is considered a valuable nutritional ingredient. Its unique fatty acid composition, high monounsaturated fatty acid content, and ability to reduce blood cholesterol levels make it beneficial for heart health. Mahua butter is also used as a substitute for cocoa butter, and its semi-solid form finds applications in cooking, ghee adulteration, and chocolate manufacturing. Blends of palm hard fraction and Mahua butter, produced through inter-esterification, yield plastic fats suitable for bakery products, devoid of Trans fatty acids. The formulated blends exhibit distinct endotherms, indicating triacylglycerol heterogeneity. Due to their absence of Trans fatty acids, these blends can be used as alternatives to hydrogenated fats. Beyond its culinary uses, Mahua butter can be employed in the production of laundry soaps and lubricants (82), (85-88), (90-91).

Toxicity level

Mahua can be regarded as a safe drug. The acute and sub-acute toxicity of leaf extract was evaluated experimentally on rats. Rats were given 2000mg/kg of doses of leaf extracts. No biochemical, no morbidity, no mortality, no changes in the behaviour of rats, and no changes in body weight of rats have been observed. In all biochemical aspects, Mahua does not show any toxicity in the animal body in a previous study conducted by Devi and Sangeetha, 2019 (95)

Ayurveda description of plants

In Ayurveda, this plant is described as Madhuca. The flower of this plant is sweet, on ingestion they act as coolant, providing nourishment to the body, but not good for the heart. The nature of the flower is heavy i.e. not easy to digest, Snigdha i.e. oily in nature, vikasi- is helpful in the relaxation of muscles and joints. Fruits of Mahua are used for the treatment of bleeding disorders, burning sensations, inflammation, cough, asthma, and other chronic diseases. Ripe fruit is good for maintaining pitta (secretion of bile juice) and vat dosh (deposition of uric acid around joints). It is also good for maintaining immunity.

Biodiesel Production from Mahua

Since the seed oil of *Madhuca longifolia* is inedible and cannot be used for cooking, many scientists are trying to utilize the seed oil for making biodiesel. The basic step has been taken to eject the seed oil by the compressing method. Acid and base

esterification has been performed to reduce the free fatty acid content present in the oil. Methanol and oil have been mixed to produce biodiesel (96, 97). A previous study suggests that biodiesel extracted from Mahua seed oil will become a great choice for obtaining biodiesel. The performance and emissions of biodiesel derived from Mahua were investigated in direct injection, single-cylinder, and four-stroke diesel engines (Kirloskar). Mahua oil was subjected to transesterification using a 6:1 molar ratio of methanol to oil, resulting in the production of the methyl ester with a low viscosity of 5.2 cSt and an impressive conversion rate of 92%. To eliminate residual alkali, the ester underwent a washing process with phosphoric acid, followed by substantial rinsing with distilled water. Compared to diesel, *Madhuca longifolia* seed oil exhibits a lower calorific value by approximately 12%, while its specific gravity remains relatively similar to that of diesel (98).

Future Prospective of Mahua

The flowers of Mahua contain all essential amino acids, proteins, carbohydrates, various vitamins, and nucleic acids and thus can be used to make processed food items. The storage and preservation of Mahua flowers are very economical and do not need any special requirements. Food and nutrient supplements based on Mahua ingredients will be helpful in eradicating malnutrition. Ministry of Food Processing Industries with the association National Institute of Food Technology Entrepreneurship and Management is preparing Mahua cookies by mixing flower powder or paste in wheat flour. Similarly, many more steps should be taken to utilize the Mahua flower. As Mahua is a potent anti-oxidant, consumption of Mahua-based food items not only provide the required nutrient but also prevent the pathophysiological condition. Mahua seed oils should be utilized in the proper way to make biodiesel. More centric and effective study is required in this scenario. New methods and applications are required to adapt the sustainable use of plants.

Conclusion

Madhuca longifolia is an important medicinal plant used for the treatment of various ailments and diseases. Flowers of *Madhuca longifolia* are used for making food supplements to counter malnutrition. The alcoholic beverage industries are also using flowers of this plant. Various pre-clinical studies proved that plants contain various pharmacological activities like antimicrobial, anti-stress, antipyretic, spermicidal, larvicidal and ovicidal, anti-ulcer, anti-helminthic, nephroprotective, hepatoprotective, anticancer, antioxidant, anti–inflammatory, anti–diabetic activity. Although the plant has significant economic value spite of this its distribution is badly affected due to habitat destruction, road construction and many anthropogenic activities. We need to promote the cultivation of this plant so that sustainable use of plant could be possible for future generations also.

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